SIEMENS

Ingenuity for life

Siemens Manufacturing and Automation

A secondary or post-secondary school course featuring
Siemens Solid Edge, TIA Portal and Solid Edge CAM Pro

--- Teachers Edition ---

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--- Acknowledgement ---

Siemens PLM wishes to acknowledge the talents of Tom White and Dick Blais in the development of the ***Siemens Manufacturing and Automation*** curriculum. We believe this curriculum to be a “Best in Class” model for excellent contemporary project/problem based engineering design curriculum for secondary school students. We are pleased to offer the ***Siemens Manufacturing and Automation*** Curriculum to secondary schools at no cost.

About the authors:
Tom White, Dick Blais, and other talented teachers at the Shenendehowa Central School District in Clifton Park, New York developed and operated a highly successful high school engineering curriculum. The Shenendehowa program began in 1988 and operated for 11 years before the curriculum became *Project Lead The Way (PLTW)* in 1999.

In 1999, Dick Blais left the Shenendehowa Central School District and founded *Project Lead The Way*. Shortly thereafter Tom White left the Shenendehowa Central School District and joined *Project Lead The Way* as Director of Curriculum and Instruction and later Director of Operations and Technology. From 1999 through 2009, Blais and White worked with other talented people to expand *Project Lead The Way* to all 50 states to include over 3500 school sites. Through that period they developed an expanding high school engineering curriculum and added the *Gateway To Technology* middle school curriculum as well as some elementary curricula through a relationship with NASA.

In 2009, Blais joined the Southern Regional Education Board (SREB) and became director of the *Preparation for Tomorrow* curriculum initiative. This initiative would be renamed *Advanced Career* (AC). In his role, Blais led the development of several AC Pathway Curricula. He is still contributing to the work of the SREB AC initiative but now as a part time Senior Advisor. Blais was a 2008 recipient of The Harold W. McGraw, Jr. Prize in Education.

White joined SREB in 2012 as the AC Director of Technology. In his role he has created technical materials to allow students in many career pathways integrate their technical studies with advanced academics. He began Tom White & Associates LLC in 2010 to write programs and technical educational materials and projects for a wide variety of schools, industries and governments. His work includes Automation, Civil Engineering, Computer Numeric Control, Computer Science, Control Systems, Data Acquisition and Analysis, Electronics, Field Programmable Gate Arrays (FPGAs), Game Design, GIS, Instrumentation, Programmable Logic Control (PLCs), Product Design, Rapid Prototyping, Robotics, the Science of Golf (Chevron), Variable Frequency Drives, Welding and several freshmen engineering curricula. His work is utilized worldwide and been translated into many languages.

Siemens would also like to extend thanks to the hardworking staffs at Quantum Leap Concepts and Tom White & Associates.

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Overview

Siemens is committed to making both the ***Siemens Engineering Design*** course and the ***Siemens Manufacturing and Automation*** course effective and affordable for any secondary school.

Both Siemens courses can be used as a stand-alone full year course or taught in a semester double period block schedule. They are a great foundation to the ***SREB Advanced Career*** program or any technical college program. These Siemens courses can serve as a set of two courses in a sequence of courses comprising a program in ***Engineering Design and Manufacturing Technology***. These courses have the flexibility to be used independently with students.

Attributes of the new ***Siemens Manufacturing and Automation*** course

- Project/Problem based
- Integrated using the latest College and Career Readiness Standards AND the Next Generation Science Standards
- Students will do research, design & development and communication of design solutions
- Uses the engineering problem solving process
- Students will keep an engineering notebook
- A list of supplies is provided for all course projects

Siemens PLM is providing this curriculum at:

1. No cost for the curriculum
2. No cost for the Siemens ***Solid Edge*** design software
3. No cost for the Siemens **TIA Portal** and **Solid Edge CAM Pro**
4. No cost for the “Siemens online academy”

The new ***Siemens Manufacturing and Automation*** course will be ready for the 2018-19 school year. For more information please contact:

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Technical Content Standards

What technical knowledge and skills are demonstrated in this course?

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation, and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Reverse Engineering

- Apply design principles which include the accommodation for disassembly and resource recovery.
- Research and apply current business practices that lead to new product development or improvement of products or procedures including the use of rapid development and deployment to be faster to market.
- Analyze the design attributes of an existing product by disassembling it into its parts, use precision measurement tools to create sketches & drawings of the parts, identify the materials and processes used in manufacturing, and create a new and improved design.

- Utilize convergent modeling to capture data and rapidly create new parts to fit existing scans.
- Collaborate with teams to combine models and parametrically create solutions.
- Utilize rapid prototyping/additive manufacturing to create highly complex parts designed in a CAD system.

Design for Manufacturing

- Apply the principles of design for manufacturing, enabling the efficient and effective production of products.
- Develop a logical argument for selecting the tools, machines and labor necessary to produce finished goods from raw materials.
- Create a strategy to increase efficiency and decrease waste by receiving goods only as they are needed in the production process, thereby reducing inventory costs and reducing the impact of water and other natural resource consumption.
- Create a plan for protecting the safety, health and welfare of people engaged in the manufacturing environment.
- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.
- Understand and apply Statistical Process Control (SPC) to acquire quality control.
- Research and apply knowledge of material properties to product design and development.

Design for Assembly

- Apply engineering design of components to assure alignment for assembly.
- Create a management plan that includes quality planning, quality control, quality assurance, and quality improvement for an advanced manufacturing environment.
- Research, construct, and evaluate a plan for an assembly line or work cell.

Computer Numeric Control (CNC) of Machines

- Apply Cartesian Coordinates to create toolpaths for machine tools.
- Research and apply proper cutting tool speeds, feeds, and directions for manufacturing.
- Create simple Numeric Control (NC) part programs using a text editor or a CAM package.
- Analyze NC part program files to identify and correct errors.
- Analyze part geometry to select appropriate cutting tools and fixturing devices needed to create a part using a CNC machine.
- Edit the tool library of a CNC machine program to establish tool offset values.

Applying CAM Software to Problem Solutions

- Design and prepare 3D models with appropriate units for use in toolpath generation.
- Setup a CAM package by editing the material and tool libraries.
- Generate tool paths from a CAD program and edit NC part program files to identify and correct errors.

Automation with Programmable Logic Controllers (PLCs)

- Design and analyze an electrical system to efficiently convert, transform, and transmit electricity to where it is needed.
- Research and specify electrical devices necessary to provide needed power.
- Apply machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.
- Use flow charts and diagrams to apply logic in the design of control programs.

Applying Logic Software (TIA Portal) to Create Problem Solutions

- Design a system of elements that manages power to accomplish a task involving defined movement.
- Design a control system to vary the speed and performance of a motor by utilizing feedback from the system to gain the most efficiency possible.
- Formulate a system to utilize data collection and analysis to maintain and improve product quality and provide adequate confidence that the product will satisfy design requirements.
- Design and analyze the application of machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.

Pneumatics Design and Control

- Construct systems that efficiently utilize a fluid (liquid or gas) under pressure to generate, transmit, and control power.
- Design an integrated system of machines, machine tools, jigs, fixtures, instruments, and control programs to produce needed parts.
- Utilize jigs, fixtures, drill guides, gauges, and other manufacturing and assembly tools.
- Research, construct and evaluate a plan for an assembly line or work cell.
- Identify systems, sub-systems and typical components of an automated manufacturing operation.
- Apply the necessary safety precautions associated with a fully automated system.

Business of Manufacturing

- Research and categorize the activities that a business conducts to make discoveries that can either lead to the development of new products or procedures, or to improve existing products or procedures.
- Research and evaluate the new approaches of rapid development and deployment of products that saves time and is more efficient.

- Review and evaluate the benefits of a plan for an assembly line or work cell.
- Create a strategy to increase efficiency and decrease waste by receiving inventory just in time for the production process to reduce costs and reduce use of natural resources.
- Evaluate the use of production organization, planning, and resources, both human and capital, as well as regulatory requirements, to successfully and efficiently bring a product to market.
- Create a management plan including quality planning, quality control, quality assurance, and quality improvement for an advance manufacturing environment.
- Create a plan for protecting the health and safety of the people engaged in a manufacturing environment.

Concepts

Research, Design and Communications

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Science and engineering professionals use data and graphical analysis in making decisions.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The Engineering Design Process is sometimes referred to as the sequential actions of research, design, build, evaluate; then redesign, and communicate.
- Engineering professionals design solutions and communicate the solutions through graphics and pictures.
- Technological knowledge and abilities can be used to design, construct, use, and evaluate products and systems that satisfy human and environmental needs.
- Technological solutions, patents, and/or new designs are of little social value unless they are promoted, sold, or marketed in some way to the end user.
- An Engineering Notebook is used to keep detailed records of the design and development process.
- Engineers sometimes communicate through a white paper that describes a problem and offers a solution.
- Engineers use integrity and ethics when communicating ideas, including citing sources of information.
- Results of experimental research in science and engineering are submitted by the person(s) conducting the studies, to professional journals where they are peer reviewed prior to publication. Reviewers are highly regarded professionals with accepted credentials in their field.

Science, Engineering, and Technology

- Nature has many methodologies allowing organisms to adapt to and excel in their ecosystems. Designers use biomimicry to take advantage of those adaptations in the creation of products to fit particular needs.

- In all systems, there is a tradeoff between performance and complexity. Higher complexity is generally associated with higher cost; hence the shortened form of the syllogism is performance versus cost.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.
- Simple and compound machines have mechanical advantages that can be used to solve real-world problems.
- Mathematical formulas are used to analyze the amount of force necessary to provide to a mechanism to overcome losses due to inefficiency of the system.
- Converting one form of energy to another is not a 1:1 ratio; some energy is lost to conversion inefficiencies such as friction, heat to the environment, and other factors.
- Engineering features are the collection of design components that allow for the assembly of components. These might include bosses, spot faces, snap fittings and joints, counter sinks, counter bores, and other elements that allow for assembly.
- Electricity is a form of energy caused by the movement of charged particles. It is often used to transfer energy from one place to another.
- Newton's laws represent the relationship between force, mass, velocity, and acceleration which can be used to predict power captured and converted by products such as a wind turbines.
- The first law of thermodynamics (conservation of energy and matter) states that output power of a system is always less than the power supplied to the system.
- Mathematical models of physical phenomena, such as heat transfer in liquids, can be used to design an automated system that will outperform any manual system.
- Computer controlled actions, such as moving an object on or off an automated assembly line, use pneumatics, a branch of physics and technology that focuses on the mechanical properties of gases.
- The Ideal Gas Law describes the relationship of temperature, pressure, and volume. A subset of this law is called Charles Law which describes how gasses behave when heated. An experiment: fill a small balloon with air and tie off the end. Place the balloon in cold water and watch the size (volume) of the balloon decrease. Then place the balloon in warm water and watch the size (volume) of the balloon increase. Because the volume of a fixed mass of gas is directly proportional to the temperature, the size (volume) of the balloon changes with temperature. In solid vessels the pressure of the gas can be changed to produce movement. In a technology setting, pneumatic cylinders are devices that are controlled by a computer to convert the pressure of compressed gasses to a force acting in a specified direction. This device is often called an actuator.

Manufacturing and Automation Technology

- Additive manufacturing produces models by adding thin layers of material, one after the other to produce a model.
- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
- Convergent modeling is the process of analyzing a component to determine how much material can be removed from the original design and meet the stress requirements specified.
- Design for manufacturing involves the analysis of the design and how the design can be changed to allow for rapid and efficient manufacturing processes.
- Design for assembly involves analysis and changes to the design to make the assembly of the product as efficient as possible.
- CNC machine tool technology uses Cartesian Coordinates to position and control tooling to produce accurate models.
- G-code is the name given to numerical control programs that are used to control all types of computerized machinery.
- Speeds and Feeds is a machining term that refers to the rate that material is removed to acquire a finished part. Speed refers to either the speed of the moving material or the speed of the cutter or both at the same time. Feed is the rate of material removal. The relationship between speed and feed can vary depending on the desired surface finish. Usually initial cuts remove more material leaving a rough finish and a finish cut removes less material with a slower feed rate leaving a smooth finished surface.
- Tooling is a term that describes many aspects of the cutters, jigs, fixtures, hold down devices, and other accessories used in the process of material removal.
- Verification is the process used to confirm the program tool path to assure the machining operation will occur properly and without damage to the tool, part or machine.
- Post processors have programs that interpret the intent of CAM software and turn the desired operations into G-code to control the CNC machines.
- A Programmable Logic Controller (PLC) is a hardened computer used for industrial automation. PLCs can automate a process, machine function, or even an entire production line.
- The term “Logic” is based upon the mathematical system called Boolean Algebra named after George Boole (Born November 2, 1815-Died December 8, 1864) who was a self-taught English mathematician and philosopher who invented this form of algebra where values are either True or False where rules are created to consistently arrive at desired values.
- The ability to collect data, transform them into information, and use that information to improve an existing process is an enabling skill for Lean manufacturing.

- Applying automated control systems to existing manual processes can dramatically improve quality and reduce the amount of human (manual) time required.
- Electronic sensors detect and transform real-world phenomena into information that is used by computers to control valves, pumps, and other industrial equipment.
- Timers allow programmers to design and control specialized clocks to turn machinery on or off for specific amounts of time.
- Keeping track of events as they occur can be accomplished using logic programs called counters.
- Analog inputs for such things as temperature, pressure, speed, etc., are voltage values that can be converted into a digital value to be stored and used by a computer.
- Computer controlled automated systems often use a solenoid valve to open and close a valve to control the flow of a medium such as pressurized gas. A solenoid valve is an electromechanical device where electrical current is used to cause movement.
- Automated manufacturing systems rely on a mechanical system called a conveyor to move material from one place to another using a continuous belt.

Material Sciences

- Materials have inherent properties making them more suitable for specific applications.
- Selecting materials for use in a product requires knowledge of material properties and characterization, based upon manufacturing processes selected, chemical composition, internal defects, temperature, previous loading, dimensions, and other factors.

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Siemens Course 2

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Major Content Areas and Associated Projects

Major Content Areas

- Drawing/Design
- Convergent modeling
- Design for manufacturing
- Design for assembly
- CNC
- Programmable Logic Controllers (PLC)
- Workcell creation

Projects by Quarter

Quarter 1

Content for Quarter 1

Drawing/Design
- Classes of fits
- Tolerance dimensioning
- Optimization

Convergent modeling
- Part redesign using Generative design

Design for manufacturing
- Part symmetry
- Intro to machinery-removal tools
- Cradle to Cradle design/Product Life Cycle Management

Design for assembly
- Only one way to fit
- Easy location

Engineering features- snap, Screw bosses etc.

Projects for Quarter 1

- Archimedes Screw
- Windmill Hub
- Reverse Engineering/Redesign of Existing Product
- Spool Mechanism for Kite String
- Bathroom Caddy

Quarter 2

Content for Quarter 2

CNC

Intro to G&M codes
Speeds and Feeds
Learning Solid Edge CAM Pro
Tooling
Speeds and feeds
Verification and analysis
Posts and Post processors

Projects for Quarter 2

- Engraved Name Plate-hand G&M Coding
- Soda Can Opener
- Game Design
- Box Design with Interlocking Top
- Split Mold

Quarter 3

Content for Quarter 3

Programmable Logic Controllers (PLC)

Basic electricity-Multimeter schematics/ Ohms law
Setup
Inputs
Outputs
Counters
Timers
Analog input
Logic
Other functions

Project ideas for Quarter 3

- Conveyor with Counter
- Garage Door Control
- Sun Tracking Solar Panel
- Conveyor Sort by Color

- Elevator Control
- Parking Lot Gate Control

Quarter 4

Content for Quarter 4

Workcell Creation

Pneumatics
Solenoids
Schematics
Electricity
Hand shaking

Project ideas for Quarter 4

- Automated Pneumatic Clamping System
- Automated Pneumatic Feeder System
- Conveyor Sorting System Using Pneumatic Rams
- Automated Work Cell for CNC Mill

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Projects and Their Attributes

What will students do to demonstrate learning of the Technical Content Standards and the College and Career Readiness Standards?

Project 1 Title: **Archimedes Screw**

Essential Question: How can we design a system for moving dry solid material in a tube using a screw design?

What students will do to answer the essential question: Students will research methods by which dry solid materials are moved from one location to another within a manufacturing process. Students are given a length of PVC pipe and are to design and produce an auger that will move dry rice from one vessel to another vessel.

Project 2 Title: **Windmill Hub**

Essential Question: How can a windmill hub be designed so it can be secured to a shaft and have four fan blades secured radially to the hub outer surface?

What students will do to answer the essential question: Students will research classifications of fits as well as positive shaft connections. They will also research the geometry of radial connections in rotation systems. Students will select one modality of a shaft connection and one fan blade connection system and build a working model.

Project 3 Title: **Reverse Engineering/Redesign of Existing Product**

Essential Question: How can an existing product be redesigned to improve its performance, ergonomics, manufacturing process, end-of-life disassembly, and resource recovery?

What students will do to answer the essential question: Students teams will go to a store (Dollar Store, Walmart, etc.) and purchase an inexpensive product having at least three parts. Teams will conduct reverse engineering to analyze the product component attributes. Team members will redesign the product to improve its performance, ergonomics, manufacturing process, end-of-life disassembly, and resource recovery.

Project 4 Title: **Spool Mechanism for Kite String**

Essential Question: How can a team effectively design a kite string storage and operating system so 300 feet of string is secured in a reel and dispensed and retrieved by the kite flying operator efficiently and accurately?

What students will do to answer the essential question: Students will research string spool systems learning about reel motion and control. They will control for “freewheeling” and string entanglement. The design must be appropriate for children and have appealing youthful design attributes. Attention to minimal material usage while assuring structural integrity is required. Students will investigate the concept of biomimicry to see if these systems in nature have applications to the design.

Project 5 Title: **Bathroom Caddy for a Blow Dryer**

Essential Question: How can we design a storage device that sits on the bathroom counter to securely hold a hand held blow dryer?

What students will do to answer the essential question: Students are given a hand held blow dryer. They replicate the blow dryer outside geometry using Solid Edge to use as the profile from which to create the matching geometry for the inside of the Blow Dryer Caddy. Students create a prototype and demonstrate its effectiveness.

Project 6 Title: **Engraved Name Plate-hand G&M Coding**

Essential Question: How can we create a code to control a CNC milling machine to generate a personalized engraved name plate?

What students will do to answer the essential question: Students will research G&M codes and coordinate geometry in order to develop a code that machines can interpret. Students will design a name plate and develop the code to control a CNC engraver to produce the desired engraving.

Project 7 Title: **Box Design with Interlocking Top**

Essential Question: How can we design an aesthetically pleasing solid wooden box with an interlocking top that can store a valued possession?

What students will do to answer the essential question: Students will research interlocking geometry in connecting parts. They will incorporate one interlocking design in the design and production of a box. Note; the box does not need to be square.

Project 8 Title: **Soda Can Opener**

Essential Question: How can a tool be designed to open a 12 oz. can of soda easily and safely?

What students will do to answer the essential question: Students will research the design of soda can seals and determine the force needed to open a typical soda can. Students will design a tool with the needed geometry, ergonomics, and aesthetics appropriate for the solution and produce a working model.

Project 9 Title: **Game Design**

Essential Question: How can we use a milling machine to produce a prototype game piece?

What students will do to answer the essential question: Students will discuss with their teams what component they will design for a game (such as a domino, custom dice or game board piece). Student teams will then design and create the G-code needed to create the part using a CNC controlled machine.

Project 10 Title: **Split Mold**

Essential Question: How are round products produced through casting?

What students will do to answer the essential question: Students will research mold design. They will design and build a split mold that can be used to produce a rounded product such as a chocolate or decorative bar of glycerin soap.

Project 11 Title: **Conveyor with Counter**

Essential Question: How can we automatically count the number of fasteners to include in a kit?

What students will do to answer the essential question: Students will create a use case to determine the needs of their clients. They design and create a counting program to control the number of fasteners to add to each kit automating the process.

Project 12 Title: **Garage Door Control**

Essential Question: How do we automate the control of a door to respond to visitors allowing the door to open and close automatically?

What students will do to answer the essential question: Teams will investigate automatic doors and the requirements for automating the door safely. Teams will create state diagrams and then the program necessary to control their prototype.

Project 13 Title: **Sun Tracking Solar Panel**

Essential Question: How can a design team create a solar panel tracking system to maximize the sun’s energy?

What students will do to answer the essential question: Students will research the sun’s azimuth for their location. They will incorporate this information in the design of a system to move the position of a solar panel during daylight to maximize the production of electricity.

Project 14 Title: **Conveyor Sort by Color**
Essential Question: How do we create a program to sort different colors into bins?

What students will do to answer the essential question: Teams will research light and how sensors see different colors. They will design a device and create a flow chart to inform the creation of a control program. Teams will demonstrate the working prototype to automatically sort by color.

Project 15 Title: **Elevator Control**
Essential Question: How is a control program designed to allow for the proper control of an elevator?

What students will do to answer the essential question: Teams research elevators and necessary control systems. They will create a prototype elevator and design the control system to allow the elevator to be called to a floor and then proceed to the desired floor automatically. Students demonstrate how their control program allows for the safe operation of the elevator.

Project 16 Title: **Parking Lot Gate Control**
Essential Question: How do we create a program to allow the gate to open?

What students will do to answer the essential question: Students will research compare statements and shift registers to create an access code to allow for the gate to open only when the proper sequence of switches are entered. Students will plan and execute a program to allow the operation of the gate.

Project 17 Title: **Automated Pneumatic Clamping System**
Essential Question: How to we design and automate a pneumatic clamping system?

What students will do to answer the essential question: Student teams research pneumatic cylinders, gas laws and solenoid control used in the creation of clamping systems. The students will prototype a system to automatically locate and secure a work piece until the machining is completed and then release the part.

Project 18 Title: **Automated Pneumatic Feeder System**
Essential Question: How can we design a system to automatically deliver a part using pneumatic components?

What students will do to answer the essential question: Students design and create a feeder that will use a pneumatic vacuum system to deliver a component at the proper time. Students will demonstrate their design and explain how their system functions.

Project 19 Title: **Conveyor Sorting System Using Pneumatic Rams**

Essential Question: How do we create a continuous sorting machine that separates components automatically?

What students will do to answer the essential question: Students research how pneumatic rams can be utilized in the creation of mechanisms to change the direction of a part on a conveyor. They design and create a control program to automate the process.

Project 20 Title: **Automated Work Cell for CNC Mill**

Essential Question: How can we create a system to automatically feed and control a manufacturing process that machines a component?

What students will do to answer the essential question: Student teams collaborate with other teams to create components that will work together. The will combine the knowledge gained in the course in the design of a system to automatically feed, clamp, machine, inspect and unload the component without human intervention.

Teacher Guide:

One of the many benefits of STEM education is the integration and application of cross curricular content. This allows students to understand the relevance of content learned in other subjects studied in secondary school. To be effective, a STEM program needs to be fully integrated. The easiest and best way demonstrated so far is with a comprehensive project based curriculum. This helps students answer the questions "Why do I need to know this" and "Where will I ever use this". The *Siemens Manufacturing and Automation* course follows this accepted framework.

Project based curriculum allows for deep exploration of a problem. There are 20 projects in the *Siemens Manufacturing and Automation* course. Each project is designed to allow different student groups to develop several and distinct solutions to the same problem. The problem presents the student with an opportunity to plan, organize, and conduct research. Enabling activities can provide students with needed skills and knowledge "just in time". Students utilize their research in the design, prototyping, testing, evaluation, and redesign of a solution.

The term "engineering" implies a mathematical evaluation of a design. This analysis allows students to create mathematical models that can inform decisions and increase the speed at which a solution can be put forth. Once the initial analysis is done, a prototype can be created and evaluated. The data is gathered and organized. Flaws are further analyzed and the design improved.

Once an acceptable design solution is reached, students create final documentation. This documentation includes sketches, drawings, notes, research reports, data analysis, flow charts, state diagrams programs, NC code and anything else utilized in the creation of the final design. Students craft explanatory or argumentative writing to detail the merits of their solutions. The writing is "glue" for the integration of the learning. Requiring the explanation of the solution elevates the learning to higher levels.

True project based curriculum needs to be standards based, utilizing several standard sets. There is a temptation to ignore the literacy standards as they do not appear in the STEM designation. They are just as important as the College and Career Readiness Math standards. Reading and Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects prepare students for further education and entering into employment.

One of the biggest impediments to successful preparation for careers in STEM fields is the need for remediation before true college work can begin. Project based STEM education provides students with the preparation necessary for successful entry into college programs. Several colleges studying those students who participated in STEM programs in high school, have found higher GPA, improved retention, and better preparation for the rigors of college study.

The *Siemens Manufacturing and Automation* course utilizes the Solid Edge, Solid Edge CAM Pro and TIA Portal software as tools for design, manufacturing and automation. The object of the course is the application of the tools to address unique problems allowing the students to rapidly create and analyze proposed solutions. These are tools used by industry and understanding how such tools are used in problem solving is critical to future success and employment.

Course Flow Guide

The course is divided into four quarters matching a schedule utilized by many districts. Schools that teach in semester blocks will be able to teach the 4 quarters in one semester. The four quarters build one upon the other. The 20 student projects are intended to utilize the design process, identifying missing information needed for further research and create a solution. Each project has some enabling learning activities providing critical information, but students decide on any additional information needed. Every project has a written component. Every project requires the use of the student’s Engineering Notebook to keep track of their progress in the projects. The Engineering Notebook is a critical device used when creating the explanation of a solution. Students present their solutions to the problems they solve. Reading, writing, and presenting are skill sets that improve with practice. Students also apply mathematics and analysis to their solutions, documenting as they progress. In this way students utilize methods used by engineers. In addition they will be using Excel to organize data, create graphs, and perform statistical analysis.

First quarter:

This quarter reintroduces students to the engineering design process. The first project introduces the students to tolerance dimensioning. They define the size of objects listing the amount they can vary from the original intent. They research classes of fits to describe how components go together. Everyone should complete the first project. Teachers and students can elect to complete two of the next four projects. Each one introduces concepts of Convergent Modeling, a method to produce organic looking models, Design for Manufacturing and Design for Assembly. These project are about preparing for the manufacturing process. Student groups research how parts need to be designed so they can be easily be manufactured. Groups then spend time figuring how the parts can be assembled quickly and easily. They eliminate design features that cause confusion and replace them with designs that have only one way to go together.

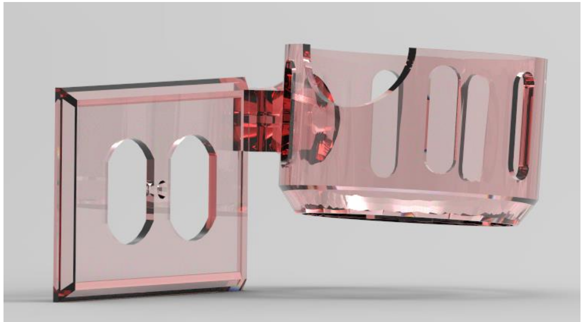
Students groups that finish early move on to other projects.

<table>
<tr><td>Introductory project Required

Drawing and Design

• Archimedes Screw</td><td></td></tr>
<tr><td colspan="2">Select two of the next four projects.</td></tr>
<tr><td>Convergent Modeling/Design for Manufacturing and Assembly

• Windmill Hub</td><td></td></tr>
</table>

Convergent Modeling/Design for Manufacturing and Assembly • Reverse Engineering	
Convergent Modeling/Design for Manufacturing and Assembly • Spool Mechanism for Kite String	
Convergent Modeling/Design for Manufacturing and Assembly • Bathroom Cady for a Blow Dryer	

Second quarter

The second quarter begins with an examination of what it takes to create a tool path for a CNC machine. Students learn G-Code by writing a simple program by hand. It reinforces the link to mathematics and allows students to see the meaning behind the codes use to control so much of today's machinery. The first project introduces the student groups to engraving and the need for G-Code. All students should complete this introduction to producing NC files as well as an introduction to the Solid Edge CAM Pro software. Student groups then select either the soda can opener or the game piece design. This will allow them to explore the tutorials included in Solid Edge CAM Pro and produce a machined product. The last project students will again select one of two projects, either the box with interlocking top or the split mold. These last two projects students need to machine two parts that will fit together raising the need for accuracy and building multiple operation toolpaths. This will reinforce the tolerance and fits from unit one. This will also allow the discussion of design for assembly as well as design for manufacture.

<table>
<tr><td>Intro to G&M codes, Speeds and Feeds, Solid Edge CAM Pro, Tooling, Verification and Analysis and Posts and Post Processors

• Engraved Name Plate</td><td></td></tr>
</table>

Select one of the next two projects

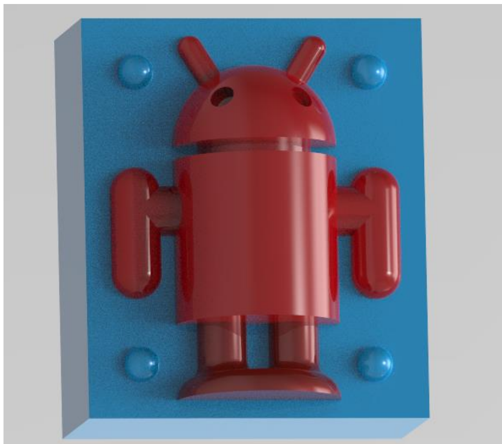
<table>
<tr><td>Choose one of two. Either the soda can opener or game piece design.

Intro to G&M codes, Speeds and Feeds, Solid Edge CAM Pro, Tooling, Verification and Analysis and Posts and Post Processors

• Soda Can Opener</td><td></td></tr>
</table>

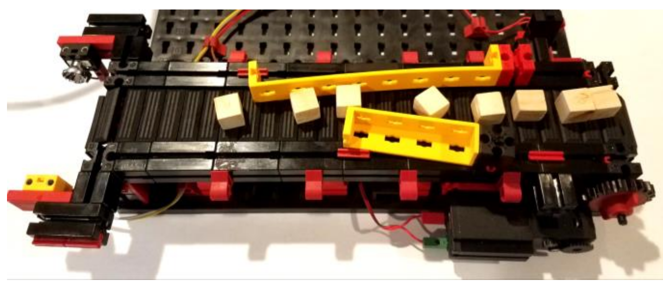
Choose one of two. Either the soda can opener or game piece design. Intro to G&M codes, Speeds and Feeds, Solid Edge CAM Pro, Tooling, Verification and Analysis and Posts and Post Processors • Game Piece Design	

Select one of the next two projects.

Choose one of the two part projects, box with the interlocking lid or the two part split mold. Intro to G&M codes, Speeds and Feeds, Solid Edge CAM Pro, Tooling, Verification and Analysis and Posts and Post Processors • Box Design with Interlocking Top	
Choose one of the two part projects, box with the interlocking lid or the two part split mold. Intro to G&M codes, Speeds and Feeds, Solid Edge CAM Pro, Tooling, Verification and Analysis and Posts and Post Processors • Split Mold	

Third quarter

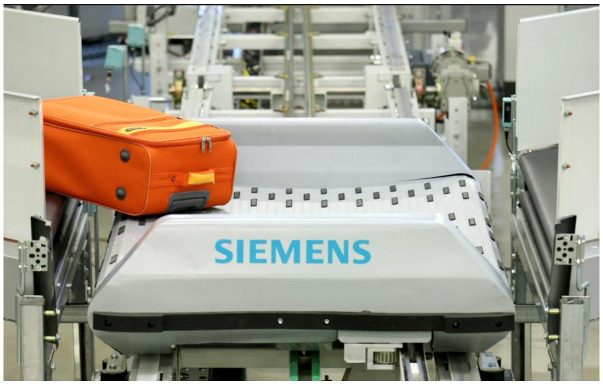
The main purpose of the third quarter is the study of automation. Student teams work through the discovery of electricity and schematics. In each project grouping students advance their knowledge of automation, logic, ladder logic and motor control. The first project introduces PLC wiring and program setup. Groups explore creating inputs, outputs and counters. The Garage Door project introduces the concept of combining directional control along with motion sensors. If there is extra time this project would be good for those students who excel and finish early. The next phase of study is analog inputs and the use of timers. Students select between the Sun Tracking Solar Collector or Sort by Color System. The final section introduces students to logic and planning for programs. Students select either an Elevator Control System or Parking Lot Combination Gate. Students will exit the quarter knowing enough about automation to begin designing

PLC setup, programming interface, inputs, outputs counters. Introductory project for all students. Conveyor with Counter	

Select one of the following three projects.

Relays, PIR Sensor timers, motor reversing. • Garage Door Control	

Continued

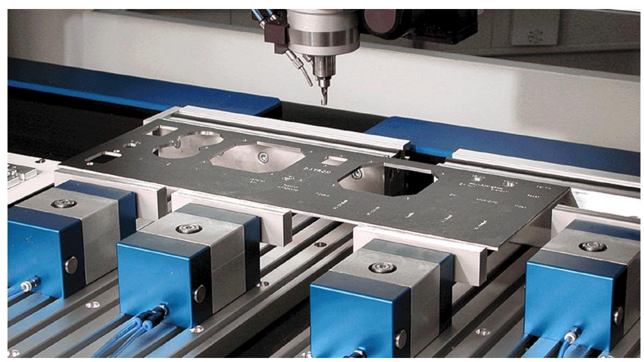
Sensor, timers, motor reversing Analog inputs, timers Sun Tracking Solar Collector	
Sensor, timers, motor reversing Analog inputs, timers Sort by Color	

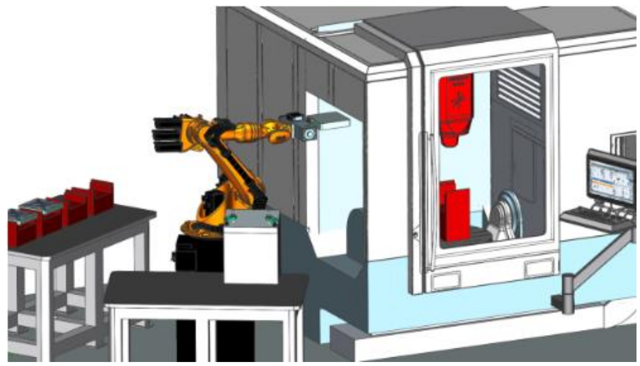
Select one of the following two projects

Logic and program planning Choose one of two projects in the logic category either the elevator control or the parking lot gate project. Elevator Control	
Logic and program planning Choose one of two projects in the logic category either the elevator control or the parking lot gate project. Parking Lot Gate	

Fourth Quarter

This quarter is different in structure than any in the course sequences before. This quarter explores pneumatics, solenoids, schematics, electricity, and hand shaking between systems. The main project is a workcell design. Teams design a product and utilize Solid Edge CAM Pro to create a tool path for that product. Teams will be larger than teams in previous quarters. As the students discuss the product to be designed, they will design and create a workcell. Groups will identify sub teams to take a different piece of the automation to support the final design. They must design an automated feeder, transport, and sorting systems to integrate with the CNC mill to safely supply parts to be milled and then remove them when done. This involves programs talking to each other and providing signals so each system will wait its turn. Teams are forced to collaborate closely and share the planning process so all the components fit together and work properly. Students will have to gain knowledge of pneumatics and schematics in order to accomplish their designs. Students will design the work cell and divide up the responsibilities for completing the various components. They will complete the other projects as needed to create the systems that make up the work cell.

<table>
<tr><td>Pneumatics Solenoids, Schematics, Electricity, Hand shaking
Automated Pneumatic Clamping System</td><td></td></tr>
<tr><td>Pneumatics Solenoids, Schematics, Electricity, Hand shaking
Automatic Pneumatic Feeder System</td><td></td></tr>
</table>

Pneumatics Solenoids, Schematics, Electricity, Hand shaking • [Conveyor Sorting System]	
Pneumatics Solenoids, Schematics, Electricity, Hand shaking, Design, CNC and Automation • [Automated Workcell for CNC Mill]	

Assessment of Students

There are two forms of student assessment; formative and summative.

The *Siemens Engineering Design* course utilizes formative assessment throughout the course. The formative assessment criteria, usually through a rubric, are a way to clearly show students in advance the level of excellence expected. It is also a way for teachers to provide guidance and support throughout the learning process and to show end-of-project performance.

Solid Edge Certification is an accreditation achieved through an online exam that tests the knowledge and skills of students who are experienced users of Solid Edge design software. Solid Edge certification enhances the competitive edge and reputation of both students and their academic institutions, and provides an industry-recognized credential that students can use to enhance their academic careers and ambitions.

Students can demonstrate their skill level by taking online examinations and qualifying as a Solid Edge Certified Associate Level I (aimed at High School students) or Level II (aimed at University students). The exams are a summative assessment, students completing the *Siemens Engineering Design* course will be well prepared to successfully complete.

Obtaining Equipment, Supplies and Software

Obtaining the Software
The curriculum makes extensive use of industry standard software to allow students to create solutions to design problems with the same tools found in today's business environment. The instructions below describe the process that schools should follow to access necessary software used in the program.

Siemens is making Solid Edge **available to schools at no charge**. Solid Edge is a portfolio of affordable, easy-to-use software tools that address all aspects of the product development process: 3D design, simulation, manufacturing, data management and more, thanks to a growing ecosystem of apps. Solid Edge combines the speed and simplicity of direct modeling with the flexibility and control of parametric design, made possible with synchronous technology. Solid Edge is technically robust, 3D CAD software and the premier design-centric solution in the CAD industry today. It allows for rapid design and testing of a digital prototype. This saves time and materials for students as they can make decisions and refine designs before construction of an actual prototype.

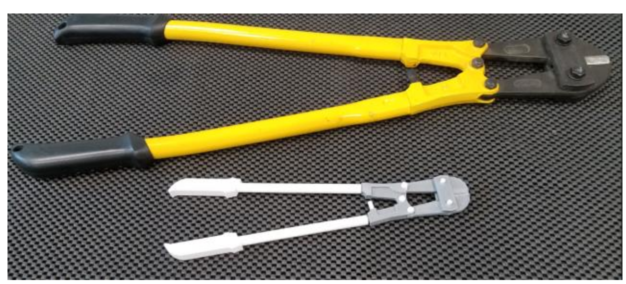
Schools must register for the software at: https://www.plm.automation.siemens.com/plmapp/education/solid-edge/en_us/free-software/teacher. Fill out the registration form found on the page. The schools information is entered into the database and a link automatically generates a link for the software download. This arrives within minutes to the contact listed on the application by email. The software is then available for download. The school may install the software on as many computers as needed by the school and has a permanent license built into the installation that never expires. Students can download a copy for their home computers. Instructors should provide the students with this link. https://www.plm.automation.siemens.com/plmapp/education/solid-edge/en_us/free-software/student.

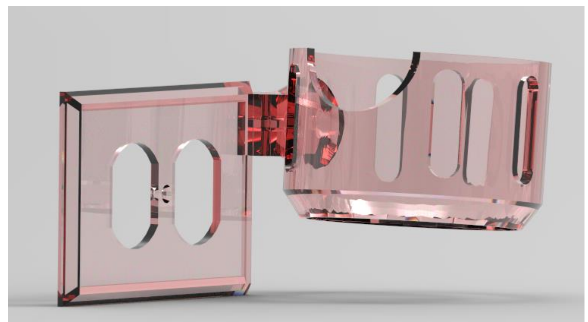
Obtaining Equipment and Supplies
Schools obtain the necessary equipment and supplies for implementing the curriculum with a single purchase order. Studica, a company long known for great service to educational institutions is providing kits on a sole source basis. The kit has all the necessary equipment, supplies and consumable materials for a class of 24.

The contact for equipment and supplies is Jim Sheehan at Studica. Jim can provide a sole source letter and W9 for business office use. Jim's contact information is:

Jim Sheehan
STEM Education Solutions
jims@studica.com
P: 888.561.7521 Ext. 208
F: 877.754.2807
www.studica.com

Projects Quarter 1

Introductory project Required Drawing and Design • Archimedes Screw	
Select two of the four projects below	
Convergent Modeling/Design for Manufacturing and Assembly • Windmill Hub	
Convergent Modeling/Design for Manufacturing and Assembly • Reverse Engineering	

Convergent Modeling/Design for Manufacturing and Assembly • Spool Mechanism for Kite String	
Convergent Modeling/Design for Manufacturing and Assembly • Bathroom Cady for a Blow Dryer	

SIEMENS

Ingenuity for life

Project: Archimedes Screw

The Archimedes screw, also called an inclined screw conveyor, was originally invented by the ancient Greek scientist, Archimedes, for removing water from the hole in a large ship. In today's applications, the inclined screw conveyor may be as small as a quarter of an inch to as large as 12 feet in diameter and has many appropriate applications.

Introduction:

Our production systems often require moving substances from one place to another. Liquid is one substance where a pumping system may be used to move it from one vessel to another vessel. Think about how one might move and combine one fruit juice with a second fruit juice to produce a fruit juice mixture as the finished product. Sometimes the product to be moved is not a liquid but it has similar challenges. Some examples are sugar, powder, or dry beans. In all instances the product must be protected from damage and external environments.

Purpose of the Project:

The purpose of the Archimedes Screw project is to design a system to move dry rice from one vessel to another vessel where the first vessel is six inches lower than the second vessel. It is an open-ended design utilizing many concepts learned from previous projects in the *Siemens Engineering Design* course. Students will research the terms tolerance, fits, and the Archimedes screw prior to proceeding to design, and construct a contained Archimedes screw system for moving dry rice. The system will have the screw, PVC containment housing with entry and exit ports, and a coupling geometry at the end of the screw shaft that will enable a small cordless drill to serve as the drive motor. Students will gauge the system performance using a transfer calculation of one ounce of dry rice per minute.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Science and engineering professionals use data and graphical analysis in making decisions.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The Engineering Design Process is sometimes referred to as the sequential actions of research, design, build, evaluate; then redesign, and communicate.
- Engineering professionals design solutions and communicate the solutions through graphics and pictures.
- Technological knowledge and abilities can be used to design, construct, use, and evaluate products and systems that satisfy human and environmental needs.
- An Engineering Notebook is used to keep detailed records of the design and development process.
- Engineers use integrity and ethics when communicating ideas, including citing sources of information.
- In all systems, there is a tradeoff between performance and complexity. Higher complexity is generally associated with higher cost; hence the shortened form of the syllogism is performance versus cost.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.
- Simple and compound machines have mechanical advantages that can be used to solve real-world problems.
- Mathematical formulas are used to analyze the amount of force necessary to provide to a mechanism to overcome losses due to inefficiency of the system.
- Converting one form of energy to another is not a 1:1 ratio; some energy is lost to conversion inefficiencies such as friction, heat to the environment, and other factors.
- Additive manufacturing produces models by adding thin layers of material, one after the other to produce a model.
- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
- Results of experimental research in science and engineering are submitted by the person(s) conducting the studies, to professional journals where they are peer reviewed prior to publication. Reviewers are highly regarded professionals with accepted credentials in their field.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://www.youtube.com/watch?v=oWeAYJ8CN70
https://www.siemens.com/global/en/home/company/topic-areas/future-of-manufacturing/digitalenterprise.html

Outline:

- Documentation
  - Engineering Notebook
  - Documentation object to be designed
- Modeling
  - Creation of 3D model
  - Assembly of 3D model
  - Exploded drawing of 3D model with appropriate tolerance noted for parts
  - Design renderings and pictorial exploded drawings
  - Construct 3D model of Archimedes Screw project
- Evaluation
  - Testing of the ability to move one ounce of dry rice per minute transfer calculation from one container to another
- Communication
  - Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation, and service requirements.

Design for Manufacturing

- Apply the principles of design for manufacturing, enabling the efficient and effective production of products.
- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.

Design for Assembly

- Apply engineering design of components to assure alignment for assembly.

College and Career Readiness Math Standards

Modeling with Geometry G-MG

Apply geometric concepts in modeling situations

1. Use geometric shapes, their measures, and their properties to describe objects (e.g., modeling a tree trunk or a human torso as a cylinder).
2. Apply concepts of density based on area and volume in modeling situations (e.g., persons per square mile, BTUs per cubic foot).
3. Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.

3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.

9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*
2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:
Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 3:
Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 5:
Students will develop an understanding of the effects of technology on the environment.

STL Standard 6:
Students will develop an understanding of the role of society in the development and use of technology.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 16:
Students will develop an understanding of and be able to select and use energy and power technologies.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Archimedes Screw

Essential Question:

How can we design a system for moving dry solid material in a tube using a screw design?

Student Scenario:

A major grain grower has contacted your team about designing an efficient system for moving dry rice from storage silos and into trucks for transport. They want a system that will have high flow volume without damage to the product.
The silos are in remote locations and can only be accessed by trucks. Your inclined screw conveyor will be designed to move dry rice from the bottom discharge opening of the silo and into trucks having a truck container opening at the top with a height of 12 feet from the road.

Your design will be presented using a scale model where the model performance will determine your company's acquisition of the contract to build 20 full size units for a contract price of $2.7M.

The research and learning activities are designed to help students:

- Create sketches to communicate to a group
- Use mathematical formulas to aid in the design of a product
- Utilize specific software features to create a solid model of their idea
- Communicate their solution to their peers

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design
- Sketches and working drawings for the elements of the inclined screw conveyor
- Analysis of the structural elements of the inclined screw conveyor design
- 3D printed model of the assembled inclined screw conveyor
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1
Key Question: What are the expectations of the project?

> Introduce students to the project by providing them with the Essential Question and the scenario.
>
> The Archimedes Screw project is the first project in the ***Siemens Manufacturing and Automation*** course. Because students begin each project with a research component it is essential that they understand that not all sources of researched information is correct and valid. One of the learning concepts in this project states,
>
>> *"Results of experimental research in science and engineering are submitted by the person(s) conducting the studies, to professional journals where they are peer reviewed prior to publication. Reviewers are highly regarded professionals with accepted credentials in their field."*

Have students research the definition of the vocabulary terms, *Peer Reviewed Journal Articles* and *Professional Credentials*. In doing this they should learn that in the world of science and engineering true research findings come from professionals with valid credentials and their research is reviewed by other professionals also holding valid credentials with research published in trusted sites and journals. Sources that are selling products or have an ulterior motive should be suspect.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of Vocabulary Terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2-3
Key Question: How do we get started in the design process?

The teams will be responsible for researching inclined screw conveyors, their attributes, and capabilities. Students must research the power requirements for the medium being transferred (dry rice), friction issues on contact surfaces, flow efficiency, structures, strength of materials, and analysis. Teams are also responsible to research classes of fits and tolerances. Teams hold a group discussion on the specifications of the inclined screw conveyor design. Students begin sketching and adding power calculations associated with inclined screw conveyor. Students add items from their reading to their Engineering Notebooks.

The student teams discuss possible inclined screw conveyor features. The teams should decide on design constraints which might include:

- What material will the inclined screw conveyor be made from?
- What is the physical size of the inclined screw conveyor?
- How will the inclined screw conveyor be powered?
- How will we control the speed of the screw?
- How much dry rice will be moved with the inclined screw conveyor?
- Can the screw be made to reverse?
- What size should we design our parts so they work together?
- What is the total capacity of the inclined screw conveyor design?

The teacher reminds students about the help system to find out how the software accomplishes basic features they might want to incorporate.
https://docs.plm.automation.siemens.com/tdoc/se/110/se_help/#uid:index

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the inclined screw conveyor. Other tutorials in the Resources section are available for use by students.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 4
Key Question: How do we get started on our individual designs?

Student teams brainstorm needed components of their design and then create their isometric sketches to add to their design brief to include with their sketches. They include preliminary sizes and power requirements including formulas used to evaluate their designs. They then meet with their clients (teacher or other designee) who will need to sign off on the design proposal before solid modeling can begin.

Students can reference Fits and Tolerances, Basic 3D Commands, Creating Drawing Views, Introduction Assembly Modeling, Analysis in Solid Edge and Working with Bodies for specific commands to use in the inclined screw conveyor design. Students can reference web links, videos, and tutorials at any time during the process of the design.

Day 5-7
Key Question: How can we begin to design our inclined screw conveyor idea?

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the inclined screw conveyor design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams discuss their proposed inclined screw conveyor and how to achieve the design given the approved sketch they presented. They work together to brainstorm ideas and begin to narrow their vision of the solution. Divide the work of creating the 3D solid model of the pieces needed and a plan to assemble the inclined screw conveyor. Utilize the division of work in the project management plan.

Teams are reminded to continually check their 3D components of the designs with their team to ensure accurate sizes. Teams discuss how the various designs work and that the designs created will meet the inclined screw conveyor requirements and the tolerance limits of their designs to assure the parts will connect as desired. Student teams also discuss how the designs will be assembled and how the clearance between the inclined screw and housing will be established and maintained.

Day 8-10
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team's final design. It could be a single design or contain elements of several designs. Once the decision is made the students create a plan for creating the team prototype. They need to create a design that incorporates their ideas. Once the final plan is created they will create individual parts in Solid Edge and assemble them into a final assembly. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin 3D printing the necessary components and assemble their scale model of the inclined screw conveyor from the printed parts. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 11-12
Key Question: How do we build and test our designs?

Students assemble their inclined screw conveyor from the materials following their plans. When students encounter problems assembling their designs they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

As students finish assembling their inclined screw conveyor, testing can begin to see if it moves the dry rice as planned. Teams identify sources of problems and redesign parts as needed.

Day 13-14
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to their clients. The deliverables could be in the form of a dimensioned working drawing pictorial representation with balloons and bill of materials and/or a 3D printed prototype as well as the final testing data and demonstrations. Students should prepare an engineering report about the process of designing their inclined screw conveyor and how the components all fit together. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 15
Key Question: How do we convey our ideas?

Student teams can present their solutions to the authentic one at a time. Students display the completed inclined screw conveyor and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs

Vocabulary:

Allowance
Archimedes Screw
Auger
Centrifugal Force
Classes of Fits
Clearance
Clearance Fit
Deviation
Dimensioning
Force or Shrink Fit
Friction
Horsepower
Impeller
Inclined Screw
Inclined Screw Conveyor
Inclined Screw Conveyor Coupling Inclined Screw Housing
Interference Fit
Locational Fits
Lower Limit
Peer Reviewed Journal Articles
Power Requirements
Professional Credentials
Rate of Flow (Capacity)
Running and Sliding Fits
Seals
Shaft
Tolerance

Upper Limit
Variation
Viscosity
Work

Resources:

CAD Tutorials

- https://drive.google.com/open?id=0B_7sFhPxnoaXRlNuckN0OXVpdUE
- https://docs.plm.automation.siemens.com/tdoc/se/109/se_help/#uid:index
- https://docs.plm.automation.siemens.com/tdoc/se/latest/se_help#uid:index_xid618399:xid482668:new_cad_user

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

Archimedes Screw

- https://www.youtube.com/watch?v=0PgA6Dz7f_M
- http://physics.kenyon.edu/EarlyApparatus/Fluids/Archimedes_Screw/Archimedes_Screw.html
- https://en.wikipedia.org/wiki/Screw_pump
- http://empoweringpumps.com/screw-pump-basics/
- http://www.spaansbabcock.com/products/screw-pumps/advantages-of-screw-pumps/
- https://www.flowcontrolnetwork.com/when-to-consider-screw-pumps-over-centrifugal/
- http://www.renewablesfirst.co.uk/hydropower/hydropower-learning-centre/archimedean-screw-hydro-turbine/

Types of Fits

- https://www.engineersedge.com/mechanical,045tolerances/preffered-mechanical-tolerances.htm
- http://mmto.org/~dclark/Reports/Encoder%20Upgrade/fittolerences%20%5BRead-Only%5D.pdf
- http://www.mechcadcam.com/what-is-the-fit-and-what-are-the-different-types-of-fits/
- https://extrudesign.com/types-of-fits-in-engineering/
- http://ignou.ac.in/upload/Unit-3-62.pdf
- http://blog.misumiusa.com/shaft-and-hole-tolerances-and-fits/
- https://www.amesweb.info/FitTolerance/FitTolerance.aspx
- https://www.engineersedge.com/calculators/mechanical-tolerances/force-fit-tolerances.htm
- https://mdmetric.com/Ch6.8wGO.pdf
- https://ay14-15.moodle.wisc.edu/prod/pluginfile.php/166546/mod_resource/content/1/ANSI-Standard-Fits.pdf

Tolerance Dimensions

- http://www.machinedesign.com/materials/working-dimensional-tolerances
- https://www.britannica.com/topic/drafting/Dimensions-and-tolerances
- https://www.fictiv.com/hwg/fabricate/gdt-101-an-introduction-to-geometric-dimensioning-and-tolerancing
- http://web2.clarkson.edu/class/es305/willmert/Dimensioning%20in%20Solid%20Edge%20ST.doc
- https://www.youtube.com/watch?v=X0pM6TqKXaM
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dimsd3d.htm
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dim_classfit1a.htm
- http://site.iugaza.edu.ps/aabuzarifa/files/METRO20152_CH52.pdf
- http://web.aeromech.usyd.edu.au/ENGG1960/Documents/Week12/Engineering%20Drawings%20Lecture%20Linear%20Fits%20and%20Tolerances%20Rev%201.pdf

Project: Windmill Hub

Wind energy technology is a major intervention toward reducing the use of fossil fuels worldwide. Converting wind energy to electricity requires the use of wind turbines to change the kinetic energy in the wind into mechanical power. This mechanical power produced by the wind turbine is the same as the power produced by a steam or gas powered turbine. In each case, the turbines produce electricity by being connected to an electrical generator. The production of electricity is the same except the wind turbine uses a renewable energy source, the wind, and no fossil fuels are used.

Introduction:

Wind energy is a clean and readily available renewable energy source. In locations around the world where the wind blows with enough velocity, wind turbines capture the wind's power and convert it to electricity. The ability of the wind turbine to capture the most power from the wind requires that the turbine always be pointed into the wind. But as important, is the shape of the turbine blade and the blade angle orientation to the flowing wind.

Purpose of the Project:

The purpose of the Windmill Hub project is to design a new hub for the Kid-Wind Generator™ (designed with three windmill blades) that can accept four windmill blades. Students will research windmill systems and design, 3D print, and construct a new and improved hub for the Kid-Wind Generator. The hub system will have four blade connector ports and will use different and improved positive connection geometry. Students will compare and be able to communicate the new system performance by measuring the increase in electrical production of the new four blade hub system design as compared to the original three blade hub system.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Selecting materials for use in a product requires knowledge of material properties and characterization, based upon manufacturing processes selected, chemical composition, internal defects, temperature, previous loading, dimensions, and other factors.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.
- Additive manufacturing creates by adding thin layers of material, one after the other to allow for the creation of designs, parts and components that are impossible to manufacture by more traditional methods.
- Mechanisms transform input forces and movements into the desired set of forces and movements.
- The design of mechanisms requires the analysis of the outcome movement and forces desired and losses due to efficiency to determine the required input forces and movements.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
- Reverse engineering is the process of disassembly and analysis with the goal of duplicating or improving a product or component of a product.
- Companies often study existing products in order to create new and improved ones.
- “Green Principles” of design are used for eventual disassembly and resource recovery.
- Power extracted from wind and converted to rotational kinetic energy can be expressed mathematically.
- Producing electrical power from wind energy requires an engineered electro-mechanical system.

- Designs are developed and evaluated so areas exposed to maximum torque transmission have sufficient strength.
- The design process may be applied to any mechanical system.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://www.youtube.com/watch?v=uWVwG2_J0hc
https://www.youtube.com/watch?v=aPxlqWriw8o
https://www.youtube.com/watch?v=qGLnhDdljTs
https://www.youtube.com/watch?v=FDyTxGvuAjk

Outline:

- Documentation
  - Engineering Notebook
  - Documentation object to be designed
- Modeling
  - Creation of 3D model
  - Assembly of 3D model
  - Exploded drawing of 3D model with appropriate tolerance noted for parts
  - Design renderings and pictorial exploded drawings
  - Construct 3D model of Kid-Wind Generator hub
- Evaluation
  - Testing of the ability of the hub to allow adjustment of pitch and transfer energy to the generator.
  - Test comparing the electrical production of the new four blade hub design to the original three blade hub design.
- Communication
  - Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.

- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation, and service requirements.

Reverse Engineering

- Apply design principles which include the accommodation for disassembly and resource recovery.
- Research and apply current business practices that lead to new product development or improvement of products or procedures including the use of rapid development and deployment to be faster to market.
- Utilize convergent modeling to capture data and rapidly create new parts to fit existing scans.
- Collaborate with teams to combine models and parametrically create solutions.

Design for Manufacturing

- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.

Design for Assembly

- Apply engineering design of components to assure alignment for assembly.
- Research and apply knowledge of material properties to product design and development.

Business of Manufacturing

- Research and categorize the activities that a business conducts to make discoveries that can either lead to the development of new products or procedures, or to improve existing products or procedures.

College and Career Readiness Math Standards

Apply geometric concepts in modeling situations

1. Use geometric shapes, their measures, and their properties to describe objects (e.g., modeling a tree trunk or a human torso as a cylinder).
2. Apply concepts of density based on area and volume in modeling situations (e.g., persons per square mile, BTUs per cubic foot).
3. Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.
3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.
9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*
2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council’s Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:
Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 3:
Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 5:
Students will develop an understanding of the effects of technology on the environment.

STL Standard 6:
Students will develop an understanding of the role of society in the development and use of technology.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 16:
Students will develop an understanding of and be able to select and use energy and power technologies.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project, one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Windmill Hub

Essential Question:

How can a windmill hub be designed to be secured to a shaft with four radially attached fan blades to the hub outer surface?

Student Scenario:

You work for a small manufacturing company called **Solutions That Work, Inc**. as design engineering. Your company does a lot of work for other manufacturing companies.

A company called **Learning Technology, Inc.** wants to develop a market for educational products related to the study of renewable energy. They want products with improved features and better performance than what is currently on the market. They have given your company, **Solutions That Work, Inc.** a contract to build 10,000 wind-mill hubs for a contract price of $500,000.

Your supervisor has asked you to lead a team to design a windmill hub with four wind blade connectors using an improved connecting geometry and create a working model meeting the contract specification.

Your design and working model will be presented to **Learning Technology, Inc.** for approval prior to the production of the 10,000 units.

The research and learning activities are designed to help students:

- Create sketches to communicate to a group
- Use mathematical formulas to aid in the design of a product
- Utilize specific software features to create a solid model of their idea
- Communicate their solution to their peers

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design
- Sketches and working drawings for the elements of the windmill hub
- Analysis of the structural elements of the windmill hub design
- Data showing performance difference between the three blade hub and the new four blade hub
- 3D printed model of the assembled windmill hub
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1
Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2
Key Question: How do we get started in the design process?

The teams will be responsible for researching windmill hubs, their attributes, and capabilities. Students must research optimal blade angles and different connecting blade and hub geometry, strength of materials, and analysis. Teams are also responsible to research classes of fits and tolerances.

Teams assemble the Kid-Wind Generator system and operate it to study its attributes. Students must be mindful of the hub design, blade rotation system, and overall mechanical performance and electrical production.

Teams hold a group discussion on the specifications of the new windmill hub design. Students begin sketching a variety of connecting design solutions. Students add items from their reading to their Engineering Notebooks.

The student teams discuss possible windmill hub features. The teams should decide on design constraints which might include:

- What material will the windmill hub be made from?
- What is the physical size of the windmill hub?
- How readily can the wind blades be adjusted or changed?
- How does the windmill hub preform?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information find tutorials about individual topics and to find out how the software accomplishes basic features they might want to incorporate. https://docs.plm.automation.siemens.com/tdoc/se/110/se_help/#uid:index

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the inclined windmill hub. Other tutorials in the Resources section are available for use by students.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3-4

Key Question: How do we get started on our individual designs?

Student teams brainstorm needed components of their design and then create their isometric sketches. They include preliminary sizes and clamping requirements including formulas used to evaluate their designs.

This is a good opportunity for students to meet with their clients. This can be facilitated having the teacher be the client or an authentic person can be utilized. The goal is to create a design brief to introduce the design proposal before solid modeling can begin.

Students complete the exercise on Generative Design where they highlight sizes and force specifications and then reduce the material required for their hub. This will allow for reduced material consumption in the manufacturing process.

Students can reference Fits and Tolerances, Basic 3D Commands, Creating Drawing Views, Introduction Assembly Modeling, Analysis in Solid Edge and Working with Bodies for specific commands to use in the Windmill hub design. Students can reference web links, videos, and tutorials at any time during the process of the design.

Teams discuss how their windmill hub will be tested. The groups decide what components they will test and how they will know when their design achieves the test requirements.

Day 5-6
Key Question: How can we begin to design our windmill hub idea?

Teams discuss their proposed windmill hub and how to achieve the design given the approved sketch they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the 3D solid model of the pieces needed and a plan to assemble the windmill hub to the wind generator. They utilize the division of work in the creation of the project management plan.

Students discuss the classes of fit they will use in their designs. Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the windmill hub design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams are reminded to continually check their 3D components of the designs with their team to ensure accurate sizes. Teams discuss how the various designs work and that the designs created will meet the windmill hub requirements and the tolerance limits of their designs to assure the parts will connect as desired. Student teams also discuss how the designs will be assembled and how the clearance between the windmill hub and generator shaft as well as the clearance between the windmill blade and hub will be established and maintained.

Day 7-8
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team final design. It could be a single design or contain elements of several designs. Once the decision is made the students create a plan for creating the team prototype. They need to create a design that incorporates their ideas. Once the final plan is created they will create individual parts in Solid Edge and create assembly and working drawings from their parts. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin 3D printing the necessary components and assemble their scale model of the windmill hub from the printed parts. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 9-10
Key Question: How do we build and test our designs?

Students assemble their windmill hub from the materials following their plans. When students encounter problems assembling their designs they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

As students finish assembling their windmill hub, testing can begin to see if it produces an increase on electrical production as planned. Teams identify sources of problems and redesign parts as needed.

Day 11-12
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to their clients. The deliverables could be in the form of a dimensioned working drawing pictorial representation with balloons and bill of materials and/or a 3D printed prototype as well as the final testing data and demonstrations. Students should prepare an engineering report about the process of designing their wind mill hub and how the components all fit together. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 13
Key Question: How do we convey our ideas?

Students can present their solutions to the authentic audience one group at a time. Students display the completed windmill hub and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs

Vocabulary:

Allowance
Centrifugal Force
Classes of Fits
Clearance
Clearance Fit
Deviation
Dimensioning
Electricity
Electrical Generator
Force or Shrink Fit
Fossil Fuel
Friction
Generator
Impeller
Intervention
Interference Fit
Kinetic Energy
Locational Fits
Lower Limit
Mechanical Power
Positive Connection Geometry
Renewable Energy
Running and Sliding Fits
Shaft
Transitional Location Fits
Tolerance
Turbine
Variation
Wind Turbine
Wind Turbine Blade
Wind Turbine Blade Angle
Wind Turbine Hub
Wind Velocity
Work

Resources:

CAD Tutorials

- https://drive.google.com/open?id=0B_7sFhPxnoaXRlNuckN0OXVpdUE
- https://docs.plm.automation.siemens.com/tdoc/se/109/se_help/#uid:index
- https://docs.plm.automation.siemens.com/tdoc/se/latest/se_help#uid:index_xid618399:xid482668:new_cad_user

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

Generative Design

- https://www.youtube.com/watch?v=J2WU_GunXoU
- https://www.youtube.com/watch?v=vro-8bpRPY4
- https://www.youtube.com/watch?v=pcWd4SHTft8

Types of Fits

- https://www.engineersedge.com/mechanical,045tolerances/preffered-mechanical-tolerances.htm
- http://mmto.org/~dclark/Reports/Encoder%20Upgrade/fittolerences%20%5BRead-Only%5D.pdf
- http://www.mechcadcam.com/what-is-the-fit-and-what-are-the-different-types-of-fits/
- https://extrudesign.com/types-of-fits-in-engineering/
- http://ignou.ac.in/upload/Unit-3-62.pdf
- http://blog.misumiusa.com/shaft-and-hole-tolerances-and-fits/
- https://www.amesweb.info/FitTolerance/FitTolerance.aspx
- https://www.engineersedge.com/calculators/mechanical-tolerances/force-fit-tolerances.htm
- https://mdmetric.com/Ch6.8wGO.pdf

- https://ay14-15.moodle.wisc.edu/prod/pluginfile.php/166546/mod_resource/content/1/ANSI-Standard-Fits.pdf

Tolerance Dimensions

- http://www.machinedesign.com/materials/working-dimensional-tolerances
- https://www.britannica.com/topic/drafting/Dimensions-and-tolerances
- https://www.fictiv.com/hwg/fabricate/gdt-101-an-introduction-to-geometric-dimensioning-and-tolerancing
- http://web2.clarkson.edu/class/es305/willmert/Dimensioning%20in%20Solid%20Edge%20ST.doc
- https://www.youtube.com/watch?v=X0pM6TqKXaM
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dimsd3d.htm
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dim_classfit1a.htm
- http://site.iugaza.edu.ps/aabuzarifa/files/METRO20152_CH52.pdf
- http://web.aeromech.usyd.edu.au/ENGG1960/Documents/Week12/Engineering%20Drawings%20Lecture%20Linear%20Fits%20and%20Tolerances%20Rev%201.pdf

Windmills

- https://sciencing.com/windmills-used-today-7220114.html
  https://www.youtube.com/watch?v=3qqifEdqf5g
- https://www.atlasobscura.com/articles/windmills-water-pumping-museum-indiana
- http://prospect.org/article/tilting-windmills
- https://www.kidwind.org/windwise-1
- http://www.hcisd.org/cms/lib4/TX01001784/Centricity/Domain/307/wind_turbinebladedesign.pdf

Project: Reverse Engineering/Redesign of Existing Product

The reverse engineering process is used by industry to study a product, its components, and the process to produce it. This is called product analysis. A company may choose to conduct a reverse engineering process to see how a competitor's product works or to create a set of working drawings should they not exist.

Introduction:

One goal of reverse engineering is to understand how and why a current design has been created. Designer engineers also go beyond the reverse engineering process and redesign the existing product to have a significant advantage in the market place. Have you ever heard anyone say, "We need a better mouse trap?" Well, a better mouse trap could acquire a large portion of mouse trap sales. This is a simple example but there are many examples in many facets of the economy in areas such as automobiles, airplanes, sporting equipment, clothing, packaging, children's furniture and toys, and so on…

Purpose of the Project:

The purpose of this project is expose students to the process of reverse engineering and redesign of existing products. Students will obtain a product, having at least 3 parts, disassemble it, measure all parts, and record the key attributes of each part. Then students will redesign the product with their own ideas for improvement incorporated into the new design. Students learn precision measurement, materials, design features, tolerances, assembly processes, and design for manufacturing. They also learn about market research, product price points, and marketing.

Concepts:

- An Engineering Notebook is used to keep detailed records of the design and development process.
- Creating unique solutions quickly requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Selecting materials for use in a product requires knowledge of material properties and characterization, based upon manufacturing processes selected, chemical composition, internal defects, temperature, previous loading, dimensions, and other factors.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.
- Simple and compound machines have mechanical advantages that can be used to solve real-world problems.
- Mathematical formulas are used to analyze the amount of force necessary to provide to a mechanism to overcome losses due to inefficiency of the system.
- Additive manufacturing creates by adding thin layers of material, one after the other to allow for the creation of designs, parts and components that are impossible to manufacture by more traditional methods.
- Mechanisms transform input forces and movements into the desired set of forces and movements.
- The design of mechanisms requires the analysis of the outcome movement and forces desired and losses due to efficiency to determine the required input forces and movements.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
- Reverse engineering is the process of disassembly and analysis with the goal of duplicating or improving a product or component of a product.
- Companies often study existing products in order to create new and improved ones.
- Engineering features are the collection of design components that allow for the assembly of components. These might include bosses, spot faces, snap fittings and joints, counter sinks, counter bores, and other elements that allow for assembly.
- “Green Principles” of design are used for eventual disassembly and resource recovery and is referred as Product Lifecycle Management (PLM)

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://www.youtube.com/watch?v=czZQ01ndNTQ
https://www.youtube.com/watch?v=csv2GnMpmy0
https://www.youtube.com/watch?v=pNXUnW1dofE

Outline:

- Documentation
  - Engineering Notebook
  - Sketches with precision annotation
- Modeling
  - Creation of 3D model
  - Assembly of 3D model
  - Exploded drawing of 3D model with appropriate tolerance noted for parts
  - Design renderings and pictorial exploded drawings
  - Redesign and improvement of parts
- Evaluation
  - Trial fit and operation of the improved model.
- Communication
  - Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Reverse Engineering

- Apply design principles which include the accommodation for disassembly and resource recovery.

- Research and apply current business practices that lead to new product development or improvement of products or procedures including the use of rapid development and deployment to be faster to market.
- Analyze the design attributes of an existing product by disassembling it into its parts, use precision measurement tools to create sketches & drawings of the parts, identify the materials and processes used in manufacturing, and create a new and improved design.
- Utilize convergent modeling to capture data and rapidly create new parts to fit existing scans.
- Collaborate with teams to combine models and parametrically create solutions.
- Utilize rapid prototyping/additive manufacturing to create highly complex parts designed in a CAD system.

Design for Manufacturing

- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.

Design for Assembly

- Apply engineering design of components to assure alignment for assembly.

College and Career Readiness Math Standards

Modeling with Geometry G-MG

Apply geometric concepts in modeling situations

1. Use geometric shapes, their measures, and their properties to describe objects (e.g., modeling a tree trunk or a human torso as a cylinder).
2. Apply concepts of density based on area and volume in modeling situations (e.g., persons per square mile, BTUs per cubic foot).
3. Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.

Interpret the structure of expressions

A1 Interpret expressions that represent a quantity in terms of its context

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.
3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.
9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*
2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:
Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 3:
Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 6:
Students will develop an understanding of the role of society in the development and use of technology.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor’s main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Reverse Engineering Rubric

Essential Question:

How can an existing product be redesigned to improve its performance, ergonomics, manufacturing process, end-of-life disassembly, and resource recovery?

Student Scenario:

You are a design engineer for ***New Visions, Inc.,*** a design and manufacturing company. The Senior Vice President for new product development has started a new department called: ***Product Re-Invent*** and wants you to lead a team of 5 people.

Your team will seek out existing products that are ripe for re-design to improve their function, ergonomics, aesthetic design qualities, better design for manufacturing attributes, and end-of-life disassembly and resource recovery. The new re-designed product may have a price point lower than the original product but if not, your team will provide the rationale as to why the new product will succeed in the market at a higher price.

Your team will present your new designs to the leadership of ***New Visions, Inc.*** and each team member will have their annual review based on the performance of the new ***Product Re-Invent*** department. ***New Visions, Inc.*** has a history of financially rewarding excellent performance of its employees.

The research and learning activities are designed to help students:

- Create sketches to communicate to a group
- Use mathematical formulas to aid in the design of a product
- Utilize specific software features to create a solid model of their idea
- Redesign parts and components
- Communicate their solution to their peers

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design.

- Sketches and working drawings for the elements of the new product
- CAD model
- Analysis of the structural elements of the new product design
- The original product and the 3D printed model of the assembled new product
- Business analysis of the new/improved product to include the improved function, ergonomics, aesthetic design qualities, design for manufacturing attributes, opinion of stakeholders, and end-of-life disassembly and resource recovery.
- The price point for the new product and rationale for either a lower or higher price.
- Engineering report of the design process
- Presentation of the development process

Daily Plan:

Day 1
Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students adequate time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2
Key Question: How do we get started in the design process?

The teams will be responsible for researching reverse engineering and re-design precision measurement, engineering design features, and materials.

Student teams should brainstorm what should be disassembled and redesigned. The teacher should discuss the importance of keeping the items selected small with a reasonable number of parts.

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information find tutorials about individual topics and to find out how the software accomplishes basic features the student might want to incorporate. https://docs.plm.automation.siemens.com/tdoc/se/110/se_help/#uid:index

Students can enter terms to view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands. Other tutorials in the Resources section are available for use by students. Student teams discuss the specifications of reverse engineering and redesign. Students list the criteria and constraints of the problem they are solving. Teams research engineering features, materials and precision measurement. The students should be recording their ideas of reverse engineering and redesign of products in the Engineering Notebook.

Remind students to record research notes and sources as well as reflections of the day in the Engineering Notebook.

Day 3-5
Key Question: How do we get started on our individual designs?

Student teams analyze the reverse engineering results. Students brainstorm some possible new design features that could be included in the redesign of the product. Students create the needed components of their redesign using isometric sketches to add these sketches to their design brief. Students include preliminary sizes and any power requirements including formulas used to evaluate their designs. They then meet with their clients (teacher or other designee) who will need to sign off on the design proposal before solid modeling can begin.

Students can reference Generative Design, Fits and Tolerances, Basic 3D Commands, Creating Drawing Views, Introduction Assembly Modeling, Analysis in Solid Edge and Working with Bodies for specific commands to use in the reverse engineering process. Students can reference web links, videos, and tutorials at any time during the process of the design

Students research the meaning of Market Research. They note in their engineering notebook how market research applies to this project. Issues related to improved function, ergonomics, aesthetic design qualities, design for manufacturing attributes, opinion of stakeholders, end-of-life disassembly and resource recovery are important.

Teams discuss how their redesigned product should be tested. Consideration is given to use of a survey with a focus group. This will inform the team's action plan.

The students review all the elements of the new product that can be evaluated and list their evaluation criteria and then decide how they will know when their design achieves the test requirements.

Day 6-10
Key Question: How can we create our model efficiently?

Teams discuss their proposed redesigned product and how to achieve the new design given the approved sketch they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the 3D solid model of the components needed and a plan for completing the full model. They utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the redesign product, they need to finalize how the design will meet the design requirements. This means students must consider how the design will be tested before building.

Teams are reminded to continually check their 3D components of the designs with their team to ensure accurate sizes. Teams discuss how the various designs work and that the designs created will meet the new redesign product requirements. Additionally, students pay attention to the tolerance limits of their designs to assure the parts will connect as desired. Student teams also discuss how the designs will be assembled and how the clearance between any moving parts will be established and maintained.

Day 11
Key Question: Are we on track with our designs?

The teacher should review the design process with the class and check with teams to assess progress with the redesign. The teacher should review any known or perceived problems encountered with the redesigns so far. The class should also be reminded of the pace of part creation and the requirements needed of the exploded assemblies.
Students will continue to model using the software and using tutorials as necessary.

Day 12-16
Key Question: How do we build and test our redesigns?

Once the assemblies are together, completed and verified, the students can create an explosion of the assembly and print pieces for their exploded original product. The teacher should help the students gather the design into the final stage for the presentation drawings.

It is important to remind students that there will be two exploded displays; one of the original product and one of the new redesigned product.

Students start 3D printing the redesigned parts as they finish them.
Students create the 3D prints of their redesigned parts and finish assembly modeling, renderings working drawings, or other media for their presentations.

Students complete the Focus Group survey and meet with the Focus Group. The survey results are reviewed by the teams and adjustments are made if needed.

Day 17-18
Key Question: How do student teams organize their thoughts for a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to their clients. The deliverables could be in the form of a dimensioned working drawing, pictorial representation with balloons, exploded models, and bill of materials and/or a 3D printed prototype as well as the final testing data and demonstrations. Students should prepare an engineering report about the process of designing their product and how the components all fit together. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 19
Key Question: How do we convey our ideas?

Students can present their solutions to the authentic audience one at a time. Students display the completed new redesigned product and demonstrate how it functions. Included in the presentation is a summary of the business analysis of the new/improved product to include the improved function, ergonomics, aesthetic design qualities, design for manufacturing attributes, opinion of stakeholders, and end-of-life disassembly and resource recovery. The price point for the new product and rationale for either a lower or higher price is included.

Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

Analysis
Assembly Modeling
Bill of Materials
Boss
Chamfers
Classes of Fits
Clearance
Clearance Fit
Clips
Design for Manufacturing
Dial Calipers
Dimensioning
Disassemble
Disassembly and Resource Recovery
Design Features
Documentation
Dovetail
Fasteners
Fillets
Focus Group
Force or Shrink or Compression or Interference Fit
Friction
Functionality
Innovation
Invention
Keyway
Knurl
Marketing
Market Research
Non-destructive
Observation
Patent
Product Analysis
Product Price Point
Repurposing
Reverse Engineering
Ribs
Rounds
Spline
Spotface
Threads
Tolerance

Resources:

CAD Tutorials

- https://drive.google.com/open?id=0B_7sFhPxnoaXRlNuckN0OXVpdUE
- https://docs.plm.automation.siemens.com/tdoc/se/109/se_help/#uid:index
- https://docs.plm.automation.siemens.com/tdoc/se/latest/se_help#uid:index_xid618399:xid482668:new_cad_user

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

Measuring with calipers:

- http://www.chicagobrand.com/help/dialcaliper.html
- https://www.youtube.com/watch?v=_7-6ALptqQQ
- http://www.aylj.com/en/expertise_dialcaliper.htm
- http://www.tresnainstrument.com/how_to_use_a_dial_caliper.html
- http://www.wikihow.com/Use-and-Read-Dial-Vernier-Caliper

Measuring with Micrometers

- http://www.popsci.com/diy/article/2009-10/basic-skills-micrometer
- https://www.miniphysics.com/how-to-read-a-micrometer-screw-gauge.html
- https://www.youtube.com/watch?v=i_jygJkJujE
- http://www.wikihow.com/Use-and-Read-an-Outside-Micrometer

Reverse Engineering:

- https://www.lce.com/Mechanical-Component-Reverse-Engineering-Project-Examples-328.html
- https://www.asme.org/engineering-topics/articles/modeling-computational-methods/the-rise-of-reverse-engineering
- http://www.npd-solutions.com/remethodology.html

- https://www.asme.org/career-education/early-career-engineers/me-today/reverse-redesigning-everyday-products-leads
- http://slideplayer.com/slide/6084123/

Types of Fits

- https://www.engineersedge.com/mechanical,045tolerances/preffered-mechanical-tolerances.htm
- http://mmto.org/~dclark/Reports/Encoder%20Upgrade/fittolerences%20%5BRead-Only%5D.pdf
- http://www.mechcadcam.com/what-is-the-fit-and-what-are-the-different-types-of-fits/
- https://extrudesign.com/types-of-fits-in-engineering/
- http://ignou.ac.in/upload/Unit-3-62.pdf
- http://blog.misumiusa.com/shaft-and-hole-tolerances-and-fits/
- https://www.amesweb.info/FitTolerance/FitTolerance.aspx
- https://www.engineersedge.com/calculators/mechanical-tolerances/force-fit-tolerances.htm
- https://mdmetric.com/Ch6.8wGO.pdf
- https://ay14-15.moodle.wisc.edu/prod/pluginfile.php/166546/mod_resource/content/1/ANSI-Standard-Fits.pdf

Tolerance Dimensions

- http://www.machinedesign.com/materials/working-dimensional-tolerances
- https://www.britannica.com/topic/drafting/Dimensions-and-tolerances
- https://www.fictiv.com/hwg/fabricate/gdt-101-an-introduction-to-geometric-dimensioning-and-tolerancing
- http://web2.clarkson.edu/class/es305/willmert/Dimensioning%20in%20Solid%20Edge%20ST.doc
- https://www.youtube.com/watch?v=X0pM6TqKXaM
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dimsd3d.htm
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dim_classfit1a.htm
- http://site.iugaza.edu.ps/aabuzarifa/files/METRO20152_CH52.pdf
- http://web.aeromech.usyd.edu.au/ENGG1960/Documents/Week12/Engineering%20Drawings%20Lecture%20Linear%20Fits%20and%20Tolerances%20Rev%201.pdf

Project: Spool Mechanism for Kite String

Wind energy has been utilized for centuries even before the industrial revolution. The power of the wind was used to move ships using wind sails. Water was moved and grain was ground using windmills. Kites were invented and used for fishing, measuring distances, and even lifting humans for observations.

Introduction:

We know that kites were flown in China about 3000 years ago. The first kites were square in shape and later different shapes were created. Today there are many kite shapes all having their own unique attributes.

Kites need to be connected to the person flying the kite. This is done by using a string. In ancient times silk was used to make kite string. Later cotton was used and today we have excellent synthetic materials such as nylon, rayon, polyester, and others all made from petro-chemicals. One challenge for the kite operator is managing the string. How can the string be let out and retrieved at the speed needed without tangling?

Most methods used to store kite string is by wrapping the string around string holder. This holder is held in one hand. The string is let out or retrieved with the other hand; not an easy thing to do, especially for a child. And it is hard to avoid string entanglement.

Purpose of the Project:

The purpose of the Spool Mechanism for Kite String project is to design a kite string storage system that can hold 300 feet of kite string. Students will research string spool systems learning about reel motion and control. They will control for “freewheeling” and string entanglement. The design must be appropriate for children and have appealing youthful design attributes. Attention to minimal material usage while assuring structural integrity is required.

Students will investigate the concept of biomimicry to see if these natural bio systems that have evolved in nature have applications to the design.

Concepts:

- Creating unique solutions quickly requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Selecting materials for use in a product requires knowledge of material properties and characterization, based upon manufacturing processes selected, chemical composition, internal defects, temperature, previous loading, dimensions, and other factors.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.
- Additive manufacturing creates by adding thin layers of material, one after the other to allow for the creation of designs, parts and components that are impossible to manufacture by more traditional methods.
- Mechanisms transform input forces and movements into the desired set of forces and movements.
- The design of mechanisms requires the analysis of the outcome movement and forces desired and losses due to efficiency to determine the required input forces and movements.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
- Reverse engineering is the process of disassembly and analysis with the goal of duplicating or improving a product or component of a product.
- Companies often study existing products in order to create new and improved ones.
- “Green Principles” of design are used for eventual disassembly and resource recovery and is referred as Product Lifecycle Management (PLM).
- Nature has many adaptive methodologies allowing organisms to adapt to and excel in their ecosystems. Designers use biomimicry to take advantage of those adaptions in the creation of products to fit particular needs.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

http://media.plm.automation.siemens.com/global-web/our-story/digital-innovation-platform.mp4
https://youtu.be/F0kKYB347Us

http://www.usa.siemens.com/advanced-manufacturing/ Advanced manufacturing magazine

Outline:

- Documentation
  - Engineering Notebook
  - Documentation object to be designed
- Modeling
  - Creation of 3D model
  - Assembly of 3D model
  - Convergent modeling
  - Exploded drawing of 3D model with appropriate tolerance noted for parts
  - Design renderings and pictorial exploded drawings
  - Construct 3D model of Spool Mechanism for Kite String project
- Evaluation
  - Test the kite string reel by having a child operate the reel effectively.
- Design for assembly
  - Engineering features
- Communication
  - Presentation of design solutions
- Business
  - Develop a new product

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Design for Manufacturing

- Apply the principles of design for manufacturing, enabling the efficient and effective production of products.
- Develop a logical argument for selecting the tools, machines and labor necessary to produce finished goods from raw materials.
- Create a strategy to increase efficiency and decrease waste by receiving goods only as they are needed in the production process, thereby reducing inventory costs and reducing the impact of water and other natural resource consumption.
- Create a plan for protecting the safety, health and welfare of people engaged in the manufacturing environment.
- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.

Design for Assembly

- Apply engineering design of components to assure alignment for assembly.

College and Career Readiness Math Standards

Modeling with Geometry G-MG

Apply geometric concepts in modeling situations

1. Use geometric shapes, their measures, and their properties to describe objects (e.g., modeling a tree trunk or a human torso as a cylinder).
2. Apply concepts of density based on area and volume in modeling situations (e.g., persons per square mile, BTUs per cubic foot).
3. Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.

3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.

9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*

2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council’s Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:
1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:
Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Kite String Reel Rubric

Essential Question:

How can a team effectively design a kite string storage and operating system so 300 feet of string is secured in a reel and dispensed and retrieved by the kite flying operator efficiently and accurately?

Student Scenario:
You work for ***Quantum Leap Toys, Inc***. as a project manager. The Vice President of Sales and Marketing has requested that you be assigned as the team leader for a project to design a revolutionary kite string storage and operating system. Your supervisor has agreed to this new assignment for you and has told you that you now report to the Vice President of Sales and Marketing for the duration of the project.

The project goals are as follows:

- The kite string holder must hold 300 feet of string.
- The design must be attractive for children.
- A 5 year old child must be able to operate the kite string holder.
- The design attributes must minimize material usage.
- Biomimicry may have applications to the design.

Your team's design will be presented by use of a working model. The Vice President of Sales and Marketing has indicated to you that she hopes this product will capture the toy kite market.

The research and learning activities are designed to help students:

- Create sketches to communicate to a group
- Use mathematical formulas to aid in the design of a product
- Utilize specific software features to create a solid model of their idea
- Select and apply simple machines and engineering features for fastening
- Communicate their solution to their peers

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design.
- Sketches and working drawings for the elements of the kite string reel
- Analysis of the structural elements of the kite string reel design
- 3D printed model of the assembled kit string reel
- Engineering report of the design process
- Focus group survey about the kite string reel design and operation
- Presentation for the authentic audience

Daily Plan:

Day 1
Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2
Key Question: How do we get started in the design process?

The teams will be responsible for researching kite string storage systems, their attributes, and capabilities. Students must research kite string storage systems, strength of materials, and analysis. Teams are also responsible to research classes of fits and tolerances. Teams hold a group discussion on the specifications of the new kite string storage systems design. Students begin sketching a variety of kite string storage systems solutions. Students add items from their reading to their Engineering Notebooks.

The student teams discuss possible kite string storage systems include:

- What material will the kite string storage systems be made from?
- What is the physical size of the kite string storage systems?
- How does the kite string storage systems preform?
- Can biomimicry be utilized?
- Can a 5 year old child operate the kite string storage systems?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information find tutorials about individual topics and to find out how the software accomplishes basic features they might want to incorporate.
https://docs.plm.automation.siemens.com/tdoc/se/110/se_help/#uid:index

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the kite string storage systems.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3
Key Question: How do we get started on our individual designs?

Student teams brainstorm needed components of their design and then create their isometric sketches to add to their design brief to be include with their sketches. They include preliminary sizes and operating requirements including formulas used to evaluate their designs.

This is a good opportunity for students to meet with their clients. This can be facilitated having the teacher be the client or an authentic person can be utilized. The goal is to create a design brief to introduce the design proposal before solid modeling can begin.

Students can reference Generative Design, Fits and Tolerances, Basic 3D Commands, Creating Drawing Views, Introduction Assembly Modeling, Analysis in Solid Edge and Working with Bodies for specific commands to use in the kite string storage systems design. Students can reference web links, videos, and tutorials at any time during the process of the design.

Teams discuss how their kite string storage systems should be tested. The groups decide what components will be tested and how they will know when their design achieves the test requirements.

Day 4-5
Key Question: How can we begin to design our kite string storage systems idea?

Teams discuss their proposed kite string storage systems and how to achieve the design given the approved sketch they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the 3D solid model of the pieces needed and a plan to assemble and test the kite string storage systems. They utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the kite string storage systems design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams are reminded to continually check their 3D components of the designs with their team to ensure accurate sizes. Teams discuss how the various designs work and that the designs created will meet the kite string storage systems requirements and the tolerance limits of their designs to assure the parts will connect as desired. Student teams also discuss how the designs will be assembled and how the clearances between moving parts will be maintained.

Day 6-9
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team final design. It could be a single design or contain elements of several designs. Once the decision is made the students create a plan for creating the team prototype. They need to create a design that incorporates their ideas. Once the final plan is created they will create individual parts in Solid Edge and assemble them into assemblies. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin 3D printing the necessary components and assemble their scale model of the kite string storage systems from the printed parts. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 10-11
Key Question: How do we build and test our designs?

Students assemble their kite string storage systems from the materials following their plans. When students encounter problems assembling their designs they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

As students finish assembling their kite string storage systems, testing can begin to see if it operates as planned. Teams identify sources of problems and redesign parts as needed.

Day 12-13
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to their clients. The deliverables could be in the form of a dimensioned working drawing pictorial representation with balloons and bill of materials and/or a 3D printed prototype as well as the final testing data and demonstrations. Students should prepare an engineering report about the process of designing their kite string storage systems and how the components all fit together. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 14
Key Question: How do we convey our ideas?

Students can present their solutions to the authentic audience one at a time. Students display the completed kite string storage systems and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

If possible, student teams enlist the help of a 5 year old child to demonstrate, after receiving a few basic instructions, how to fly a kite using the new spool mechanism.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

Allowance
Biomimicry
Boss
Centrifugal Force
Classes of Fits
Clearance
Clearance Fit
Cog Wheel
Crank
Deviation
Dimensioning
Force or Shrink Fit
Freewheeling
Friction
Interference Fit
Locational Fits
Lower Limit
Mechanical Power
Nylon
Pawl
Petro-Chemicals
Polyester
Ratchet
Rayon
Running and Sliding Fits
Shaft
Snap-Fit Joints

Synthetic Materials
Tolerance
Variation
Work

Resources:

CAD Tutorials

- https://drive.google.com/open?id=0B_7sFhPxnoaXRlNuckN0OXVpdUE
- https://docs.plm.automation.siemens.com/tdoc/se/109/se_help/#uid:index
- https://docs.plm.automation.siemens.com/tdoc/se/latest/se_help#uid:index_xid618399:xid482668:new_cad_user

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

Engineering features for Assembly

- https://www.fictiv.com/hwg/assemble/how-to-design-assemblies-to-be-self-locating-and-self-fixturing
- http://me.gatech.edu/files/capstone/L071ME4182DFA
- https://www.creativemechanisms.com/blog/design-for-assembly-dfa
- https://www.creativemechanisms.com/ratchets
- https://www.emachineshop.com/ratchet-wheel/
- https://en.wikipedia.org/wiki/Ratchet_(device)
- https://www.youtube.com/watch?v=l4CXz2UywVQ
- https://www.youtube.com/watch?v=qAFjvguO6U8
- https://www.youtube.com/watch?v=yIzIXeBVxIc
- https://www.youtube.com/watch?v=zae2ZePQTwQ

Types of Fits

- https://www.engineersedge.com/mechanical,045tolerances/preffered-mechanical-tolerances.htm
- http://mmto.org/~dclark/Reports/Encoder%20Upgrade/fittolerences%20%5BRead-Only%5D.pdf
- http://www.mechcadcam.com/what-is-the-fit-and-what-are-the-different-types-of-fits/
- https://extrudesign.com/types-of-fits-in-engineering/
- http://ignou.ac.in/upload/Unit-3-62.pdf
- http://blog.misumiusa.com/shaft-and-hole-tolerances-and-fits/
- https://www.amesweb.info/FitTolerance/FitTolerance.aspx
- https://www.engineersedge.com/calculators/mechanical-tolerances/force-fit-tolerances.htm
- https://mdmetric.com/Ch6.8wGO.pdf
- https://ay14-15.moodle.wisc.edu/prod/pluginfile.php/166546/mod_resource/content/1/ANSI-Standard-Fits.pdf

Tolerance Dimensions

- http://www.machinedesign.com/materials/working-dimensional-tolerances
- https://www.britannica.com/topic/drafting/Dimensions-and-tolerances
- https://www.fictiv.com/hwg/fabricate/gdt-101-an-introduction-to-geometric-dimensioning-and-tolerancing
- http://web2.clarkson.edu/class/es305/willmert/Dimensioning%20in%20Solid%20Edge%20ST.doc
- https://www.youtube.com/watch?v=X0pM6TqKXaM
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dimsd3d.htm
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dim_classfit1a.htm
- http://site.iugaza.edu.ps/aabuzarifa/files/METRO20152_CH52.pdf
- http://web.aeromech.usyd.edu.au/ENGG1960/Documents/Week12/Engineering%20Drawings%20Lecture%20Linear%20Fits%20and%20Tolerances%20Rev%201.pdf

SIEMENS

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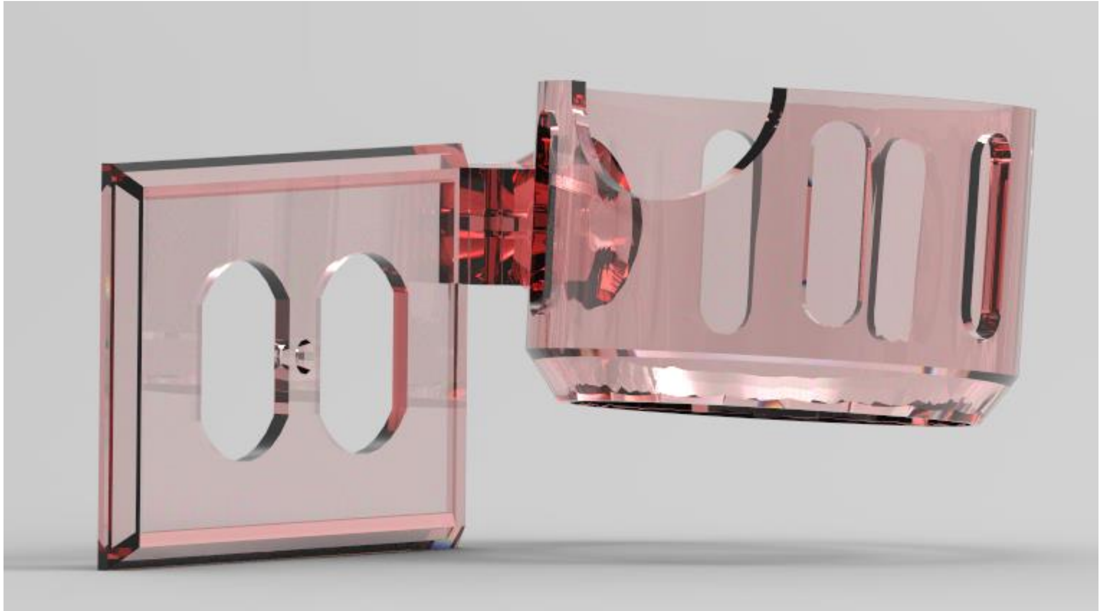

Project: Bathroom Caddy for a Blow Dryer

Bathrooms have multiple purposes and one is to make the user presentable to the outside world. One common task is blow drying ones' hair. Usually this task is done using a hand held blow dryer. Often the blow dryer is stowed in a drawer, closet, box, or sometimes is hanging from the towel bar. In all these cases the blow dryer is not readily available.

Introduction:

Blow dryers are an essential personal grooming tool. They use electricity to heat an element that provides hot air and a fan to blow the hot air on your hair. At first the blow dryer is room temperature but in short order it can become hot. When hot the blow dryer likely expands so the outside geometry is somewhat larger. The caddy must accommodate for this differential as part of the design. Also, the design must address the need to diffuse accumulated heat safely.

Finally, the Bathroom Caddy for a Blow Dryer must have aesthetically pleasing design features as well as being functional and durable.

Purpose of the Project:

The purpose of the Bathroom Caddy for a Blow Dryer project is to provide an experience for students where they must create a matching geometry for a product with just enough clearance between the blow dryer and the caddy so the blow dryer is stowed securely when not in use. Students are given a hand held blow dryer. They replicate the blow dryer's outside geometry using Solid Edge to use as the profile from which to create the matching geometry for the inside of the Blow Dryer Caddy. Students create a prototype and demonstrate its effectiveness.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Selecting materials for use in a product requires knowledge of material properties and characterization, based upon manufacturing processes selected, chemical composition, internal defects, temperature, previous loading, dimensions, and other factors.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.
- Additive manufacturing creates by adding thin layers of material, one after the other to allow for the creation of designs, parts and components that are impossible to manufacture by more traditional methods.
- Mechanisms transform input forces and movements into the desired set of forces and movements.
- The design of mechanisms requires the analysis of the outcome movement and forces desired and losses due to efficiency to determine the required input forces and movements.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
- Reverse engineering is the process of disassembly and analysis with the goal of duplicating or improving a product or component of a product.
- Companies often study existing products in order to create new and improved ones.
- "Green Principles" of design are used for eventual disassembly and resource recovery.
- Power extracted from wind and converted to rotational kinetic energy can be expressed mathematically.
- Producing electrical power from wind energy requires an engineered electro-mechanical system.
- Designs are developed and evaluated so areas exposed to maximum torque transmission have sufficient strength.
- The design process may be applied to any mechanical system.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://www.youtube.com/watch?v=oWeAYJ8CN70
https://www.siemens.com/global/en/home/company/topic-areas/future-of-manufacturing/digitalenterprise.html

Outline:

- Documentation
  - Engineering Notebook
  - Documentation object to be designed
- Modeling
  - Creation of 3D model
  - Assembly of 3D model
  - Exploded drawing of 3D model with appropriate tolerance noted for parts
  - Design renderings and pictorial exploded drawings
  - Construct 3D model of Bathroom Caddy for a Blow Dryer project
- Evaluation
  - Evaluation will be based on results from a survey to be completed by testers as to the functionality, durability and design aesthetic.
- Communication
  - Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation, and service requirements.

Reverse Engineering

- Apply design principles which include the accommodation for disassembly and resource recovery.
- Research and apply current business practices that lead to new product development or improvement of products or procedures including the use of rapid development and deployment to be faster to market.
- Utilize convergent modeling to capture data and rapidly create new parts to fit existing scans.
- Collaborate with teams to combine models and parametrically create solutions.

Design for Manufacturing

- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.

Design for Assembly

- Apply engineering design of components to assure alignment for assembly.
- Research and apply knowledge of material properties to product design and development.

Business of Manufacturing

- Research and categorize the activities that a business conducts to make discoveries that can either lead to the development of new products or procedures, or to improve existing products or procedures.

College and Career Readiness Math Standards

Apply geometric concepts in modeling situations

1. Use geometric shapes, their measures, and their properties to describe objects (e.g., modeling a tree trunk or a human torso as a cylinder).
2. Apply concepts of density based on area and volume in modeling situations (e.g., persons per square mile, BTUs per cubic foot).
3. Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.

3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.

9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*

2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

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STL Standard 4:
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STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:

Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

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STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

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Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
[Bathroom Caddy Rubric]

Essential Question:
How can we design a storage device that sits on the bathroom counter to securely hold a hand held blow dryer?

Student Scenario:
You work for ***Essential Home Products, Inc***. as a design engineer. Your company prides itself on providing high quality products for home use.

The New Product Team has been talking about the Bathroom Caddy for a Blow Dryer for several weeks. The team is now ready to direct development resources to create a prototype. You, as the design engineer, have been asked to produce a prototype for the next meeting in two weeks. There is optimism for this new product from the team members.

The design requirements are as follows:

- The model must be made from a material appropriate for the first prototype.
- The design must be durable, functional, and aesthetically pleasing.
- The model must address the accumulated heat in the blow dryer after use and provide passive venting of the heat.
- The model must have a matching profile slightly larger than the blow dryer accommodating for the normal blow dryer expansion due to heat. A clearance between the caddy inside profile and the blow dryer outside profile, when hot, of .0625 inches is the goal.

The research and learning activities are designed to help students:

- Create sketches to communicate to a group
- Use mathematical formulas to aid in the design of a product
- Utilize specific software features to create a solid model
- Communicate their solution to their peers

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design.
- Sketches and working drawings for the elements of the Bathroom Caddy for a Blow Dryer
- Analysis of the structural elements of the Bathroom Caddy for a Blow Dryer design
- 3-D solid model of the Bathroom Caddy for a Blow Dryer
- Engineering report of the design process
- Product testers survey results
- Presentation for an authentic audience

Daily Plan:

Day 1

Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2

Key Question: How do we get started in the design process?

The teams will be responsible for researching options for the Bathroom Caddy for a Blow Dryer. Students must research caddy systems, material options, and analysis. Teams are also responsible for researching classes of fits and tolerances. Teams are expected to conduct measurement differentials on the blow dryer comparing room temperature geometry to operational hot geometry. What's the differential?

Teams hold a group discussion on the specifications of the Bathroom Caddy for a Blow Dryer design. Students begin sketching a variety of caddy design systems solutions. Students add items from their reading to their Engineering Notebooks.

The student teams discuss possible Bathroom Caddy for a Blow Dryer systems including:

- What material will the bathroom caddy systems be made from?
- What is the physical size of the bathroom caddy systems within the design requirements?
- How does the Bathroom Caddy for a Blow Dryer system preform?
- Does the model meet the stated design requirements?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information find tutorials about individual topics and to find out how the software accomplishes basic features the student might want to incorporate. https://docs.plm.automation.siemens.com/tdoc/se/110/se_help/#uid:index

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the Bathroom Caddy for a Blow Dryer systems. Other tutorials in the Resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3
Key Question: How do we get started on our individual designs?

Student teams brainstorm needed components of their design and then create their isometric sketches to add to their design brief to be include with their sketches. They include preliminary sizes and operating requirements including formulas used to evaluate their designs.

Students can reference Generative Design, Fits and Tolerances, Basic 3D Commands, Creating Drawing Views, Introduction Assembly Modeling, Analysis in Solid Edge and Working with Bodies for specific commands to use in the Bathroom Caddy for a Blow Dryer project. Students can reference web links, videos, and tutorials at any time during the process of the design.

Teams discuss how their Bathroom Caddy for a Blow Dryer system should be tested. The groups decide what components will be tested and how they will know when their design achieves the test requirements.

Day 4-5
Key Question: How can we begin to design our Bathroom Caddy for a Blow Dryer systems model?

Teams discuss their proposed Bathroom Caddy for a Blow Dryer system and how to achieve the design. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the 3D solid model of the Bathroom Caddy for a Blow Dryer system. They utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the Bathroom Caddy for a Blow Dryer system design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams are reminded to continually check their 3D components of the design to ensure accurate sizes and that the model created will meet the Bathroom Caddy for a Blow Dryer system requirements. The clearances between the caddy and the blow dryer are important factors when the blow dryer is hot and at room temperature.

Day 6-9
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs created so far. They look at the criteria and testing protocols. They discuss which design they wish to use as the team final design. It could be a single design or contain elements of several designs. Once the design decision is made the students create a plan for creating the prototype using additive manufacturing technology. When the team has the final design they will create the model of the caddy in Solid Edge. A Solid Edge model showing the Caddy and Blow Dryer assembly is required. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin 3-D Additive Manufacturing of the Bathroom Caddy for a Blow Dryer. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 10-11
Key Question: How do we build and test our designs?

Students assemble their Bathroom Caddy for a Blow Dryer system from their 3-D Additive Manufacturing model. When students encounter problems assembling their model they need to discuss how they will resolve the issue and change the design as needed.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

As students finish their Bathroom Caddy for a Blow Dryer system, testing can begin to see if the model meets the stated design requirements. Evaluation will utilize a focus group of testers to examine and test the product. Testers will complete a survey assessing the following criteria:

- Is the product made from a material appropriate for the first prototype?
- Is the product durable, functional, and aesthetically pleasing?
- Does the product address the accumulated heat in the blow dryer after use and provide passive venting of the heat?
- Does the product have a matching profile slightly larger than the blow dryer accommodating for the normal blow dryer expansion due to heat?

Teams identify sources of problems and redesign parts as needed.

Day 12-13
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to the New Product Team. The deliverables could be in the form of a dimensioned working drawing pictorial representation with balloons and bill of materials and the 3-D Additive Manufacturing model prototype as well as the final testing data and demonstrations. Students should prepare an engineering report about the process of designing their Bathroom Caddy for a Blow Dryer system and how the blow dryer and caddy fit together. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 14
Key Question: How do we convey our ideas?

Students can present their solutions to the authentic audience one at a time. Students display the completed Bathroom Caddy for a Blow Dryer system model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs

Vocabulary:

Allowance
Classes of Fits
Clearance
Clearance Fit
Deviation
Differential
Dimensioning
Joining Geometry
Locational Fits
Lower Limit
Running and Sliding Fits
Tolerance
Variation

Resources:

CAD Tutorials

- https://drive.google.com/open?id=0B_7sFhPxnoaXRlNuckN0OXVpdUE
- https://docs.plm.automation.siemens.com/tdoc/se/109/se_help/#uid:index
- https://docs.plm.automation.siemens.com/tdoc/se/latest/se_help#uid:index_xid618399:xid482668:new_cad_user

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

Types of Fits

- https://www.engineersedge.com/mechanical,045tolerances/preffered-mechanical-tolerances.htm
- http://mmto.org/~dclark/Reports/Encoder%20Upgrade/fittolerences%20%5BRead-Only%5D.pdf
- http://www.mechcadcam.com/what-is-the-fit-and-what-are-the-different-types-of-fits/
- https://extrudesign.com/types-of-fits-in-engineering/
- http://ignou.ac.in/upload/Unit-3-62.pdf
- http://blog.misumiusa.com/shaft-and-hole-tolerances-and-fits/
- https://www.amesweb.info/FitTolerance/FitTolerance.aspx
- https://www.engineersedge.com/calculators/mechanical-tolerances/force-fit-tolerances.htm
- https://mdmetric.com/Ch6.8wGO.pdf
- https://ay14-15.moodle.wisc.edu/prod/pluginfile.php/166546/mod_resource/content/1/ANSI-Standard-Fits.pdf

Tolerance Dimensions

- http://www.machinedesign.com/materials/working-dimensional-tolerances
- https://www.britannica.com/topic/drafting/Dimensions-and-tolerances
- https://www.fictiv.com/hwg/fabricate/gdt-101-an-introduction-to-geometric-dimensioning-and-tolerancing
- http://web2.clarkson.edu/class/es305/willmert/Dimensioning%20in%20Solid%20Edge%20ST.doc
- https://www.youtube.com/watch?v=X0pM6TqKXaM
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dimsd3d.htm
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dim_classfit1a.htm
- http://site.iugaza.edu.ps/aabuzarifa/files/METRO20152_CH52.pdf
- http://web.aeromech.usyd.edu.au/ENGG1960/Documents/Week12/Engineering%20Drawings%20Lecture%20Linear%20Fits%20and%20Tolerances%20Rev%201.pdf

Projects Quarter 2

Intro to G&M codes, Speeds and Feeds, Solid Edge CAM Pro, Tooling, Verification and Analysis and Posts and Post Processors • [Engraved Name Plate]()	

Select one of the next two projects

Intro to G&M codes, Speeds and Feeds, Solid Edge CAM Pro, Tooling, Verification and Analysis and Posts and Post Processors • [Soda Can Opener]()	

<table>
<tr>
<td>Intro to G&M codes, Speeds and Feeds, Solid Edge CAM Pro, Tooling, Verification and Analysis and Posts and Post Processors

• Game Piece Design</td>
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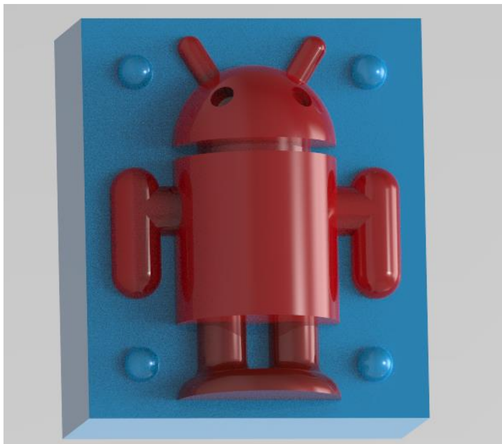
</table>

Select one of the next two projects.

<table>
<tr>
<td>Intro to G&M codes, Speeds and Feeds, Solid Edge CAM Pro, Tooling, Verification and Analysis and Posts and Post Processors

• Box Design with Interlocking Top</td>
<td></td>
</tr>
<tr>
<td>Intro to G&M codes, Speeds and Feeds, Solid Edge CAM Pro, Tooling, Verification and Analysis and Posts and Post Processors

• Split Mold</td>
<td></td>
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Project: Engraved Name Plate

Manufacturing is vital to the nation's economic health and high standard of living. Manufacturing as a science is constantly evolving. Advances in software, materials, and tooling have allowed for new products to be designed, tested, and produced in shorter time and with better quality. The process requires quality, accuracy, and speed that only modern machinery can provide. Our ability to control these machines is of critical importance and is a major factor in the creation of Lean Manufacturing so mistakes and inefficiencies are limited.

Introduction:

It is increasingly rare to find manual machines used in the manufacturing process today. Computer Numeric Control (CNC) is a technology used in all types of processes. Both additive (building layer by layer sometimes known as 3D Printing) and subtractive (starting with a block then removing material e.g.: milling, cutting, plasma arc, wire EDM etc.) utilize CNC to precisely control movement. To be competitive in manufacturing requires extensive knowledge and application of modern manufacturing technology which will lead to improvements in productivity.

Purpose of the Project:

Students will research G&M codes and coordinate geometry in order to develop code that machines can interpret. The students will design a name plate and develop the code to control a CNC mill to produce the desired engraving. Students will explore materials, cutting tools, and feeds and speeds in the creation of their codes. They will research the code necessary to communicate the coordinate system and units used by the CNC mill. Students will be able to identify components of the G-code and what effect those components will have on the finished part.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Materials have certain properties that make them more suitable for certain applications than others.
- Selecting materials for use in a product requires knowledge of material properties and characterization, based upon manufacturing processes selected, chemical composition, internal defects, temperature, previous loading, dimensions, and other factors.
- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- CNC machine tool technology uses Cartesian Coordinates to position and control tooling to produce accurate models.
- G-code is the name given to numerical control programs that are used to control all types of computerized machinery.
- Speeds and Feeds is a machining term that refers to the rate that material is removed to acquire a finished part. Speed refers to either the speed of the moving material or the speed of the cutter or both at the same time. Feed is the rate of material removal. The relationship between speed and feed can vary depending on the desired surface finish. Usually initial cuts remove more material leaving a rough finish and a finish cut removes less material with a slower feed rate leaving a smooth finished surface.
- Design for manufacturing involves the analysis of the design and how the design can be changed to allow for rapid and efficient manufacturing processes.
- Design for assembly involves analysis and changes to the design to make the assembly of the product as easy as possible.
- Post processors have programs that interpret the intent of CAM software and turn the desired operations into G-code to control the CNC machines.

Siemens Real World Application Videos:

https://www.youtube.com/watch?v=1rIIuJF5cmM
https://vimeo.com/34547576

Outline:

- Documentation
  - Engineering Notebook
  - Documentation of desired designed
- Programming
  - Creation of NC program

Verification of NC Program
Rendering of NC Program results
Evaluation
Comparison of G-code results to original sketch
Communication
Presentation of design solutions

Standards:

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation, and service requirements.

Design for Manufacturing

- Apply the principles of design for manufacturing, enabling the efficient and effective production of products.
- Develop a logical argument for selecting the tools, machines and labor necessary to produce finished goods from raw materials.
- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Create a plan for protecting the safety, health and welfare of people engaged in the manufacturing environment.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.

Computer Numeric Control (CNC) of Machines

- Apply Cartesian Coordinates to create toolpaths for machine tools.
- Research and apply proper cutting tool speeds, feeds, and directions for manufacturing.

- Create simple Numeric Control (NC) part programs using a text editor or a CAM package.
- Analyze NC part program files to identify and correct errors.

Applying CAM Software to Problem Solutions

- Design and prepare 3D models with appropriate units for use in toolpath generation.
- Setup a CAM package by editing the material and tool libraries.
- Generate tool paths from a CAD program and edit NC part program files to identify and correct errors.

College and Career Readiness Math Standards

Circles

C.A.2 Identify and describe relationships among inscribed angles, radii, and chords

Modeling with Geometry G-MG

Apply geometric concepts in modeling situations

1. Use geometric shapes, their measures, and their properties to describe objects (e.g., modeling a tree trunk or a human torso as a cylinder).

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.

3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.

9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*
2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations

4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:
Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 16:
Students will develop an understanding of and be able to select and use energy and power technologies.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Engraved Name Plate

Essential Question:

How can we create a code to control a CNC milling machine to generate a personalized engraved name plate?

Student Scenario:

An office supply retailer has contacted your team about a line of custom name plates they would like to sell. Customers will email designs to the retailer that will then be produced using the CNC engraver. Special stock will be acquired to allow for vivid displays and engraving artwork.

Your team has been asked to create a program to show how the name plate will look after manufacture. They would like a demonstration of the type of code it would take to create the name plate. You and your team will experiment with all aspects of the design to be able to demonstrate how this will work.

Once your team has created the demonstration code, they will design a program to automatically generate the name sent by email. Teams will identify the name area available so the text will be readable but not crowded.

The research and learning activities are designed to help students:

- Create sketches to communicate to a group
- Use mathematical formulas to aid in the design of a toolpath
- Utilize specific software code to control machinery
- Communicate their solution to their peers
- Understand and apply G-Code to their solutions

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design of a tool path
- Sketches and program flow used to develop the NC Program
- Name plate with student design
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1

Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2-3

Key Question: How do we get started in the design process?

The teams will be responsible for researching name plates, their attributes, text readability, and costs. Students must research the tooling requirements for the engraving tools. Topics such as CNC of machines and G-Code must also be researched. Students add items from their reading to their Engineering Notebooks.

The student teams discuss possible name plate features. The teams should decide on design constraints which might include:

- What material will the name plate be made from?
- What is the cost of the material?
- How will the workpiece be held in place and allow the tooling to reach the work piece?
- How will we control the speed of the engraving tool?
- How quickly can a part be made?
- How can we set up a program so text will generate its own code?
- What might be the cost to manufacture each custom nameplate?

The teacher reminds students about the help system to find out how the software accomplishes basic features they might want to incorporate. https://docs.plm.automation.siemens.com/tdoc/nx/11.0.1/nx_help#uid:xid1128418:index_mfgmilling

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the name plate. Other tutorials in the Resources section are available for use by students.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 4

Key Question: How do we get started on our individual designs?

Student teams brainstorm needed components of their design and then create their isometric sketches to add to their design brief to include with their sketches. They then meet with their clients who will need to sign off on the design proposal before solid modeling can begin.

Students can reference Generative Design, Fits and Tolerances, Basic 3D Commands, Creating Drawing Views, Introduction Assembly Modeling, Analysis in Solid Edge and Working with Bodies for specific commands to use in the name plate design. Students can reference web links, videos, and tutorials at any time during the process of the design.

Day 5-9
Key Question: How do we learn how to control a machine?

Students work through the exercise on generating code by following the procedures listed in the learning plan Learning G-Code. Be sure students understand how to create G-code and translate that safely to the mill.

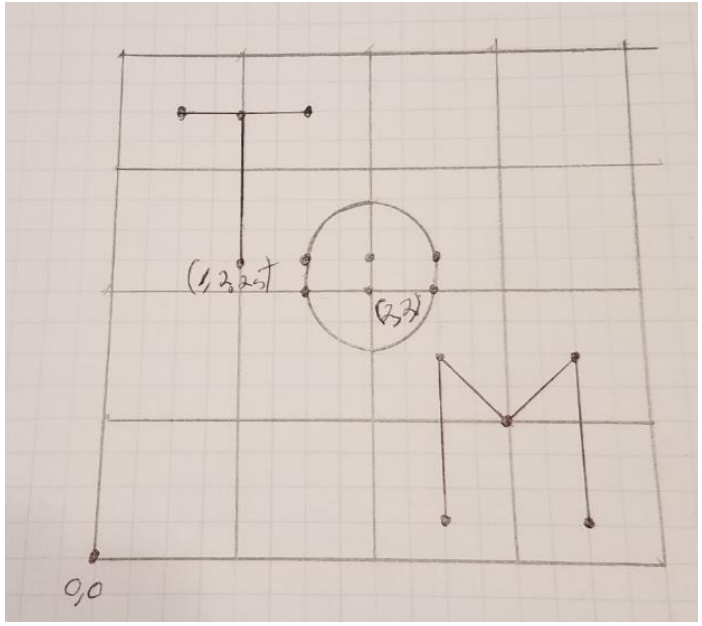
Students should begin by exploring the internet to find sites and videos that introduce G&M codes for milling. Some common search terms to find videos and tutorials are:

G&M codes introduction
Basic CNC programming
Beginners guide to CNC programming
G code circular interpolation
CNC tutorial
How to program a CNC machine
Introduction to CNC mill

Once students are somewhat familiar with G codes they will be creating a simple code by hand to create their initials or graphic outline. Be sure students know how to create the following g codes.

Rapid move
Linear interpolation
Circular interpolation (clockwise and counter clockwise)
Turn the motor on and off
Set the speed of the motor
Set the feed of the machine
Set the tool necessary

Provide the students with a piece of graph paper with ¼ inch squares. Ask students to layout a 4” x 4” Square and center their initials in the 4X4. Students should establish all the important points including centers similar to the picture below.



Students create their code to create the program one line or arc at a time. The semicolon is used to place comments on each program step. It is a good habit to document all steps. Students create a new text document by right clicking on the desktop and selecting new and selecting text document from the options.

```
File  Edit  Format  View  Help
G90                     ;Absolute coordinates
G20                     ;Measurements in inches
G00 X 0.5 Y 0.5 Z 2.0   ;Rapid to tool change position
M06 T1                  ;Tool change tool 1 end mill
M03 S2500               ;Sets the spindle to clockwise and the speed
G00 X1 Y2.25 Z.5        ;Rapid to point above the first point
G01 X1 Y2.25 Z -0.1 F15 ;Linear motion into the part at feed of 15
```

Once students have created their code they should save it. Have them enter the code into a simulation program such as CAMotics (www.camotics.org) an open source software which will simulate the results of the coding. The manual for CAMotics is available from https://camotics.org/manual.html. The manual is short but provides a good overview of the process. Students will have to define their cutting tool to match the tool they specify in their code. This will allow students to find mistakes before going to the milling machine.

Day 10-13
Key Question: How can we begin to design our nameplate?

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the nameplate design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building. Students participate in the Learning CNC tutorial to learn the basic functions of the CAM software.

Teams discuss their proposed automated text engraver and how to achieve the design given the approved sketch they presented. They work together to brainstorm ideas and begin to narrow their vision of the solution. Divide the work of designing the name plate. Utilize the division of work in the project management plan.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 14
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team's final design. It could be a single design or contain elements of several designs. Once the decision is made, the students create a plan for creating the team prototype. They need to create a design that incorporates their ideas. The teams discuss the final testing of their prototypes and how that will be achieved.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 15
Key Question: How do we build and test our designs?

Once the final plan is created they will create individual nameplates for each member of the team. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 16-17
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to their clients. The deliverables will include code, nameplates, and proposal for the process they are proposing to automate the name plate production. The students should be required to write an engineering report including the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 18
Key Question: How do we convey our ideas?

Students can present their solutions to the authentic audience one at a time. Students display the completed nameplates and process for automating the process for the company and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

3 Axis
Circular interpolation
Climb Milling
CNC
Contour
Conventional Milling
Coolant
Cutting Tools
End Mill
Engraving tool
Feeds and Speeds
Finish
G&M Code
G-Code
Hold-down
Lathe
Mill
NC Code
Offset
Pocket
Programming
Roughing
Round nose
Router
Touch off
Vise

Resources:

CAD Tutorials

- https://drive.google.com/open?id=0B_7sFhPxnoaXRlNuckN0OXVpdUE
- https://docs.plm.automation.siemens.com/tdoc/se/109/se_help/#uid:index
- https://docs.plm.automation.siemens.com/tdoc/se/latest/se_help#uid:index_xid618399:xid482668:new_cad_user

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

CNC Machining

- https://www.youtube.com/watch?v=2u7OH43NEUo
- https://www.youtube.com/watch?v=txCMvRF4Bm8
- https://www.youtube.com/watch?v=uE-49w6JtTk
- https://www.youtube.com/watch?v=sxs9j8Ydc8E
- https://www.youtube.com/watch?v=WjkMKHN8Zd0
- https://www.youtube.com/watch?v=kHjCvL3X6xc
- https://www.youtube.com/watch?v=nAdBW-A4hbI
- https://mecsoft.com/blog/understanding-climb-vs-conventional-milling/
- http://www.shars.com/products/cutting/end-mills
- https://www.mmsonline.com/articles/cnc-intro-the-key-concepts-of-computer-numerical-control
- http://www.mmsonline.com/articles/key-cnc-concept-1the-fundamentals-of-cnc

Cutting Tools and Workholding

- https://www.youtube.com/watch?v=ckzK-LbeZmY
- http://www.youtube.com/watch?v=J1VtofzVG24&list=PLDB7440122C72886B&inde=6
- http://www.youtube.com/watch?v=6uB2FsUvuE4
- http://www.youtube.com/watch?v=r7-eEj_qq5M&list=PLDB7440122C72886B&index=5

Solid Edge CAM Pro

- http://vimeo.com/83476434
- https://youtu.be/8jtGgjBJGAU
- https://www.youtube.com/watch?v=1rIIuJF5cmM
- https://vimeo.com/34547576
- https://www.youtube.com/watch?v=P6NediFZnTA

G-Code

- https://makezine.com/2016/10/24/get-to-know-your-cnc-how-to-read-g-code/
- https://reprap.org/wiki/G-code
- https://machmotion.com/blog/gcode-the-stuff-that-dreams-are-made-of
- https://www.cnccookbook.com/g-code-m-code-reference-list-cnc-mills/
- https://nraynaud.github.io/webgcode/
- https://camotics.org/
- http://www.editcnc.com/GandMcodes.html

SIEMENS

Ingenuity for life

Project: Soda Can Opener

Soft drink containers have been available for many years. They are made from aluminum and have a pop tab that permits the can to be opened. The pop tab is safe to use but not everyone can open the can with ease.

Introduction:

Soda cans are made from aluminum. To gain access to the beverage inside, the can must be opened. The old way to open a beverage can was with a tool called a “church key can and bottle opener”. This tool would puncture a triangular opening in the top of the can. The one main problem with this opening solution was centered on the church key; if you didn’t have one with you there was no easy way to open the can.

The first solution to this problem was to design a method to open the can without the need for an opening tool like a church key. This solution was the design of an aluminum can tab. This tab was a strip of aluminum with a ring attached. To open the can one pulled on the ring and the aluminum strip would rip off and the can was open. But now there was a new problem. The aluminum strip and ring now was a throw away item that had a very sharp edge on the aluminum strip. Often these can tabs were discarded and in some instances would cause people to step on them at the beach or other places causing cuts to feet and hands. They were also hazardous to animals.

The second solution to this problem was to design a method to open the can without the need for an opening tool like a church key and without the leftover can tab. So, today we have cans that have “pop tabs” which makes opening a can safer.

However, as you know from your own experience, it takes relatively strong hands and fingers to open a can tab. Unfortunately, not all of us have strong hands and fingers; especially children, elderly or challenged individuals.

Purpose of the Project:

The purpose of the Soda Can Opener project is to learn how to design and produce, with precision, a product that can assist a person open a beverage can tab with ease. The model must be ergonomically functional, have pleasing design features, and be conveniently available.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Materials have certain properties that make them more suitable for certain applications than others.
- Selecting materials for use in a product requires knowledge of material properties and characterization, based upon manufacturing processes selected, chemical composition, internal defects, temperature, previous loading, dimensions, and other factors.
- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- CNC machine tool technology uses Cartesian Coordinates to position and control tooling to produce accurate models.
- G-code is the name given to numerical control programs that are used to control all types of computerized machinery.
- Speeds and Feeds is a machining term that refers to the rate that material is removed to acquire a finished part. Speed refers to either the speed of the moving material or the speed of the cutter or both at the same time. Feed is the rate of material removal. The relationship between speed and feed can vary depending on the desired surface finish. Usually initial cuts remove more material leaving a rough finish and a finish cut removes less material with a slower feed rate leaving a smooth finished surface.

- Design for manufacturing involves the analysis of the design and how the design can be changed to allow for rapid and efficient manufacturing processes.
- Design for assembly involves analysis and changes to the design to make the assembly of the product as easy as possible.
- Post processors have programs that interpret the intent of CAM software and turn the desired operations into G-code to control the CNC machines.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://www.youtube.com/watch?v=L8F0K5JF5fY&fs=1&rel=0&enablejsapi=1&playerapiid=ytPlayerID0EAEAAAAAAB&wmode=transparent
https://www.youtube.com/watch?v=L8F0K5JF5fY&fs=1&rel=0&enablejsapi=1&playerapiid=ytPlayerID0EAEAAAAAAB&wmode=transparent

Outline:

- Documentation
  - Engineering Notebook
  - Documentation object to be designed
- Modeling
  - Creation of 3D model
  - Design renderings and pictorial exploded drawings
  - Construct 3D model of Soda Can Opener project
- Programming
  - Creation of NC program
  - Verification of NC Program
  - Rendering of NC Program results
- Evaluation
  - Comparison of G-code results to original sketch
  - Test the ability of a child to open a soda can with the soda can opener.
- Communication
  - Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.

- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Design for Manufacturing
- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.

Design for Assembly
- Apply engineering design of components to assure alignment for assembly.

Computer Numeric Control (CNC) of Machines
- Apply Cartesian Coordinates to create toolpaths for machine tools.
- Research and apply proper cutting tool speeds, feeds, and directions for manufacturing.
- Create simple Numeric Control (NC) part programs using a text editor or a CAM package.
- Analyze NC part program files to identify and correct errors.

Applying CAM Software to Problem Solutions
- Design and prepare 3D models with appropriate units for use in toolpath generation.
- Setup a CAM package by editing the material and tool libraries.
- Generate tool paths from a CAD program and edit NC part program files to identify and correct errors.

College and Career Readiness Math Standards

Modeling with Geometry G-MG

Apply geometric concepts in modeling situations

1. Use geometric shapes, their measures, and their properties to describe objects (e.g., modeling a tree trunk or a human torso as a cylinder).
2. Apply concepts of density based on area and volume in modeling situations (e.g., persons per square mile, BTUs per cubic foot).
3. Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.
3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.
9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*
2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:

Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:

Students will develop an understanding of the core concepts of technology.

STL Standard 4:

Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 6:

Students will develop an understanding of the role of society in the development and use of technology.

STL Standard 7:

Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 14:
Students will develop an understanding of and be able to select and use medical technologies.

STL Standard 16:
Students will develop an understanding of and be able to select and use energy and power technologies.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Soda Can Opener

Essential Question:

How can a tool be designed to open a 12 oz. can of soda, with the conventional ring tab, easily and safely?

Student Scenario:

You work for ***Exceptional Catering, Inc***. as an event planner. Your company is noted for its exemplary food and services throughout your region.

Your supervisor is the Director of Human Resources for the company. She has indicated to you that several employees have complained about the difficulty they have when there are many beverage cans that need opening. Their hands are not strong to keep up with the pace of service. She worried that this problem may cause lost work time injuries which is bad for both the employees and the company.

She has asked you to solve this problem with the creation of a device to help these workers. She has arranged for you to work with a local engineering design firm to have the engineering skill set available to you to solve this problem. She has asked you to be prepared to produce a model for review by the company's leadership team in two weeks.

The design requirements are as follows:

- The model must be made from a material appropriate for the first prototype.
- The model must be ergonomically functional, have pleasing design features, and be conveniently available.

Your design will be presented by use of a working model. The Director of Human Resources has indicated to you that she hopes this solution will prevent worker injuries and be seen as a great help on the job.

The research and learning activities are designed to help students:

- Create sketches to communicate to a group
- Use mathematical formulas to aid in the design of a product
- Utilize specific software code to control machinery
- Communicate their solution to their peers
- Understand and apply G-Code to their solutions

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design.
- Sketches and working drawings for the elements of the soda can opener.
- Analysis of the structural elements of the soda can opener design
- CNC model of the soda can opener
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1
Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2
Key Question: How do we get started in the design process?

The teams will be responsible for researching leverage systems options. Students must research systems using levers, material options, and analysis. Teams are also responsible to research tolerances. Teams hold a group discussion on the specifications of the soda can opener design. Students begin sketching a variety of soda can opener systems solutions. Students add items from their reading to their Engineering Notebooks.

The student teams discuss possible soda can opener systems including:

- What material will the soda can opener system be made from?
- What is the physical size of the soda can opener system within the design requirements?
- Does the model meet the stated design requirements?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information find tutorials about individual topics and to find out how the software accomplishes basic features they might want to incorporate. https://docs.plm.automation.siemens.com/tdoc/se/110/se_help/#uid:index and https://docs.plm.automation.siemens.com/tdoc/nx/11.0.1/nx_help#uid:xid1128418:index_mfgmilling.

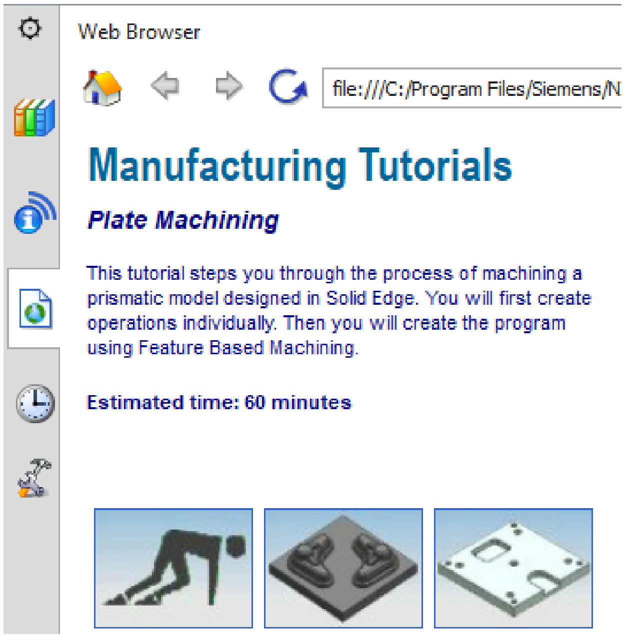
Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the soda can opener systems. Other tutorials in the Resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3
Key Question: How do we get started on our individual designs?

Student teams brainstorm needed components of their design and then create their isometric sketches to add to their design brief to be include with their sketches. They include preliminary sizes and operating requirements including formulas used to evaluate their designs. They then meet with their clients who will need to sign off on the design proposal before solid modeling can begin.

Students work through the tutorials found in the Solid Edge CAM Pro Software. These will help locate the meaning of the terminology as well as the organization of the software. Access the tutorials from the web browser bar on the left of the screen. Students should look at the first three tutorials.



Students can reference Learning CNC, Generative Design, Fits and Tolerances, Basic 3D Commands, Creating Drawing Views, Introduction Assembly Modeling, Analysis in Solid Edge and Working with Bodies for specific commands to use in the Soda Can Opener systems design.

Teams discuss how their soda can opener systems should be tested. The groups decide what components will be tested and how the team will know when the design achieves the test requirements.

Day 4-5
Key Question: How can we begin to design our soda can opener systems model?

Teams discuss their proposed soda can opener systems and how to achieve the design given the approved sketch they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the 3D solid model and a plan to test the soda can opener system. They utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the soda can opener systems design, the team determines how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams are reminded to continually check their 3D model of the designs with their team to ensure accurate sizes. Teams discuss how the various designs work and that the designs created will meet the soda can opener systems requirements and the tolerance limits of their designs.

Day 6-8
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team final design. It could be a single design or contain elements of several designs. Once the decision is made the students create a plan for creating the team prototype using CNC technology. They need to create a design that incorporates their ideas. Once the final plan is created they will create the model in Solid Edge. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin CNC machining the soda can opener systems. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 9-10
Key Question: How do we build and test our designs?

Students review their soda can opener CNC model. When students encounter problems with the model they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

As students finish their soda can opener systems, testing can begin to see if the model meets the stated design requirements. Teams identify sources of problems and redesign parts as needed.

Day 11-12
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to their clients. The deliverables could be in the form of a dimensioned working drawing pictorial representation with balloons and bill of materials and the CNC produced prototype as well as the final testing data and demonstrations. Students should prepare an engineering report about the process of designing their soda can opener systems. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 13
Key Question: How do we convey our ideas?

Students can present their solutions to the authentic audience one at a time. Students display the completed soda can opener model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

Allowance
Artisans
Ball Mill
Classes of Fits
Clearance
Clearance Fit
Contour
Church Key
Deviation
Dimensioning
End Mill
Engrave
Feeds and Speeds
Finish Floor
Finish Wall
Locational Fits
Lower Limit
Pocket
Running and Sliding Fits
Tolerance
Tooling
Variation
Vise

Resources:

CAD Tutorials

- https://drive.google.com/open?id=0B_7sFhPxnoaXRlNuckN0OXVpdUE
- https://docs.plm.automation.siemens.com/tdoc/se/109/se_help/#uid:index
- https://docs.plm.automation.siemens.com/tdoc/se/latest/se_help#uid:index_xid618399:xid482668:new_cad_user

Engineering Notebook:
- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports
- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

CNC Machining
- https://www.youtube.com/watch?v=2u7OH43NEUo
- https://www.youtube.com/watch?v=txCMvRF4Bm8
- https://www.youtube.com/watch?v=uE-49w6JtTk
- https://www.youtube.com/watch?v=sxs9j8Ydc8E
- https://www.youtube.com/watch?v=WjkMKHN8Zd0
- https://www.youtube.com/watch?v=kHjCvL3X6xc
- https://www.youtube.com/watch?v=nAdBW-A4hbI
- https://mecsoft.com/blog/understanding-climb-vs-conventional-milling/
- http://www.shars.com/products/cutting/end-mills
- https://www.mmsonline.com/articles/cnc-intro-the-key-concepts-of-computer-numerical-control
- http://www.mmsonline.com/articles/key-cnc-concept-1the-fundamentals-of-cnc

Cutting Tools and Workholding
- https://www.youtube.com/watch?v=ckzK-LbeZmY
- http://www.youtube.com/watch?v=J1VtofzVG24&list=PLDB7440122C72886B&inde=6
- http://www.youtube.com/watch?v=6uB2FsUvuE4
- http://www.youtube.com/watch?v=r7-eEj_qq5M&list=PLDB7440122C72886B&index=5

G-Code
- https://makezine.com/2016/10/24/get-to-know-your-cnc-how-to-read-g-code/
- https://reprap.org/wiki/G-code
- https://machmotion.com/blog/gcode-the-stuff-that-dreams-are-made-of

- https://www.cnccookbook.com/g-code-m-code-reference-list-cnc-mills/
- https://nraynaud.github.io/webgcode/
- https://camotics.org/
- http://www.editcnc.com/GandMcodes.html

Solid Edge CAM Pro

- http://vimeo.com/83476434
- https://youtu.be/8jtGgjBJGAU
- https://www.youtube.com/watch?v=1rIIuJF5cmM
- https://vimeo.com/34547576
- https://www.youtube.com/watch?v=P6NediFZnTA

Types of Fits

- https://www.engineersedge.com/mechanical,045tolerances/preffered-mechanical-tolerances.htm
- http://mmto.org/~dclark/Reports/Encoder%20Upgrade/fittolerences%20%5BRead-Only%5D.pdf
- http://www.mechcadcam.com/what-is-the-fit-and-what-are-the-different-types-of-fits/
- https://extrudesign.com/types-of-fits-in-engineering/
- http://ignou.ac.in/upload/Unit-3-62.pdf
- http://blog.misumiusa.com/shaft-and-hole-tolerances-and-fits/
- https://www.amesweb.info/FitTolerance/FitTolerance.aspx
- https://www.engineersedge.com/calculators/mechanical-tolerances/force-fit-tolerances.htm
- https://mdmetric.com/Ch6.8wGO.pdf
- https://ay14-15.moodle.wisc.edu/prod/pluginfile.php/166546/mod_resource/content/1/ANSI-Standard-Fits.pdf

Tolerance Dimensions

- http://www.machinedesign.com/materials/working-dimensional-tolerances
- https://www.britannica.com/topic/drafting/Dimensions-and-tolerances
- https://www.fictiv.com/hwg/fabricate/gdt-101-an-introduction-to-geometric-dimensioning-and-tolerancing
- http://web2.clarkson.edu/class/es305/willmert/Dimensioning%20in%20Solid%20Edge%20ST.doc
- https://www.youtube.com/watch?v=X0pM6TqKXaM
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dimsd3d.htm
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dim_classfit1a.htm
- http://site.iugaza.edu.ps/aabuzarifa/files/METRO20152_CH52.pdf
- http://web.aeromech.usyd.edu.au/ENGG1960/Documents/Week12/Engineering%20Drawings%20Lecture%20Linear%20Fits%20and%20Tolerances%20Rev%201.pdf

SIEMENS

Ingenuity for life

Project: Game Piece Design

Traditional hand held games have been in existence for thousands of years. They are low tech but can be very entertaining. Many are designed with well-crafted geometric patterns.

Introduction:

We know that hand held games have been available for thousands of years. Some examples are domino games, custom dice, or game boards where a small ball is moved on a flat surface through a path. Some games are designed for one player while others are designed for more than one player.

Purpose of the Project:

The purpose of the Game Design project is to learn how to design and produce a product using Cartesian Coordinates, G-Code for generating a tool path.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.

- Materials have certain properties that make them more suitable for certain applications than others.
- Selecting materials for use in a product requires knowledge of material properties and characterization, based upon manufacturing processes selected, chemical composition, internal defects, temperature, previous loading, dimensions, and other factors.
- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- CNC machine tool technology uses Cartesian Coordinates to position and control tooling to produce accurate models.
- G-code is the name given to numerical control programs that are used to control all types of computerized machinery.
- Speeds and Feeds is a machining term that refers to the rate that material is removed to acquire a finished part. Speed refers to either the speed of the moving material or the speed of the cutter or both at the same time. Feed is the rate of material removal. The relationship between speed and feed can vary depending on the desired surface finish. Usually initial cuts remove more material leaving a rough finish and a finish cut removes less material with a slower feed rate leaving a smooth finished surface.
- Design for manufacturing involves the analysis of the design and how the design can be changed to allow for rapid and efficient manufacturing processes.
- Design for assembly involves analysis and changes to the design to make the assembly of the product as easy as possible.
- Post processors have programs that interpret the intent of CAM software and turn the desired operations into G-code to control the CNC machines.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://youtu.be/s4FDbbrq6Qw
https://youtu.be/lyufc1LhGCU

Outline:

- Documentation
  - Engineering Notebook
  - Documentation object to be designed
- Modeling
  - Creation of 3D model
  - Assembly of 3D model
  - Exploded drawing of 3D model with appropriate tolerance noted for parts
  - Construct CNC model of the Game Design
- Programming
  - Creation of NC program

Verification of NC Program
Rendering of NC Program results

Evaluation
Comparison of G-code results to original sketch

Communication
Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Design for Manufacturing

- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.

Design for Assembly

- Apply engineering design of components to assure alignment for assembly.

Computer Numeric Control (CNC) of Machines

- Apply Cartesian Coordinates to create toolpaths for machine tools.
- Research and apply proper cutting tool speeds, feeds, and directions for manufacturing.
- Create simple Numeric Control (NC) part programs using a text editor or a CAM package.
- Analyze NC part program files to identify and correct errors.

Applying CAM Software to Problem Solutions

- Design and prepare 3D models with appropriate units for use in toolpath generation.
- Setup a CAM package by editing the material and tool libraries.
- Generate tool paths from a CAD program and edit NC part program files to identify and correct errors.

College and Career Readiness Math Standards

Modeling with Geometry G-MG

Apply geometric concepts in modeling situations

1. Use geometric shapes, their measures, and their properties to describe objects (e.g., modeling a tree trunk or a human torso as a cylinder).
2. Apply concepts of density based on area and volume in modeling situations (e.g., persons per square mile, BTUs per cubic foot).
3. Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.

3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.

9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*
2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:
Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 16:
Students will develop an understanding of and be able to select and use energy and power technologies.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Game Piece Rubric

Essential Question:

How can we use a milling machine to produce a prototype game piece?

Student Scenario:

You work for ***Traditional Games, Inc***. as a design engineer. Your company has been in the game design and production industry for over 100 years.

Your supervisor is the Director of New Product Development. He believes there is a market for some older games such as domino games, custom dice, or board games. He notes that these games are currently available from other companies but believes that more precise digital technology can make these products more attractive to consumers.

He has asked you to design and produce a model for review by the company's leadership team.

The design requirements are as follows:

- The model must be made from a material appropriate for the first prototype.
- The design must be masterful and have high quality.

Your design will be presented by use of a model. The Director of New Product Development has indicated to you that he hopes this model will expand your company's product line.

The research and learning activities are designed to help students:

- Create sketches to communicate to a group
- Use mathematical formulas to aid in the design of a product
- Utilize specific software features to create a solid model
- Communicate their solution to their peers
- Understand and apply G-Code to their solutions

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design.
- Sketches and working drawings for the elements of the game design
- Analysis of the structural elements of the game design
- G-Code for the CNC tool path
- CNC model of the game design
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1

Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2
Key Question: How do we get started in the design process?

The teams will be responsible for researching traditional game system options. Students must research game design, material options, and analysis. Teams hold a group discussion on the specifications of the game design. Students begin sketching a variety of game design systems solutions. Students add items from their reading to their Engineering Notebooks.

The student teams discuss possible game design systems including:

- What material will the game design systems be made from?
- What is the physical size of the game design systems within the design requirements?
- How will the game design perform?
- Does the model meet the stated design requirements?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information find tutorials about individual topics and to find out how the software accomplishes basic features they might want to incorporate. https://docs.plm.automation.siemens.com/tdoc/se/110/se_help/#uid:index and https://docs.plm.automation.siemens.com/tdoc/nx/11.0.1/nx_help#uid:xid1128418:index_mfgmilling.

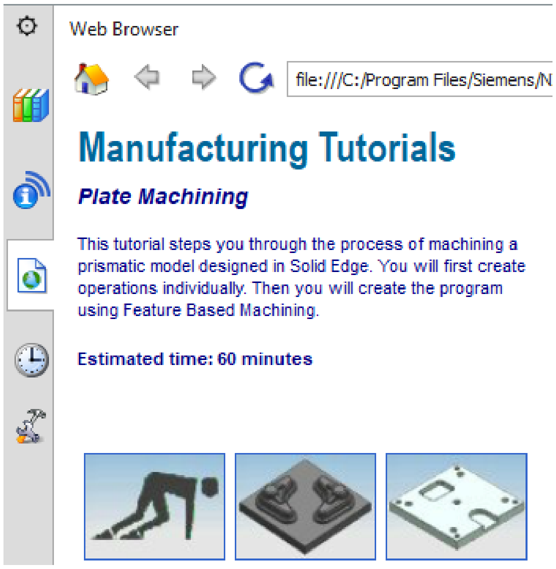
Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the game design systems. Other tutorials in the Resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3
Key Question: How do we get started on our individual designs?

Student teams brainstorm needed components of their design and then create their isometric sketches to add to their design brief to be include with their sketches. They include preliminary sizes and operating requirements including formulas used to evaluate their designs. They then meet with their clients who will need to sign off on the design proposal before solid modeling can begin.

Students work through the tutorials found in the Solid Edge CAM Pro Software. These will help locate the meaning of the terminology as well as the organization of the software. Access the tutorials from the web browser bar on the left of the screen of the home page. Students should look at the first three tutorials.



Students can reference Learning CNC, Generative Design, Fits and Tolerances, Basic 3D Commands, Creating Drawing Views, Introduction Assembly Modeling, Analysis in Solid Edge and Working with Bodies for specific commands to use in the game piece design.

Teams discuss how their game design systems should be tested. The groups decide what components will be tested and how the team will know when their design achieves the test requirements.

Day 4-5

Key Question: How can we begin to design our game design model?

Teams discuss their proposed game design and how to achieve the design given the approved sketch they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the 3D solid model needed. They utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the game design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams are reminded to continually check their 3D components of the designs with their team to ensure the accurate sizes. Teams discuss how the various designs work and that the designs created will meet the game design requirements.

Day 6-8
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team final design. It could be a single design or contain elements of several designs. Once the decision is made the students create a plan for creating the team prototype using CNC technology. They need to create a design that incorporates their ideas. Once the final plan is created they will create the model in Solid Edge. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin CNC machining the model of the game design. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 9-11
Key Question: How do we build and test our designs?

Students finish the CNC game model. When students encounter problems with their model they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

As students finish their game systems, testing can begin to see if the model meets the stated design requirements. Teams identify sources of problems and redesign parts as needed.

Day 12
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas. Students discuss the outline of the presentation to their clients. The deliverables could be in the form of a dimensioned working drawing pictorial representation with balloons and bill of materials and the CNC produced prototype as well as the final testing data and demonstrations. Students should prepare an engineering report about the process of designing their game systems. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 13
Key Question: How do we convey our ideas?

Students can present their solutions to the authentic audience one at a time. Students display the completed game model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

Allowance
Artisans
Ball Mill
Classes of Fits
Clearance
Clearance Fit
Contour
Deviation
Dimensioning
End Mill
Engrave
Feeds and Speeds
Finish Floor
Finish Wall
Locational Fits
Lower Limit
Pocket
Running and Sliding Fits
Tolerance
Tooling
Variation
Vise

Resources:

CAD Tutorials

- https://drive.google.com/open?id=0B_7sFhPxnoaXRlNuckN0OXVpdUE
- https://docs.plm.automation.siemens.com/tdoc/se/109/se_help/#uid:index
- https://docs.plm.automation.siemens.com/tdoc/se/latest/se_help#uid:index_xid618399:xid482668:new_cad_user

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

CNC Machining

- https://www.youtube.com/watch?v=2u7OH43NEUo
- https://www.youtube.com/watch?v=txCMvRF4Bm8
- https://www.youtube.com/watch?v=uE-49w6JtTk
- https://www.youtube.com/watch?v=sxs9j8Ydc8E
- https://www.youtube.com/watch?v=WjkMKHN8Zd0
- https://www.youtube.com/watch?v=kHjCvL3X6xc
- https://www.youtube.com/watch?v=nAdBW-A4hbI
- https://mecsoft.com/blog/understanding-climb-vs-conventional-milling/
- http://www.shars.com/products/cutting/end-mills
- https://www.mmsonline.com/articles/cnc-intro-the-key-concepts-of-computer-numerical-control

- http://www.mmsonline.com/articles/key-cnc-concept-1the-fundamentals-of-cnc

Cutting Tools and Workholding

- https://www.youtube.com/watch?v=ckzK-LbeZmY
- http://www.youtube.com/watch?v=J1VtofzVG24&list=PLDB7440122C72886B&inde=6
- http://www.youtube.com/watch?v=6uB2FsUvuE4
- http://www.youtube.com/watch?v=r7-eEj_qq5M&list=PLDB7440122C72886B&index=5

G-Code

- https://makezine.com/2016/10/24/get-to-know-your-cnc-how-to-read-g-code/
- https://reprap.org/wiki/G-code
- https://machmotion.com/blog/gcode-the-stuff-that-dreams-are-made-of
- https://www.cnccookbook.com/g-code-m-code-reference-list-cnc-mills/
- https://nraynaud.github.io/webgcode/
- https://camotics.org/
- http://www.editcnc.com/GandMcodes.html

Solid Edge CAM Pro

- http://vimeo.com/83476434
- https://youtu.be/8jtGgjBJGAU
- https://www.youtube.com/watch?v=1rIluJF5cmM
- https://vimeo.com/34547576
  https://www.youtube.com/watch?v=P6NediFZnTA

Types of Fits

- https://www.engineersedge.com/mechanical,045tolerances/preffered-mechanical-tolerances.htm
- http://mmto.org/~dclark/Reports/Encoder%20Upgrade/fittolerences%20%5BRead-Only%5D.pdf
- http://www.mechcadcam.com/what-is-the-fit-and-what-are-the-different-types-of-fits/
- https://extrudesign.com/types-of-fits-in-engineering/
- http://ignou.ac.in/upload/Unit-3-62.pdf
- http://blog.misumiusa.com/shaft-and-hole-tolerances-and-fits/
- https://www.amesweb.info/FitTolerance/FitTolerance.aspx
- https://www.engineersedge.com/calculators/mechanical-tolerances/force-fit-tolerances.htm
- https://mdmetric.com/Ch6.8wGO.pdf
- https://ay14-15.moodle.wisc.edu/prod/pluginfile.php/166546/mod_resource/content/1/ANSI-Standard-Fits.pdf

Tolerance Dimensions

- http://www.machinedesign.com/materials/working-dimensional-tolerances
- https://www.britannica.com/topic/drafting/Dimensions-and-tolerances
- https://www.fictiv.com/hwg/fabricate/gdt-101-an-introduction-to-geometric-dimensioning-and-tolerancing
- http://web2.clarkson.edu/class/es305/willmert/Dimensioning%20in%20Solid%20Edge%20ST.doc
- https://www.youtube.com/watch?v=X0pM6TqKXaM
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dimsd3d.htm
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dim_classfit1a.htm
- http://site.iugaza.edu.ps/aabuzarifa/files/METRO20152_CH52.pdf
- http://web.aeromech.usyd.edu.au/ENGG1960/Documents/Week12/Engineering%20Drawings%20Lecture%20Linear%20Fits%20and%20Tolerances%20Rev%201.pdf

Project: Box Design with Interlocking Top

Ornamental boxes have been in use for thousands of years. They are carefully crafted by artisans and usually store valued possessions. Historically these special boxes were hand crafted. With the modern digital technology available today we are able to produce amazingly beautiful shapes and features in a special box that would rival the artisans of old.

Introduction:

We know that ornamental boxes have been available for thousands of years. Many times these boxes are decorative and may house secrets and surprises. These boxes may be rectangular or round in shape and be of any size. Today there are many kinds of decorative boxes having many shapes and sizes all having their own unique attributes.

In most instances decorative boxes are made from quality hardwoods. Hardwood is usually an excellent choice of material because it is hard and durable. It is also carvable and machinable and the surfaces can be finished to a beautiful luster.

Purpose of the Project:

The purpose of the Box Design with Interlocking Top project is to learn how to design and produce, with precision, a product with a top and bottom with unique location geometry. The model must have aesthetically pleasing design features.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Materials have certain properties that make them more suitable for certain applications than others.
- Selecting materials for use in a product requires knowledge of material properties and characterization, based upon manufacturing processes selected, chemical composition, internal defects, temperature, previous loading, dimensions, and other factors.
- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- Engineering features are the collection of design components that allow for the assembly of components. These might include bosses, spot faces, snap fittings and joints, counter sinks, counter bores, and other elements that allow for assembly.
- CNC machine tool technology uses Cartesian Coordinates to position and control tooling to produce accurate models.
- G-code is the name given to numerical control programs that are used to control all types of computerized machinery.
- Speeds and Feeds is a machining term that refers to the rate that material is removed to acquire a finished part. Speed refers to either the speed of the moving material or the speed of the cutter or both at the same time. Feed is the rate of material removal. The relationship between speed and feed can vary depending on the desired surface finish. Usually initial cuts remove more material leaving a rough finish and a finish cut removes less material with a slower feed rate leaving a smooth finished surface.
- Design for manufacturing involves the analysis of the design and how the design can be changed to allow for rapid and efficient manufacturing processes.
- Design for assembly involves analysis and changes to the design to make the assembly of the product as easy as possible.

- Post processors have programs that interpret the intent of CAM software and turn the desired operations into G-code to control the CNC machines.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

> https://www.industry.usa.siemens.com/services/us/en/industry-services/services-glance/video/Pages/Machine_tool_analytics_Video.aspx
> https://www.youtube.com/watch?v=nUQ1rm69I9w&fs=1&rel=0&enablejsapi=1&playerapiid=ytPlayerID0EAAAAAAB&wmode=transparent

Outline:

- Documentation
  - Engineering Notebook
  - Documentation object to be designed
- Modeling
  - Creation of 3D model
  - Assembly of 3D model
  - Exploded drawing of 3D model with appropriate tolerance noted for parts
- Programming
  - Creation of NC program
  - Verification of NC Program
  - Rendering of NC Program results
- Evaluation
  - Comparison of G-code results to original sketch
  - Solid Edge model
  - Finished box with interlocking top
- Communication
  - Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.

- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Design for Manufacturing

- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.
- Research and apply knowledge of material properties to product design and development.

Design for Assembly

- Apply engineering design of components to assure alignment for assembly.

Computer Numeric Control (CNC) of Machines

- Apply Cartesian Coordinates to create toolpaths for machine tools.
- Research and apply proper cutting tool speeds, feeds, and directions for manufacturing.
- Create simple Numeric Control (NC) part programs using a text editor or a CAM package.
- Analyze NC part program files to identify and correct errors.

Applying CAM Software to Problem Solutions

- Design and prepare 3D models with appropriate units for use in toolpath generation.
- Setup a CAM package by editing the material and tool libraries.
- Generate tool paths from a CAD program and edit NC part program files to identify and correct errors.

College and Career Readiness Math Standards

Modeling with Geometry G-MG

Apply geometric concepts in modeling situations

1. Use geometric shapes, their measures, and their properties to describe objects (e.g., modeling a tree trunk or a human torso as a cylinder).
2. Apply concepts of density based on area and volume in modeling situations (e.g., persons per square mile, BTUs per cubic foot).
3. Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations.

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.
3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.
9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*
2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:
Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

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Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Box Design Rubric

Essential Question:

How can we design an aesthetically pleasing solid wooden box with an interlocking top suitable for storing a valued possession?

Student Scenario:

You work for ***Packaging Science, Inc***. as a design engineer. Your company is noted for its precision packaging for use in the electronics and aerospace industries.

Your supervisor is the Director of New Product Development. She believes there is a market for beautiful hardwood boxes that can be used to store personal special possessions. She knows that this market is currently being supplied by the hand work of artisans and believes modern digital technology can be applied to create masterful designs of unsurpassed uniqueness and quality.

She has asked you to design and produce a model for review by the company's leadership team.

The design requirements are as follows:

- The model must be made from a material appropriate for the first prototype.
- The design must be masterful and have high quality.
- The first model must not exceed 3.5 in. wide x 2.5 in. deep x 1.5 in. high
- There will be only two parts, a top and a bottom that join with precision.

Your team's design will be presented using a model. The Director of New Product Development has indicated to you that she hopes this model will be the first step to a major company expansion.

The research and learning activities are designed to help students:

- Create sketches to communicate to a group
- Use mathematical formulas to aid in the design of a product
- Utilize specific software features to create a solid model
- Understand and apply G-Code to their solutions
- Communicate their solution to their peers

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design.
- Sketches and working drawings for the elements of the Box Design with Interlocking Top dimensioned with tolerances
- Analysis of the structural elements of the Box Design with Interlocking Top design
- CNC program of the Box Design with Interlocking Top
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1

Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2

Key Question: How do we get started in the design process?

The teams will be responsible for researching box systems and interlocking options. Students must research box systems, material options, and analysis. Teams are also responsible to research classes of fits and tolerances. Teams hold a group discussion on the specifications of the Box Design with Interlocking Top design. Students begin sketching a variety of box design systems solutions. Students add items from their reading to their Engineering Notebooks.

The student teams discuss possible box storage systems including:

- What material will the box storage systems be made from?
- What is the physical size of the box storage systems within the design requirements?
- How does the box storage systems interlocking top and bottom perform?
- Does the model meet the stated design requirements?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information find tutorials about individual topics and to find out how the software accomplishes basic features they might want to incorporate. https://docs.plm.automation.siemens.com/tdoc/se/110/se_help/#uid:index and https://docs.plm.automation.siemens.com/tdoc/nx/11.0.1/nx_help#uid:xid1128418:index_mfgmilling.

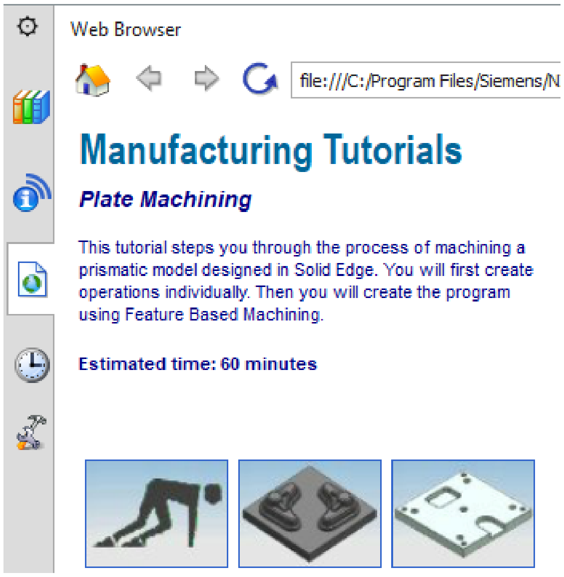
Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the box storage systems. Other tutorials in the Resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3
Key Question: How do we get started on our individual designs?

Student teams brainstorm needed components of their design and then create their isometric sketches to add to their design brief to be included with their sketches. They include preliminary sizes and operating requirements including formulas used to evaluate their designs. They then meet with their clients who will need to sign off on the design proposal before solid modeling can begin.

Students work through the tutorials found in the Solid Edge CAM Pro Software. These will help locate the meaning of the terminology as well as the organization of the software. Access the tutorials from the web browser bar on the left of the screen of the main page. Students should look at the first three tutorials.



Students can reference Learning CNC, Generative Design, Fits and Tolerances, Basic 3D Commands, Creating Drawing Views, Introduction Assembly Modeling, Analysis in Solid Edge and Working with Bodies for specific commands to use in the box storage systems design.

Students can reference web links, videos, and tutorials at any time during the process of the design.

Teams discuss how their box storage systems should be tested. The groups decide what components will be tested and how the team will know when the design achieves the test requirements.

Day 4-5
Key Question: How can we begin to design our box storage systems model?

Teams discuss their proposed box storage system and how to achieve the design given the approved sketch they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the 3D solid model of the two box parts needed and a plan to assemble and test the box storage systems. They utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the box storage systems design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams are reminded to continually check the 3D components of the design to ensure accurate sizes. Teams discuss how the various designs work and that the designs created will meet the box storage systems requirements and the tolerance limits of their designs to assure the parts will connect as desired.

Day 6-8
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team final design. It could be a single design or contain elements of several designs. Once the decision is made the students create a plan for creating the team prototype using CNC technology. They need to create a design that incorporates their ideas. Once the final plan is created they will create the model parts in Solid Edge and assemble them into assemblies. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin CNC machining the components and assemble the model of the box storage systems from the CNC machined parts. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 9-10
Key Question: How do we build and test our designs?

Students assemble their box storage systems from their CNC parts. When students encounter problems assembling their model they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

As students finish assembling their box storage systems, testing can begin to see if the model meets the stated design requirements. Teams identify sources of problems and redesign parts as needed.

Day 11-12
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to their clients. The deliverables could be in the form of a dimensioned working drawing pictorial representation with balloons and bill of materials and the CNC produced prototype as well as the final testing data and demonstrations. Students should prepare an engineering report about the process of designing their box storage systems and how the top and bottom fit together. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 13
Key Question: How do we convey our ideas?

Students can present their solutions to the authentic audience one at a time. Students display the completed box storage model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

Allowance
Artisans
Ball Mill
Classes of Fits
Clearance
Clearance Fit
Contour
Deviation
Dimensioning
End Mill
Engrave
Feeds and Speeds
Finish Floor
Finish Wall
Locational Fits
Lower Limit
Pocket
Running and Sliding Fits
Tolerance
Tooling
Variation
Vise

Resources:

CAD Tutorials

- https://drive.google.com/open?id=0B_7sFhPxnoaXRlNuckN0OXVpdUE
- https://docs.plm.automation.siemens.com/tdoc/se/109/se_help/#uid:index
- https://docs.plm.automation.siemens.com/tdoc/se/latest/se_help#uid:index_xid618399:xid482668:new_cad_user

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

CNC Machining

- https://www.youtube.com/watch?v=2u7OH43NEUo
- https://www.youtube.com/watch?v=txCMvRF4Bm8
- https://www.youtube.com/watch?v=uE-49w6JtTk
- https://www.youtube.com/watch?v=sxs9j8Ydc8E
- https://www.youtube.com/watch?v=WjkMKHN8Zd0
- https://www.youtube.com/watch?v=kHjCvL3X6xc
- https://www.youtube.com/watch?v=nAdBW-A4hbI
- https://mecsoft.com/blog/understanding-climb-vs-conventional-milling/
- http://www.shars.com/products/cutting/end-mills
- https://www.mmsonline.com/articles/cnc-intro-the-key-concepts-of-computer-numerical-control
- http://www.mmsonline.com/articles/key-cnc-concept-1the-fundamentals-of-cnc

Cutting Tools and Workholding

- https://www.youtube.com/watch?v=ckzK-LbeZmY
- http://www.youtube.com/watch?v=J1VtofzVG24&list=PLDB7440122C72886B&inde=6
- http://www.youtube.com/watch?v=6uB2FsUvuE4
- http://www.youtube.com/watch?v=r7-eEj_qq5M&list=PLDB7440122C72886B&index=5

G-Code

- https://makezine.com/2016/10/24/get-to-know-your-cnc-how-to-read-g-code/
- https://reprap.org/wiki/G-code
- https://machmotion.com/blog/gcode-the-stuff-that-dreams-are-made-of
- https://www.cnccookbook.com/g-code-m-code-reference-list-cnc-mills/
- https://nraynaud.github.io/webgcode/
- https://camotics.org/
- http://www.editcnc.com/GandMcodes.html

Solid Edge CAM Pro

- http://vimeo.com/83476434
- https://youtu.be/8jtGgjBJGAU
- https://www.youtube.com/watch?v=1rIIuJF5cmM
- https://vimeo.com/34547576
- https://www.youtube.com/watch?v=P6NediFZnTA

Types of Fits

- https://www.engineersedge.com/mechanical,045tolerances/preffered-mechanical-tolerances.htm
- http://mmto.org/~dclark/Reports/Encoder%20Upgrade/fittolerences%20%5BRead-Only%5D.pdf
- http://www.mechcadcam.com/what-is-the-fit-and-what-are-the-different-types-of-fits/
- https://extrudesign.com/types-of-fits-in-engineering/
- http://ignou.ac.in/upload/Unit-3-62.pdf
- http://blog.misumiusa.com/shaft-and-hole-tolerances-and-fits/
- https://www.amesweb.info/FitTolerance/FitTolerance.aspx
- https://www.engineersedge.com/calculators/mechanical-tolerances/force-fit-tolerances.htm
- https://mdmetric.com/Ch6.8wGO.pdf
- https://ay14-15.moodle.wisc.edu/prod/pluginfile.php/166546/mod_resource/content/1/ANSI-Standard-Fits.pdf

Tolerance Dimensions

- http://www.machinedesign.com/materials/working-dimensional-tolerances
- https://www.britannica.com/topic/drafting/Dimensions-and-tolerances
- https://www.fictiv.com/hwg/fabricate/gdt-101-an-introduction-to-geometric-dimensioning-and-tolerancing
- http://web2.clarkson.edu/class/es305/willmert/Dimensioning%20in%20Solid%20Edge%20ST.doc
- https://www.youtube.com/watch?v=X0pM6TqKXaM
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dimsd3d.htm
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dim_classfit1a.htm

- http://site.iugaza.edu.ps/aabuzarifa/files/METRO20152_CH52.pdf
- http://web.aeromech.usyd.edu.au/ENGG1960/Documents/Week12/Engineering%20Drawings%20Lecture%20Linear%20Fits%20and%20Tolerances%20Rev%201.pdf

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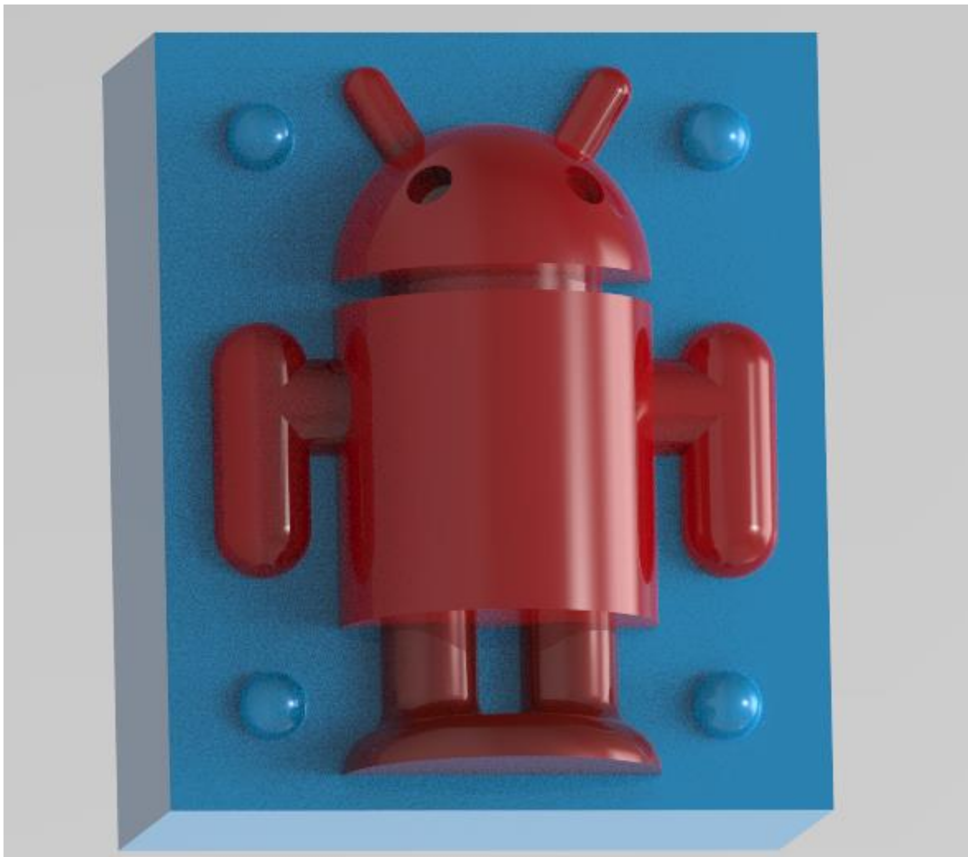

Project: Split Mold

The casting process has been used for thousands of years. Casting is widely used because it produces a final product in one step; liquid to a solid using a mold. As casting technology has evolved the speed, accuracy, and quality of products produced by casting is exceptional.

Introduction:

Think about a time when you were a child playing with sand at the beach or in a sand box at home. Some of the containers you had to play with were shaped like a pail or bucket. These containers were usually wider at the top than at the bottom. The reason for that shape was to permit the sand to be compacted in the container and then removed by carefully turning the container upside down and tapping on the bottom to remove the sand in a way that maintained the internal shape of the container.

Making cupcakes is another example. The cupcake pan has openings that are wider at the top than at the bottom. In both these examples, cupcakes and sand, without the smaller diameter at the bottom, the product could not be removed without breaking.

Now, think about a rounded shape. Some examples are chocolate truffles, bar soap, light bulbs, golf balls, and many others that you can easily list. They are made by injecting a liquid into a mold cavity, waiting for the liquid to become a solid, and opening the split mold to remove the product.

The processes described above are various forms of casting.

The first use of casting as a process to produce objects dates back to ancient China around the 4th century. Molten metal was poured into a mold, allowed to cool, and opened to reveal the finished product. Later, about 2000 years ago, the Romans learned how to make concrete and pour it in molds to create parts for buildings.

The Industrial Revolution could not have developed without extracting iron from iron ore and casting the molten iron into all the parts that produced the machines of industry. These machines made possible locomotives, stoves, cast iron cook pans, and thousands of other products.

Today, we use the casting process to produce many products such as automobile components, plane, ship, and rocket parts, blow dryers, computer & phone cases, bottles and replacement human knee parts. The list is endless.

Purpose of the Project:

The purpose of the Split Mold project is to learn how to design and produce, with precision, a two part mold that can be used to produce a product with a round shape. The split mold when closed will have a cavity inside exactly the shape of the product.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Materials have certain properties that make them more suitable for certain applications than others.
- Selecting materials for use in a product requires knowledge of material properties and characterization, based upon manufacturing processes selected, chemical composition, internal defects, temperature, previous loading, dimensions, and other factors.
- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- CNC machine tool technology uses Cartesian Coordinates to position and control tooling to produce accurate models.

- G-code is the name given to numerical control programs that are used to control all types of computerized machinery.
- Speeds and Feeds is a machining term that refers to the rate that material is removed to acquire a finished part. Speed refers to either the speed of the moving material or the speed of the cutter or both at the same time. Feed is the rate of material removal. The relationship between speed and feed can vary depending on the desired surface finish. Usually initial cuts remove more material leaving a rough finish and a finish cut removes less material with a slower feed rate leaving a smooth finished surface.
- Design for manufacturing involves the analysis of the design and how the design can be changed to allow for rapid and efficient manufacturing processes.
- Design for assembly involves analysis and changes to the design to make the assembly of the product as easy as possible.
- Post processors have programs that interpret the intent of CAM software and turn the desired operations into G-code to control the CNC machines.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://youtu.be/SAyZ47pv8aU
https://youtu.be/tzzEGxiEIBo

Outline:

Documentation
- Engineering Notebook
- Documentation object to be designed

Modeling
- Creation of 3D model
- Assembly of 3D model
- Exploded drawing of 3D model with appropriate tolerance noted for parts
- Design renderings and pictorial exploded drawings
- Construct 3D model of the split mold

Evaluation
- Testing of the ability to produce chocolate truffles

Communication
- Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.

- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Design for Manufacturing

- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.

Design for Assembly

- Apply engineering design of components to assure alignment for assembly.

Computer Numeric Control (CNC) of Machines

- Apply Cartesian Coordinates to create toolpaths for machine tools.
- Research and apply proper cutting tool speeds, feeds, and directions for manufacturing.
- Create simple Numeric Control (NC) part programs using a text editor or a CAM package.
- Analyze NC part program files to identify and correct errors.

Applying CAM Software to Problem Solutions

- Design and prepare 3D models with appropriate units for use in toolpath generation.
- Setup a CAM package by editing the material and tool libraries.
- Generate tool paths from a CAD program and edit NC part program files to identify and correct errors.

College and Career Readiness Math Standards

Modeling with Geometry G-MG

Apply geometric concepts in modeling situations

1. Use geometric shapes, their measures, and their properties to describe objects (e.g., modeling a tree trunk or a human torso as a cylinder).
2. Apply concepts of density based on area and volume in modeling situations (e.g., persons per square mile, BTUs per cubic foot).

3. Apply geometric methods to solve design problems (e.g., designing an object or structure to satisfy physical constraints or minimize cost; working with typographic grid systems based on ratios).

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Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Split Mold Rubric

Essential Question:
How are round products produced through casting?

Student Scenario:
You work for a candy maker called ***Sweet Delights, Inc***. as a mechanical engineer. Your company is noted for its high quality candy products.

The company president has discussed with you about expanding the line of products the company produces. As you know, all candy products produced by ***Sweet Delights, Inc***. is made in open molds that produces candy bars, candy droplets, and other similar products.

She believes that there is opportunity for the company to move into the production of chocolate truffles. The profit margins will be higher and is a good move for the company. She believes the excellent reputation that ***Sweet Delights, Inc***. has will result in the new product line being accepted by its supply chain and consumers.

She has asked you to produce a model of the company's new product. She wants to see if the company logo, "SD", can be incorporated into the look of the finished chocolate truffles. She has asked for a presentation in two weeks.

The design requirements are as follows:
- The model must a rounded shape and be made from chocolate.
- The split mold must be made from a material safe for food production.
- The design must be masterful and have high quality.
- The chocolate truffle model must not exceed one ounce in volume.

Your team's design will be presented by use of a model. The president has indicated to you that she hopes this new product line will be the first step to a major company expansion.

The research and learning activities are designed to help students:

- Create sketches to communicate to a group
- Use mathematical formulas to aid in the design of a product
- Utilize specific software features to create a solid model
- Communicate their solution to their peers
- Understand and apply G-Code to their solutions

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design.
- Sketches and working drawings of the split mold
- Analysis of the structural elements of the split mold
- CNC model of the split mold
- Cast Product
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1

Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2

Key Question: How do we get started in the design process?

The teams will be responsible for researching split mold systems. Students must research split mold systems, material options, and analysis. Teams are also responsible to research classes of fits and tolerances. Teams hold a group discussion on the specifications of the split mold design. Students begin sketching a variety of split mold systems solutions. Students add items from their reading to their Engineering Notebooks.

The student teams discuss possible split mold systems including:

- What material will the split mold systems be made from?
- What is the physical size of the split mold systems within the design requirements?
- How do the split mold systems halves connect?
- Does the model meet the stated design requirements including the company initial on the final product?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information find tutorials about individual topics and to find out how the software accomplishes basic features they might want to incorporate. https://docs.plm.automation.siemens.com/tdoc/se/110/se_help/#uid:index and https://docs.plm.automation.siemens.com/tdoc/nx/11.0.1/nx_help#uid:xid1128418:index_mfgmilling.

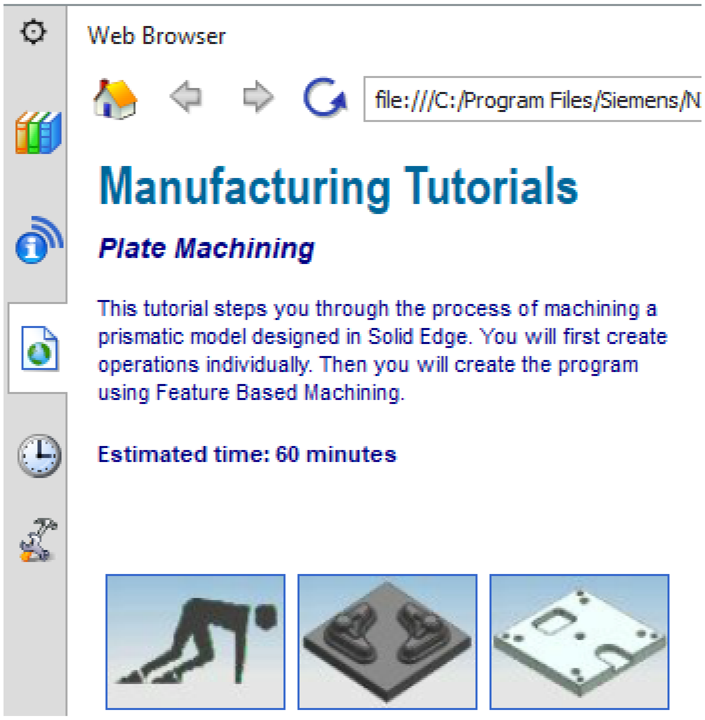
Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the split mold systems. Other tutorials in the Resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3
Key Question: How do we get started on our individual designs?

Student teams brainstorm needed components of their design and then create their isometric sketches to add to their design brief to be include with their sketches. They include preliminary sizes and operating requirements including formulas used to evaluate their designs. The design plan also includes the appearance of the company logo on the final product. They then meet with their clients who will need to sign off on the design proposal before solid modeling can begin. The client can be the teacher or an authentic advisor.

Students work through the tutorials found in the Solid Edge CAM Pro Software. These will help locate the meaning of the terminology as well as the organization of the software. Access the tutorials from the web browser bar on the left of the screen of the home page. Students should look at the first three tutorials.



Students can reference Learning CNC, Generative Design, Fits and Tolerances, Basic 3D Commands, Creating Drawing Views, Introduction Assembly Modeling, Analysis in Solid Edge and Working with Bodies for specific commands to use in the Split Mold design.

Teams discuss how their split mold systems should be tested. The groups decide what components will be tested and how the team will know when their design achieves the test requirements.

Day 4-5

Key Question: How can we begin to design our split mold systems model?

Teams discuss their proposed split mold systems and how to achieve the design given the approved sketch they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the 3D solid model of the two mold parts needed and a plan to assemble and test the split mold systems. They utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the split mold systems design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams are reminded to continually check their 3D components of the designs with their team to ensure accurate sizes. Teams discuss how the various designs work and that the designs created will meet the split mold systems requirements and the tolerance limits of their designs to assure the parts will connect as desired.

Day 6-9
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team final design. It could be a single design or contain elements of several designs. Once the decision is made the students develop a plan for creating the team prototype using CNC technology. They need to create a design that incorporates their ideas. Once the final plan is completed they will create the model parts in Solid Edge and assemble them into assemblies. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin CNC machining the components and assemble the model of the split mold systems from the CNC machined parts. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 10-12
Key Question: How do we build and test our designs?

Students assemble their split mold systems from their CNC parts. When students encounter problems assembling their model they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

As students finish assembling their split mold systems, testing can begin to see if the model meets the stated design requirements. Students melt some chocolate in a clean bowl using a double boiler pot. They clean the split mold and wrap the mold halves with rubber bands and pour the melted chocolate in the mold. Teams identify sources of problems and redesign parts as needed.

Day 13-14
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to their clients. The deliverables could be in the form of a dimensioned working drawing pictorial representation with balloons and bill of materials and the CNC produced mold with chocolate truffles as well as the final testing data and demonstrations. Students should prepare an engineering report about the process of designing their split mold systems. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 15
Key Question: How do we convey our ideas?

Students can present their solutions to the authentic audience one at a time. Students display the completed split mold systems model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

Allowance
Artisans
Blow mold
Casting
Classes of Fits
Clearance
Clearance Fit
Core
Deviation
Dimensioning
Draft Angles
Gates
Injection molds
Investment casting
Locational Fits
Lower Limit
Pattern
Riser
Running and Sliding Fits
Sprue Holes
Tolerance
Variation
Vent

Resources:

CAD Tutorials

- https://drive.google.com/open?id=0B_7sFhPxnoaXRlNuckN0OXVpdUE
- https://docs.plm.automation.siemens.com/tdoc/se/109/se_help/#uid:index
- https://docs.plm.automation.siemens.com/tdoc/se/latest/se_help#uid:index_xid618399:xid482668:new_cad_user

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

CNC Machining

- https://www.youtube.com/watch?v=2u7OH43NEUo
- https://www.youtube.com/watch?v=txCMvRF4Bm8
- https://www.youtube.com/watch?v=uE-49w6JtTk
- https://www.youtube.com/watch?v=sxs9j8Ydc8E
- https://www.youtube.com/watch?v=WjkMKHN8Zd0
- https://www.youtube.com/watch?v=kHjCvL3X6xc
- https://www.youtube.com/watch?v=nAdBW-A4hbI
- https://mecsoft.com/blog/understanding-climb-vs-conventional-milling/
- http://www.shars.com/products/cutting/end-mills
- https://www.mmsonline.com/articles/cnc-intro-the-key-concepts-of-computer-numerical-control
- http://www.mmsonline.com/articles/key-cnc-concept-1the-fundamentals-of-cnc

Cutting Tools and Workholding

- https://www.youtube.com/watch?v=ckzK-LbeZmY
- http://www.youtube.com/watch?v=J1VtofzVG24&list=PLDB7440122C72886B&inde=6

- http://www.youtube.com/watch?v=6uB2FsUvuE4
- http://www.youtube.com/watch?v=r7-eEj_qq5M&list=PLDB7440122C72886B&index=5

G-Code

- https://makezine.com/2016/10/24/get-to-know-your-cnc-how-to-read-g-code/
- https://reprap.org/wiki/G-code
- https://machmotion.com/blog/gcode-the-stuff-that-dreams-are-made-of
- https://www.cnccookbook.com/g-code-m-code-reference-list-cnc-mills/
- https://nraynaud.github.io/webgcode/
- https://camotics.org/
- http://www.editcnc.com/GandMcodes.html

Molding

- https://www.youtube.com/watch?v=Ag5CzNb_JxI
- https://www.youtube.com/watch?v=RMjtmsr3CqA&t=342s
- https://www.youtube.com/watch?v=b1U9W4iNDiQ
- https://www.youtube.com/watch?v=597VXfz2_ME
- https://www.youtube.com/watch?v=LSH19G_6Yeo
- https://www.youtube.com/watch?v=tyrXq_u1OH0
- https://www.youtube.com/watch?v=UrUsaGussfc
- https://www.youtube.com/watch?v=WLyaZbT97EI
- https://www.youtube.com/watch?v=dN1RozHsuDM
- https://www.youtube.com/watch?v=8W6P5KU5ONQ
- https://www.youtube.com/watch?v=Ggzos1ZZZzU
- https://www.3dhubs.com/knowledge-base/3d-printing-low-run-injection-molds
- http://fab.cba.mit.edu/classes/863.12/people/dsawada/w6.html

Solid Edge CAM Pro

- http://vimeo.com/83476434
- https://youtu.be/8jtGgjBJGAU
- https://www.youtube.com/watch?v=1rIIuJF5cmM
- https://vimeo.com/34547576
- https://www.youtube.com/watch?v=P6NediFZnTA

Types of Fits

- https://www.engineersedge.com/mechanical,045tolerances/preffered-mechanical-tolerances.htm
- http://mmto.org/~dclark/Reports/Encoder%20Upgrade/fittolerences%20%5BRead-Only%5D.pdf
- http://www.mechcadcam.com/what-is-the-fit-and-what-are-the-different-types-of-fits/
- https://extrudesign.com/types-of-fits-in-engineering/
- http://ignou.ac.in/upload/Unit-3-62.pdf

- http://blog.misumiusa.com/shaft-and-hole-tolerances-and-fits/
- https://www.amesweb.info/FitTolerance/FitTolerance.aspx
- https://www.engineersedge.com/calculators/mechanical-tolerances/force-fit-tolerances.htm
- https://mdmetric.com/Ch6.8wGO.pdf
- https://ay14-15.moodle.wisc.edu/prod/pluginfile.php/166546/mod_resource/content/1/ANSI-Standard-Fits.pdf

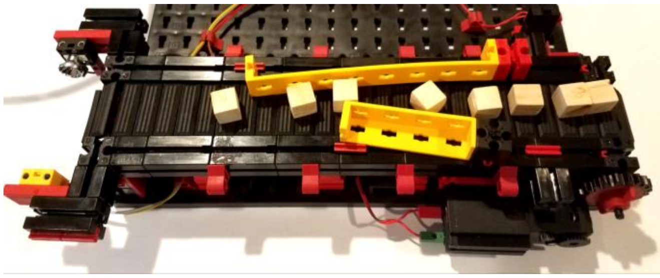
Tolerance Dimensions

- http://www.machinedesign.com/materials/working-dimensional-tolerances
- https://www.britannica.com/topic/drafting/Dimensions-and-tolerances
- https://www.fictiv.com/hwg/fabricate/gdt-101-an-introduction-to-geometric-dimensioning-and-tolerancing
- http://web2.clarkson.edu/class/es305/willmert/Dimensioning%20in%20Solid%20Edge%20ST.doc
- https://www.youtube.com/watch?v=X0pM6TqKXaM
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dimsd3d.htm
- http://www.soliddna.com/SEHelp/ST5/EN/a_h/dim_classfit1a.htm
- http://site.iugaza.edu.ps/aabuzarifa/files/METRO20152_CH52.pdf
- http://web.aeromech.usyd.edu.au/ENGG1960/Documents/Week12/Engineering%20Drawings%20Lecture%20Linear%20Fits%20and%20Tolerances%20Rev%201.pdf

Projects Quarter 3

<table>
<tr><td>PLC setup, programming interface, inputs, outputs counters.

Introductory project for all students.

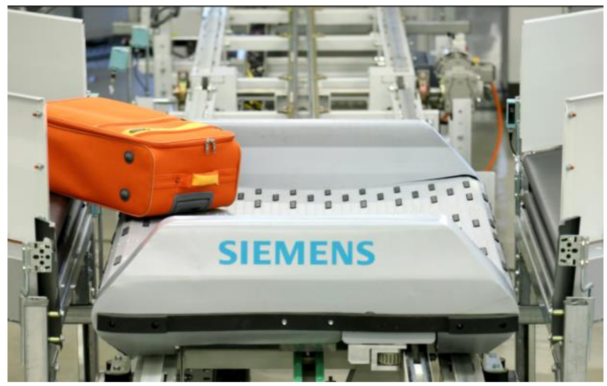
Conveyor with Counter</td><td></td></tr>
</table>

Select one of the following three projects.

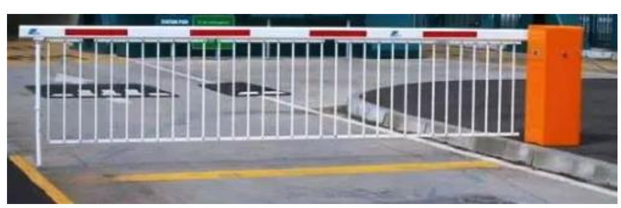
<table>
<tr><td>Relays, PIR Sensor timers, motor reversing.

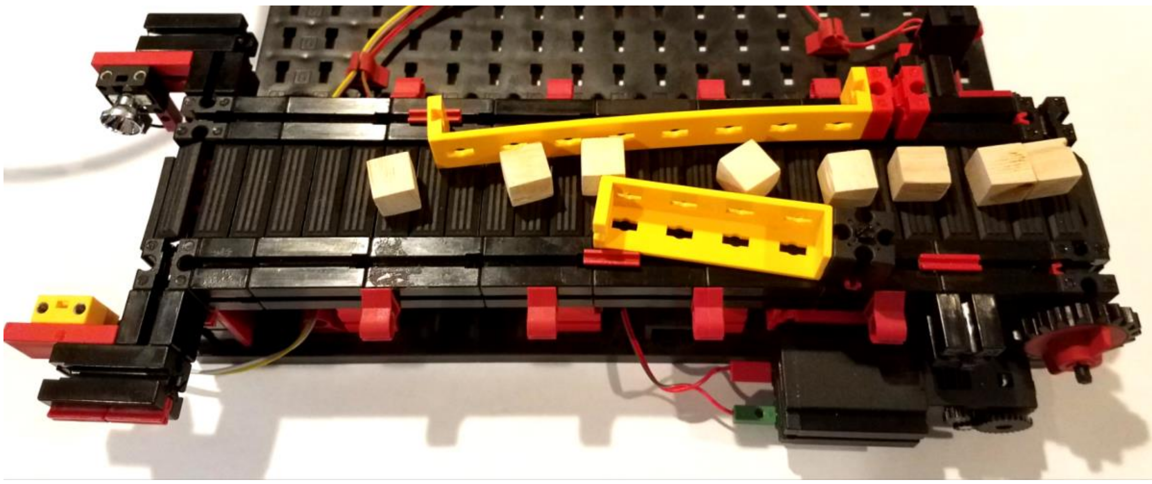
• Garage Door Control</td><td></td></tr>
</table>

Continued

Sensor, timers, motor reversing Analog inputs, timers Sun Tracking Solar Collector	
Sensor, timers, motor reversing Analog inputs, timers Sort by Color	

Select one of the following two projects

Logic and program planning Choose one of two projects in the logic category either the elevator control or the parking lot gate project. Elevator Control	
Logic and program planning Choose one of two projects in the logic category either the elevator control or the parking lot gate project. Parking Lot Gate	



Project: Conveyor with Counter

Think about a time when you were in a hardware store or craft store or an office supply store. Did you ever wonder how the small packages containing items like screws, buttons, pencils, and other items were prepared? Sometimes entire kits are available which include the friendly statement, “Some Assembly Required”. How are these kits prepared? Who assembles them? How is the item count accuracy assured? These are all key questions that must be addressed if businesses are to be successful.

Preparing these packages and kits manually can be challenging because this type of work can be repetitive and boring which may lead to errors. Businesses have solved these issues through the use of automation which allows for speed and accuracy.

Introduction:

Conveyors are devices for moving material from one place to another. Essentially they consist of a continuous belt. They come in all shapes and sizes. An escalator a type of conveyor designed for moving people. Conveyors are found in all kinds of locations. Airport luggage conveyors, manufacturing assembly lines, and conveyors for hay bales are common. The post office and other delivery services all have high speed conveyors to move packages. Warehouses, manufacturing, and mining industries all utilize conveyors. The longest conveyor is 61 miles long and is used to transport phosphate from mines to shipping terminals.

Conveyors are used in many different ways. By adding sensors, timers, and controls, the conveyors become a component of smart systems which can make decisions and follow complex programming. Central to controlling the conveyor is the Programmable Logic Controller (PLC) which is a hardened computer designed to run the program associated with the automated systems. They are used anyplace where repetition, reliability, and repeatability are needed.

PLC programming is done using computer languages that are based on “Ladder Logic”. Ladder Logic a visual language designed to permit technicians to transfer their knowledge of electrical relays into the PLC program. These PLC program languages have evolved and have been combined with other programming languages making the PLC capable of very complex control.

According to www.mynextmove.org, careers using PLC program languages average $97,250 a year in salary. The current outlook for employment is good. Candidates need to be innovative and analytical with attention to detail.

Purpose of the Project:

The purpose of the Conveyor with Counter project is to introduce some basic concepts of automation, PLC programming, and sensors. Students will apply the design process to solve the problem of how to place the correct number of parts in a container.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Science and engineering professionals use data and graphical analysis in making decisions.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The Engineering Design Process is sometimes referred to as the sequential actions of research, design, build, evaluate; then redesign, and communicate.
- Engineering professionals design solutions and communicate the solutions through graphics and pictures.
- Engineers use integrity and ethics when communicating ideas, including citing sources of information.
- In all systems, there is a tradeoff between performance and complexity. Higher complexity is generally associated with higher cost; hence the shortened form of the syllogism is performance versus cost.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.
- Electricity is a form of energy caused by the movement of charged particles. It is often used to transfer energy from one place to another.
- The first law of thermodynamics (conservation of energy and matter) states that output power of a system is always less than the power supplied to the system.

- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
- “Green Principles” of design are used for eventual disassembly and resource recovery and is referred as Product Lifecycle Management (PLM).
- A Programmable Logic Controller (PLC) is a hardened computer used for industrial automation. PLCs can automate a process, machine function, or even an entire production line.
- The term “Logic” is based upon the mathematical system called Boolean Algebra named after George Boole (Born November 2, 1815-Died December 8, 1864) who was a self-taught English mathematician and philosopher who invented this form of algebra where values are either True or False where rules are created to consistently arrive at desired values.
- The ability to collect data, transform them into information, and use that information to improve an existing process is an enabling skill for Lean manufacturing.
- Applying automated control systems to existing manual processes can dramatically improve quality and reduce the amount of human (manual) time required.
- Electronic sensors detect and transform real-world phenomena into information that is used by computers to control valves, pumps, and other industrial equipment.
- Timers allow programmers to design and control specialized clocks to turn machinery on or off for specific amounts of time.
- Keeping track of events as they occur can be accomplished using logic programs called counters.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://www.industry.usa.siemens.com/98680cb3-8064-4d48-ac16-52d8efec3960
https://f1.media.brightcove.com/12/1813624294001/1813624294001_5397119177001_5397105535001.mp4?pubId=1813624294001&videoId=5397105535001

Outline:

Documentation
- Engineering Notebook
- Documentation object to be designed

Programmable Logic Controllers (PLC)
- Basic electricity-Multimeter schematics/ Ohms law
- Setup
- Inputs
- Outputs
- Logic
- Timers
- Counters

Evaluation
Testing of the ability to control a conveyor and count items
Communication
Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Design for Manufacturing

- Understand and apply Statistical Process Control (SPC) to acquire quality control.

Design for Assembly

- Create a management plan that includes quality planning, quality control, quality assurance, and quality improvement for an advanced manufacturing environment.

Automation with Programmable Logic Controllers (PLCs)

- Design and analyze an electrical system to efficiently convert, transform, and transmit electricity to where it is needed.
- Research and specify electrical devices necessary to provide needed power.
- Apply machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.
- Use flow charts and diagrams to apply logic in the design of control programs.

Applying Logic Software (TIA Portal) to Create Problem Solutions

- Design a system of elements that manages power to accomplish a task involving defined movement.
- Design a control system to vary the speed and performance of a motor by utilizing feedback from the system to gain the most efficiency possible.
- Formulate a system to utilize data collection and analysis to maintain and improve product quality and provide adequate confidence that the product will satisfy design requirements.
- Design and analyze the application of machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.

Business of Manufacturing

- Research and evaluate the new approaches of rapid development and deployment of products that saves time and is more efficient.
- Create a management plan including quality planning, quality control, quality assurance and quality improvement for an advance manufacturing environment.

College and Career Readiness Math Standards

Creating Equations

CED.A1 Create equations and inequalities in one variable and use them to solve problems.

CED.A.2 Create equations in two or more variables to represent relationships between quantities

CED.A.3 Represent constraints by equations or inequalities, and by systems of equations and/or inequalities, and interpret solutions as viable or nonviable options in a modeling context

CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Making Inferences & Justifying Conclusions

IC.A.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population.

IC.B.3 Recognize the purposes of and differences among sample surveys, experiments, and observational studies; explain how randomization relates to each.

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.
3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.
9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*
2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards
The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:
1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:
Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 3:
Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 5:
Students will develop an understanding of the effects of technology on the environment.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 14:
Students will develop an understanding of and be able to select and use medical technologies.

STL Standard 16:
Students will develop an understanding of and be able to select and use energy and power technologies.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 18:
Students will develop an understanding of and be able to select and use transportation technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative

assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.
Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Conveyor with Counter

Essential Question:

How can we automatically count the number of fasteners to include in a kit?

Student Scenario:

You work for Furniture PackNGo as a member of the new automation team created to streamline many of the company's manufacturing processes. Management has identified a problem that is costing the company a lot of money. The package of fastening nuts that are shipped with each kit are inconsistent and result in many customer phone calls complaining about missing fasteners. This results in the company having to send out a shipment of additional fasteners to each complaining customer. Since each shipment must be processed, packaged, and tracked, the estimate for each shipment is about $30.00; a cost that is affecting the company's profits.

To avoid this problem the company has instructed the assembly supervisor to add additional fasteners in each kit to avoid a short count and a costly second shipment.

Your boss would like your team to design a way to count the correct number of fastener nuts into a container automatically. The assembly supervisor would like to see a test of the new automated system. She will select ten random counts to determine the accuracy of the conveyor system performance. Plan to run the process 100 times to provide enough samples. Create a histogram of the results.

The design requirements are as follows:

- The program must run the conveyor until the desired number of fasteners is delivered to the container then stop.
- The conveyor must have a switch to begin operation.
- The conveyor must have an emergency stop.
- The program must report the count number.

Your team's design will be presented using a working model of the conveyor with a counter system controlled by the PLC. It is hoped that by increasing the accuracy of the count, complaints will be reduced by 95% resulting in savings of tens of thousands of dollars.

The research and learning activities are designed to help students:

- Learn the basic principles of PLC control
- Apply counters to control motion
- Understand the role of statistics in automation requirements

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design.
- Sketches and planning for programming
- Descriptions of the sensors utilized
- Histogram of the testing
- Working prototype
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1

Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2
Key Question: How do we get started in the design process?

The teams will be responsible for researching conveyors, PLCs, and Ladder Logic. Teams are also responsible for research into program design and basic statistics.

The student teams discuss possible conveyor counting and control systems including:

- How does a counter work?
- What kinds of sensors might be used?
- Where might sensors be located where they will be effective?
- Does the model meet the stated design requirements?
- Are there safety switches in place?
- What are the basic electrical safety issues?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information, find tutorials about individual topics, and to find out how the software accomplishes basic features. Students can search for design elements they might want to incorporate. This can be accessed from the help menu in the TIA Portal software.

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of conveyor counting and control systems. Other tutorials in the Resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3-8
Key Question: How do we get started on our individual designs?

First, student teams brainstorm components of their design. Next create a written description of what the program must accomplish. Add this to the team's design brief to be included with the sketches of the location of sensors. Include operating requirements as well as expected voltage readings. The design plan must also include the statistical data needed to assess performance and how it will be gathered. They then meet with the assembly supervisor (can be the teacher or authentic advisor) who will need to sign off on the design proposal before programming and system model building begins.

Students begin by accessing tutorials on Introduction to the PLC, Wiring the PLC, Wiring Inputs, Wiring Outputs, Setting up the Programming Environment, Setting up Communication, Introduction to a Project, Writing a First Program and Counters. This will take several days to work through these necessary basics.

Teams discuss how their counting systems should be tested. The groups decide what components will be tested and how the team will know when their design achieves the test requirements.

Day 9-10
Key Question: How can we begin to design our conveyor counter system model?

Teams discuss their proposed counting systems and how to achieve the design given the approved design brief they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the conveyor (https://drive.google.com/open?id=0B_7sFhPxnoaXU1hrRzI4SmM3VlE), sensors, wiring, and program. Students utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the conveyor counting system design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams discuss how the various designs and placement of sensors work and that the designs created will meet the counter system requirements and the performance will be within the specifications established.

Day 11-13
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs elements created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team's final design. It could be a single design or contain elements of several designs. Once the decision is made the students develop a plan for creating the team prototype using PLC technology. They need to create a design that incorporates their ideas. Once the final plan is completed they will create a prototype program. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin programming and testing to see how they are communicating with the various sensors they selected. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 14-16
Key Question: How do we build and test our designs?

Students assemble their prototype counting system. When students encounter problems assembling their prototype they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Once the working prototype is assembled, testing can begin to see if the model meets the stated design requirements. Students begin runs of the process to check the accuracy of their systems. They gather data on tests and build histograms to show how accurate the system is. Students discuss results of their initial testing and propose improvements to the system.

Day 17-18
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to the assembly supervisor. The deliverables will include the prototype, program design, and information about the design process and how they solved many of the issues encountered. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 19
Key Question: How do we convey our ideas?

Student teams present their solutions one at a time. Students display the completed conveyor counting system model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

Analog
Connection Terminals
Counter

CPU
Digital
DIN Rail
Histogram
Input
Ladder Logic
Load
L Terminal
Logic
M Terminal
Network
Normally Open
Normally Closed
Organizational Blocks
Output
Phototransistor
PLC
Power Supply
Power Terminals
Schematic
Set Reset Flip Flop
Switch
Tag Table
Wiring

Resources:

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

Electricity

- https://www.allaboutcircuits.com/textbook/direct-current/
- https://learn.sparkfun.com/tutorials/alternating-current-ac-vs-direct-current-dc
- https://engineering.mit.edu/engage/ask-an-engineer/whats-the-difference-between-ac-and-dc/
- https://www.school-for-champions.com/science/dc.htm#.W372zehKguU
- http://sinovoltaics.com/learning-center/basics/direct-current-dc-power-definition-and-applications/
- https://whatis.techtarget.com/definition/DC-direct-current
- http://macao.communications.museum/eng/exhibition/secondfloor/MoreInfo/2_3_1_DCCircuit.html
- https://www.khanacademy.org/science/ap-physics-1/ap-circuits-topic/introduction-to-dc-circuits-ap/a/circuit-introduction
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-1/static-electricity/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-2/voltage-current-resistance-relate/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-3/importance-electrical-safety/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-9/analog-and-digital-signals/

Ladder Logic

- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://library.automationdirect.com/understanding-ladder-logic/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/ladder-diagrams/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/permissive-interlock-circuits/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/motor-control-circuits/
- http://www.plcacademy.com/ladder-logic-tutorial/
- https://www.techopedia.com/definition/20292/ladder-logic

Logic

- http://www.plcdev.com/book/export/html/9
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/digital-logic-functions/
- https://www.i-programmer.info/babbages-bag/235-logic-logic-everything-is-logic.html
- https://academo.org/demos/logic-gate-simulator/
- https://sciencedemos.org.uk/logic_gates.php

- http://www.cburch.com/logisim/

PLC

- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://www.youtube.com/watch?v=ReTtgzN-Dm
- chttps://unitronicsplc.com/what-is-plc-programmable-logic-controller/
- https://www.industry.usa.siemens.com/automation/us/en/automation-systems/industrial-automation/plc/pages/plc.aspx
- http://www.plcdev.com/how_plcs_work
- https://www.elprocus.com/programmable-logic-controllers-and-types-of-plcs/
- http://www.plctutor.com/plc-components.html
- http://www.plcdev.com/book/export/html/9
- https://www.amci.com/industrial-automation-resources/plc-automation-tutorials/what-plc/
- https://www.ecmweb.com/content/troubleshooting-plcs
- https://unitronicsplc.com/what-is-plc-programmable-logic-controller/

SIEMENS

Ingenuity for life

Project: Garage Door Control

Automated doors are everywhere in our lives today. This automation technology allows for the safe entry and exit from buildings. Automated doors use a sensor to determine when movement is occurring near the door. The automated door computer program decides when the door should open and after a set amount of time, when the door closes automatically saving heat or air conditioning.

Introduction:

Proximity sensors are digital sensors that provide a Boolean signal when something in the field changes. Technically, they are in a category of sensors called Passive Infrared Sensors (PIR). Objects emit heat energy. This energy is in the spectrum of infrared light. The sensor detects energy being emitted from the objects around it generating small voltages. These are active sensors requiring a power supply to operate. There is a computer chip in the sensor that continuously compares the existing voltage with what was just there. When there is no change, the sensor knows this. Motion causes the computer chip to notice differences in the detected voltage and delivers an output action such as opening a door. This makes these sensors ideal for automatic door control, burglar alarms, and automated lighting.

Automating a door is a convenient way to address the need to enter a home or building. However, some important factors must be included in the design. For example, the door should not open or close when conditions are not right. The door should not close on people, animals, or anything else that might be crushed by the action of the door. Modern garage doors have a sensor that prevents the door from closing when there is a person, child, animal, or object in the door's path.

Purpose of the Project:

The purpose of the Automatic Garage Door project is to introduce sensor technology and how this technology can be used to provide input signals in a system. This project will also introduce students to timer technology. This allows for further study of automation and the use of relays to control the direction of doors along with basic concepts of automation, PLC programming as well as different kinds of sensors. Students will apply the design process to solve the problem of how to automate a door so it will open when a person or vehicle approaches the door and close it after a set amount of time.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Science and engineering professionals use data and graphical analysis in making decisions.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The Engineering Design Process is sometimes referred to as the sequential actions of research, design, build, evaluate; then redesign, and communicate.
- Engineering professionals design solutions and communicate the solutions through graphics and pictures.
- Engineers use integrity and ethics when communicating ideas, including citing sources of information.
- In all systems, there is a tradeoff between performance and complexity. Higher complexity is generally associated with higher cost; hence the shortened form of the syllogism is performance versus cost.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.
- Electricity is a form of energy caused by the movement of charged particles. It is often used to transfer energy from one place to another.
- The first law of thermodynamics (conservation of energy and matter) states that output power of a system is always less than the power supplied to the system.
- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
- "Green Principles" of design are used for eventual disassembly and resource recovery and is referred as Product Lifecycle Management (PLM).

- A Programmable Logic Controller (PLC) is a hardened computer used for industrial automation. PLCs can automate a process, machine function, or even an entire production line.
- The term “Logic” is based upon the mathematical system called Boolean Algebra named after George Boole (Born November 2, 1815-Died December 8, 1864) who was a self-taught English mathematician and philosopher who invented this form of algebra where values are either True or False where rules are created to consistently arrive at desired values.
- The ability to collect data, transform them into information, and use that information to improve an existing process is an enabling skill for Lean manufacturing.
- Applying automated control systems to existing manual processes can dramatically improve quality and reduce the amount of human (manual) time required.
- Electronic sensors detect and transform real-world phenomena into information that is used by computers to control valves, pumps, and other industrial equipment.
- Timers allow programmers to design and control specialized clocks to turn machinery on or off for specific amounts of time.
- Keeping track of events as they occur can be accomplished using logic programs called counters.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://youtu.be/JoHka8thD0Q
https://f1.media.brightcove.com/12/1813624294001/1813624294001_5523058005001_4855494617001.mp4?pubId=1813624294001&videoId=4855494617001

Outline:

- Documentation
  - Engineering Notebook
  - Documentation object to be designed
- Programmable Logic Controllers (PLC)
  - Basic electricity-Multimeter schematics/ Ohms law
  - Setup
  - Inputs
  - Outputs
  - Logic
  - Timers
  - Counters
- Evaluation
  - Testing of the ability to control a garage door with motion detection
- Communication
  - Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Design for Manufacturing

- Understand and apply Statistical Process Control (SPC) to acquire quality control.

Design for Assembly

- Create a management plan that includes quality planning, quality control, quality assurance, and quality improvement for an advanced manufacturing environment.

Automation with Programmable Logic Controllers (PLCs)

- Design and analyze an electrical system to efficiently convert, transform, and transmit electricity to where it is needed.
- Research and specify electrical devices necessary to provide needed power.
- Apply machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.
- Use flow charts and diagrams to apply logic in the design of control programs.

Applying Logic Software (TIA Portal) to Create Problem Solutions

- Design a system of elements that manages power to accomplish a task involving defined movement.
- Design a control system to vary the speed and performance of a motor by utilizing feedback from the system to gain the most efficiency possible.

- Formulate a system to utilize data collection and analysis to maintain and improve product quality and provide adequate confidence that the product will satisfy design requirements.
- Design and analyze the application of machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.

Business of Manufacturing

- Research and evaluate the new approaches of rapid development and deployment of products that saves time and is more efficient.
- Create a management plan including quality planning, quality control, quality assurance and quality improvement for an advance manufacturing environment.

College and Career Readiness Math Standards

Creating Equations

CED.A1 Create equations and inequalities in one variable and use them to solve problems.
CED.A.2 Create equations in two or more variables to represent relationships between quantities
CED.A.3 Represent constraints by equations or inequalities, and by systems of equations and/or inequalities, and interpret solutions as viable or nonviable options in a modeling context
CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Making Inferences & Justifying Conclusions

IC.A.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population.
IC.B.3 Recognize the purposes of and differences among sample surveys, experiments, and observational studies; explain how randomization relates to each.

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.
3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas
7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.
9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity
10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes
1. Write arguments focused on *discipline-specific content.*
2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing
4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge
7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing
10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

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STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 3:
Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

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STL Standard 5:
Students will develop an understanding of the effects of technology on the environment.

STL Standard 6:
Students will develop an understanding of the role of society in the development and use of technology.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:

Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

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Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

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STL Standard 12:
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Students will develop the abilities to assess the impact of products and systems.

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Students will develop an understanding of and be able to select and use medical technologies.

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Students will develop an understanding of and be able to select and use manufacturing technologies.

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Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor’s main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Garage Door Control

Essential Question:
How do we automate the control of a door to respond to visitors allowing the door to open and close automatically?

Student Scenario:
You company, Closer Specialties, Inc. has a contract to supply a large warehouse with automatic overhead doors. These automatic overhead doors will save on heating and cooling while allowing easy access to the interior.

The overhead doors should automatically open when a truck approaches the door. The doors should stay open for thirty seconds to allow time for the truck to enter the warehouse. The door should then automatically close. The warehouse has also required a safety system which will stop the door from closing should something enter the path of the door while it is closing.

Your team will conduct research on the sensors to be used in this project and study how timers are used in automated control.

The design requirements are as follows:
- The program must open the door when a truck approaches the door and stay open until safe to close.
- The door must have an override switch to lock the door at the end of the day.
- It must have a safety switch to prevent accidents at the door.
- The door must have a timer to close after a certain time.
- The door should have a manual switch to open the door if needed.

Your team's design will be presented using a working model of the automatic door opening system controlled by the PLC.

The research and learning activities are designed to help students:
- Learn the basic principles of PLC control
- Apply timers to control motion

- Understand the functions of sensors

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design.
- Sketches and planning for programming
- Descriptions of the sensors utilized
- Working prototype
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1

Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2

Key Question: How do we get started in the design process?

The teams will be responsible for researching infrared sensors, PLCs, and Ladder Logic. Teams need to research timers, particularly where they are used and when another method would be more accurate.

The student teams discuss possible automatic door control systems including:

- How does a timer work?
- What kinds of sensors might be used?
- Location of sensors to be most effective?
- Does the model meet the stated design requirements?

- Are there safety switches in place?
- What are the basic electrical safety issues?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information, find tutorials about individual topics, and to find out how the software accomplishes basic features. Students can search for design elements they might want to incorporate. This can be accessed from the help menu in the TIA Portal software.

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the garage door control systems. Other tutorials in the Resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3-7
Key Question: How do we get started on our individual designs?

First, student teams brainstorm components of their design. Next, create the written description of what the program must accomplish. Add this to the team's design brief to be included with their sketches of the location of sensors. Include operating requirements as well as expected voltage readings. The design plan must also include the statistical data needed to assess performance and how it will be gathered. They then meet with the client who will need to sign off on the design proposal before programming and system model building begins. The client can be the teacher or an authentic advisor.

Students should work through the tutorials on PIR Sensor, Motor Reversing, Timers and Running a Simulation, This will take several days to work through these necessary basics.

Students can reference Introduction to the PLC, Wiring the PLC, Wiring Inputs, Wiring Outputs, Setting up the Programming Environment, Setting up Communication, Introduction to a Project, Writing a First Program and Counters. for specific commands to use in the automatic door control system.

Teams discuss how their door systems will be tested. The groups decide which components will be tested and how the team will know when their design achieves the test requirements.

Day 8-10
Key Question: How can we begin to design our automatic door control system model?

Teams discuss their proposed counting systems and how to achieve the design given the approved design brief presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the garage door. Components are available in the Do Engineering Kit. An assembly manual is available from (https://drive.google.com/open?id=1-r1IwRnOTBFuRP-wMpY99ArFvluXhphF) The team must also decide on sensors, wiring, and programing. They utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the automatic door opening system design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams discuss how the various designs and placement of sensors work and that the designs created will meet the automatic door system requirements and the performance will be within the specifications established.

Day 11-13
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all design elements created so far. They look at the criteria and testing protocols created. They discuss which design to use as the team final design. It could be a single design or contain elements of several designs. Once the decision is made the students develop a plan for creating the team prototype using PLC technology. They need to create a design that incorporates their ideas. Once the final plan is completed they will create a prototype program. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin programming and testing to see how they are communicating with the various sensors they selected. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 14-16
Key Question: How do we build and test our designs?

Students assemble their prototype automatic door system. When students encounter problems assembling their prototype they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Once the working prototype is assembled testing can begin to see if the model meets the stated design requirements. Students begin runs of the process to check the accuracy of their systems. They gather data on tests to show how accurate the system is and how the various functions are performing. Students discuss results of their initial testing and propose improvements to the system.

Day 17-18
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to their clients. The deliverables will include the prototype, program design, and information about the design process and how they solved many of the issues encountered. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 19
Key Question: How do we convey our ideas?

Student teams present their solutions one at a time. Students display the completed automatic door system model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

Analog
Connection Terminals
Counter
CPU
Digital
DIN Rail
Input
L Terminal
Ladder Logic
Load
Logic
M Terminal
Network

Normally Closed
Normally Open
Organizational Blocks
Output
PIR Sensor
Phototransistor
PLC
Power Supply
Power Terminals
Schematic
Set Reset Flip Flop
Switch
Tag Table
Timers
Wiring

Resources:

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

Electricity

- https://www.allaboutcircuits.com/textbook/direct-current/
- https://learn.sparkfun.com/tutorials/alternating-current-ac-vs-direct-current-dc
- https://engineering.mit.edu/engage/ask-an-engineer/whats-the-difference-between-ac-and-dc/
- https://www.school-for-champions.com/science/dc.htm#.W372zehKguU
- http://sinovoltaics.com/learning-center/basics/direct-current-dc-power-definition-and-applications/
- https://whatis.techtarget.com/definition/DC-direct-current

- http://macao.communications.museum/eng/exhibition/secondfloor/MoreInfo/2_3_1_DCCircuit.html
- https://www.khanacademy.org/science/ap-physics-1/ap-circuits-topic/introduction-to-dc-circuits-ap/a/circuit-introduction
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-1/static-electricity/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-2/voltage-current-resistance-relate/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-3/importance-electrical-safety/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-9/analog-and-digital-signals/

Ladder Logic

- https://euroec.by/assets/files/siemens/s71200_easy_book_en-US_en-US.pdf
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://library.automationdirect.com/understanding-ladder-logic/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/ladder-diagrams/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/permissive-interlock-circuits/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/motor-control-circuits/
- http://www.plcacademy.com/ladder-logic-tutorial/
- https://www.techopedia.com/definition/20292/ladder-logic

Logic

- http://www.plcdev.com/book/export/html/9
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/digital-logic-functions/
- https://www.i-programmer.info/babbages-bag/235-logic-logic-everything-is-logic.html
- https://academo.org/demos/logic-gate-simulator/
- https://sciencedemos.org.uk/logic_gates.php
- http://www.cburch.com/logisim/

PLC

- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://www.youtube.com/watch?v=ReTtgzN-Dm
- chttps://unitronicsplc.com/what-is-plc-programmable-logic-controller/
- https://www.industry.usa.siemens.com/automation/us/en/automation-systems/industrial-automation/plc/pages/plc.aspx

- http://www.plcdev.com/how_plcs_work
- https://www.elprocus.com/programmable-logic-controllers-and-types-of-plcs/
- http://www.plctutor.com/plc-components.html
- http://www.plcdev.com/book/export/html/9
- https://www.amci.com/industrial-automation-resources/plc-automation-tutorials/what-plc/
- https://www.ecmweb.com/content/troubleshooting-plcs
- https://unitronicsplc.com/what-is-plc-programmable-logic-controller/

Project: Sun Tracking Solar Panel

Solar panels generate electricity when photons (a light particle) knock electrons free from the specially developed materials generating a flow of electrons. The majority of solar panels are mounted to a fixed frame and the frame is either mounted to the ground or to the roof of a building. This way of mounting solar panels is the less expensive method to setup a solar panel system. Because the solar panels do not move, they produce the most electricity when the sun is facing the solar panels directly which is for a very short period of time. Before and after that time the amount of electricity produced is variably less.

A solar panel system that has a sun tracking mechanism is more expensive but assures that the solar panels are always facing the sun directly and therefore produces the optimum amount of electricity.

Introduction:

Solar cells or photo voltaic cells, the individual components that make up solar panels, are semiconductor devices. The amount of energy produced is based upon many factors including the color of the light, the amount of photons that strike at the correct angle and even climate conditions. Obviously cloudy days produce less electricity than sunny days.

The electrical grid is the term that means an interconnected network for delivering electricity from all producers to the consumers. The demand on the grid for electricity varies but is greatest through the day when we are all awake and going about our daily routines. The most important aspect about solar panels is centered on the fact that they produce the most electricity during the day which is when the grid has the most demand placed on it. Also, solar panels have become more efficient in recent years meaning each square foot of panel is generating more electricity and the cost of solar panels continue to drop in price.

Since the electrical output of solar panels is tied to the angle of the light striking the panel many solar installations now include tracking devices that are designed to rotate in several dimensions to be always pointed at the sun, maximizing the amount of electricity produced. The costs of these tracking systems are now being offset by gains in the amount of electricity generated. This is especially important in off grid installations, where maximizing the output of electricity is critical.

Purpose of the Project:

The purpose of the Sun Tracking Solar Panel project is the introduction to analog sensors and how they might be used to provide input signals. This project will also introduce students to comparison decision making. Students will apply the design process to solve the problem of how to automate a solar panel tracking system to keep the panel always pointed at the sun.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Science and engineering professionals use data and graphical analysis in making decisions.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The Engineering Design Process is sometimes referred to as the sequential actions of research, design, build, evaluate; then redesign, and communicate.
- Engineering professionals design solutions and communicate the solutions through graphics and pictures.
- Engineers use integrity and ethics when communicating ideas, including citing sources of information.
- In all systems, there is a tradeoff between performance and complexity. Higher complexity is generally associated with higher cost; hence the shortened form of the syllogism is performance versus cost.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.

- Electricity is a form of energy caused by the movement of charged particles. It is often used to transfer energy from one place to another.
- The first law of thermodynamics (conservation of energy and matter) states that output power of a system is always less than the power supplied to the system.
- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
- “Green Principles” of design are used for eventual disassembly and resource recovery and is referred as Product Lifecycle Management (PLM).
- A Programmable Logic Controller (PLC) is a hardened computer used for industrial automation. PLCs can automate a process, machine function, or even an entire production line.
- The term “Logic” is based upon the mathematical system called Boolean Algebra named after George Boole (Born November 2, 1815-Died December 8, 1864) who was a self-taught English mathematician and philosopher who invented this form of algebra where values are either True or False where rules are created to consistently arrive at desired values.
- The ability to collect data, transform them into information, and use that information to improve an existing process is an enabling skill for Lean manufacturing.
- Applying automated control systems to existing manual processes can dramatically improve quality and reduce the amount of human (manual) time required.
- Electronic sensors detect and transform real-world phenomena into information that is used by computers to control valves, pumps, and other industrial equipment.
- Timers allow programmers to design and control specialized clocks to turn machinery on or off for specific amounts of time.
- Keeping track of events as they occur can be accomplished using logic programs called counters.
- Analog inputs for such things as temperature, pressure, speed, etc., are voltage values that can be converted into a digital value to be stored and used by a computer.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://www.siemens.com/global/en/home/markets/machinebuilding/solar-production-machines/solar-tracking.html
https://f1.media.brightcove.com/12/1813624294001/1813624294001_5523058005001_4855494617001.mp4?pubId=1813624294001&videoId=4855494617001

Outline:

Documentation
    Engineering Notebook
    Documentation object to be designed

Programmable Logic Controllers (PLC)
- Basic electricity-Multimeter schematics/ Ohms law
- Setup
- Inputs
- Outputs
- Logic
- Timers
- Counters

Evaluation
- Testing of the ability to control a solar panel to track the sun

Communication
- Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Design for Manufacturing

- Understand and apply Statistical Process Control (SPC) to acquire quality control.

Design for Assembly

- Create a management plan that includes quality planning, quality control, quality assurance, and quality improvement for an advanced manufacturing environment.

Automation with Programmable Logic Controllers (PLCs)

- Design and analyze an electrical system to efficiently convert, transform, and transmit electricity to where it is needed.

- Research and specify electrical devices necessary to provide needed power.
- Apply machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.
- Use flow charts and diagrams to apply logic in the design of control programs.

Applying Logic Software (TIA Portal) to Create Problem Solutions

- Design a system of elements that manages power to accomplish a task involving defined movement.
- Design a control system to vary the speed and performance of a motor by utilizing feedback from the system to gain the most efficiency possible.
- Formulate a system to utilize data collection and analysis to maintain and improve product quality and provide adequate confidence that the product will satisfy design requirements.
- Design and analyze the application of machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.

Business of Manufacturing

- Research and evaluate the new approaches of rapid development and deployment of products that saves time and is more efficient.
- Create a management plan including quality planning, quality control, quality assurance and quality improvement for an advance manufacturing environment.

College and Career Readiness Math Standards

Creating Equations

CED.A1 Create equations and inequalities in one variable and use them to solve problems.

CED.A.2 Create equations in two or more variables to represent relationships between quantities

CED.A.3 Represent constraints by equations or inequalities, and by systems of equations and/or inequalities, and interpret solutions as viable or nonviable options in a modeling context

CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Making Inferences & Justifying Conclusions

IC.A.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population.
IC.B.3 Recognize the purposes of and differences among sample surveys, experiments, and observational studies; explain how randomization relates to each.

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.
3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.
9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*
2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.
8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:
Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 3:
Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 5:
Students will develop an understanding of the effects of technology on the environment.

STL Standard 6:
Students will develop an understanding of the role of society in the development and use of technology.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 14:
Students will develop an understanding of and be able to select and use medical technologies.

STL Standard 16:
Students will develop an understanding of and be able to select and use energy and power technologies.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:

Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Sun Tracking Solar Panel Rubric

Essential Question:

How can a design team create a solar panel tracking system to maximize the sun's energy?

Student Scenario:

You are working with a design team at Sun Tracker LLC, a firm that supplies solar panel installations to remote areas. This allows areas far from the grid to have reliable power. In the past these installations were done with fuel powered generators adding noise and pollution to sensitive areas as well as the cost of trucking and storing fuel.

Because the costs of solar panel systems are falling and the efficiency of solar panels are increasing, it is now more cost effective than ever to use solar installations for electrical power. Much of the costs of solar panel systems are in electrical storage systems and the need for electrical inverters, which convert the DC electricity which the solar panels produce to AC electricity which the products that use electricity need. (Washing machines, TVs, refrigerators, etc.)

Your team has been charged with the design of a two axis solar panel tracking system that will track the sun and keep the panels at the ideal angle for the greatest electrical production. The team will have to conduct research on the sensors to be used and study how those sensors can be used in controlling the motion of the solar panel tracking system.

The design requirements are as follows:

- The program must control the solar panels in two axis.
- The program must point the solar panels at the best angle to track the sun.
- The system must have a safety switch to send the solar panels to the morning position.
- The program must have a dark setting where the panel rotation control is turned off to wait for the sun to rise the next day.

Your team's design will be presented using a working model of the Sun Tracking System controlled by the PLC. This system is proposed to increase the production of solar energy by 40%. The design must reduce the total number of solar panels needed and be able to provide enough electricity on days when the weather is not sunny.

The research and learning activities are designed to help students:

- Learn the basic principles of PLC control
- Apply analog sensors to monitor environmental conditions
- Apply ranges to the control so motion is incremental not continuous
- Apply understanding of Double Pole Double Throw (DPDT) relays for use in reversing motor control

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design.
- Sketches of the device and planning for programming
- Descriptions of the sensors utilized and where they should be positioned
- Working prototype
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1

Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2
Key Question: How do we get started in the design process?

The teams will be responsible for researching types of analog sensors, PLCs and Ladder Logic. Teams need to research creating comparison statements and where they are used to control the logic of a program.

The student teams discuss possible sun tracking solar control systems including:

- How does an analog sensor work?
- What kinds of sensors might we need to use?
- Where might sensors be located where they will be effective?
- Will the model meet the stated design requirements?
- Are there safety switches in place?
- What are the basic electrical safety issues?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information, find tutorials about individual topics, and to find out how the software accomplishes basic features. Students can search for design elements they might want to incorporate. This can be accessed from the help menu in the TIA Portal software.

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the solar tracking control system. Other tutorials in the Resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3-7
Key Question: How do we get started on our individual designs?

First, student teams brainstorm components of their design. Next, create a written description of what the program must accomplish. Add this to the team's design brief to be included with the sketches of the location of sensors. Include operating requirements as well as expected voltage readings. The design plan must also include the statistical data needed to assess performance and how it will be gathered. They then meet with the "design team" who will need to sign off on the design proposal before programming and system model building begins. The design team can be the teacher or an authentic advisor.

Students should work through the tutorials on Analog Inputs, Using Relays to Control Motor Direction and Building Blocks. This will take several days to work through these necessary basics.

Students can reference Introduction to the PLC, Wiring the PLC, Wiring Inputs, Wiring Outputs, Setting up the Programming Environment, Setting up Communication, Introduction to a Project, Writing a First Program and Counters. for specific commands to use in the sun tracking system.

Teams discuss how their sun tracking systems should be tested. The groups decide what components will be tested and how the team will know when their design achieves the test requirements.

Day 8-10
Key Question: How can we begin to design our Sun Tracking Control System model?

Teams discuss their proposed sun tracking systems and how to achieve the design given the approved design brief they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the sun tracking device. Components are available in the Do Engineering and the Automation and Robotics kits. They must also decide on sensors, wiring, and programming. They utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the sun tracking system design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams discuss how the various designs and placement of sensors work and that the designs created will meet the sun tracking system requirements and the performance will be within the specifications they established

Day 11-13
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs elements created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team final design. It could be a single design or contain elements of several designs. Once the decision is made the students develop a plan for creating the team prototype using PLC technology. They need to create a design that incorporates their ideas. Once the final plan is completed they will create a prototype program. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin programming and testing to see how they are communicating with the various sensors they selected. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 14-16
Key Question: How do we build and test our designs?

Students assemble their prototype sun tracking system. When students encounter problems assembling their prototype they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Once the working prototype is assembled testing can begin to see if the model meets the stated design requirements. Students begin runs of the process to check the accuracy of their systems. They gather data on tests and to show how accurate the system is and how the various functions are performing. Students discuss results of their initial testing and propose improvements to the system.

Day 17-18
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to their clients. The deliverables will include the prototype, program design and information about the design process and how they solved many of the issues they encountered. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 19
Key Question: How do we convey our ideas?

Student teams present their solutions one at a time to the authentic audience. Students display the completed sun tracking system model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.
In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

Analog
AC & DC
Azimuth
Connection Terminals
Counter
CPU
Digital
DIN Rail
Dual axis
Electrical Grid
In_Range
Input
Inverter
L Terminal
Ladder Logic
Load
Logic
M Terminal
Network
Normally Closed
Normally Open
Organizational Blocks
Off Grid
Output
Photons
Phototransistor
Photovoltaic
PIR Sensor
PLC
Power Supply
Power Terminals
Schematic
Set Reset Flip Flop
Single Axis
Switch
Tag Table
Tilt angle
Timers
Two Axis
Wiring

Resources:

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

Electricity

- https://www.allaboutcircuits.com/textbook/direct-current/
- https://learn.sparkfun.com/tutorials/alternating-current-ac-vs-direct-current-dc
- https://engineering.mit.edu/engage/ask-an-engineer/whats-the-difference-between-ac-and-dc/
- https://www.school-for-champions.com/science/dc.htm#.W372zehKguU
- http://sinovoltaics.com/learning-center/basics/direct-current-dc-power-definition-and-applications/
- https://whatis.techtarget.com/definition/DC-direct-current
- http://macao.communications.museum/eng/exhibition/secondfloor/MoreInfo/2_3_1_DCCircuit.html
- https://www.khanacademy.org/science/ap-physics-1/ap-circuits-topic/introduction-to-dc-circuits-ap/a/circuit-introduction
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-1/static-electricity/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-2/voltage-current-resistance-relate/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-3/importance-electrical-safety/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-9/analog-and-digital-signals/

Ladder Logic

- https://euroec.by/assets/files/siemens/s71200_easy_book_en-US_en-US.pdf
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://library.automationdirect.com/understanding-ladder-logic/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/ladder-diagrams/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/permissive-interlock-circuits/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/motor-control-circuits/
- http://www.plcacademy.com/ladder-logic-tutorial/
- https://www.techopedia.com/definition/20292/ladder-logic

Logic

- http://www.plcdev.com/book/export/html/9
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/digital-logic-functions/
- https://www.i-programmer.info/babbages-bag/235-logic-logic-everything-is-logic.html
- https://academo.org/demos/logic-gate-simulator/
- https://sciencedemos.org.uk/logic_gates.php
- http://www.cburch.com/logisim/

PLC

- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://www.youtube.com/watch?v=ReTtgzN-Dm
- chttps://unitronicsplc.com/what-is-plc-programmable-logic-controller/
- https://www.industry.usa.siemens.com/automation/us/en/automation-systems/industrial-automation/plc/pages/plc.aspx
- http://www.plcdev.com/how_plcs_work
- https://www.elprocus.com/programmable-logic-controllers-and-types-of-plcs/
- http://www.plctutor.com/plc-components.html
- http://www.plcdev.com/book/export/html/9
- https://www.amci.com/industrial-automation-resources/plc-automation-tutorials/what-plc/
- https://www.ecmweb.com/content/troubleshooting-plcs
- https://unitronicsplc.com/what-is-plc-programmable-logic-controller/

Solar Panels and Control

- https://www.energy.gov/eere/solar/homeowner-s-guide-going-solar
- https://w3.siemens.com/verticals/mea/en/solar-industry/field-supply/tracking-control/Documents/e20001-a100-t112-x-7600.pdf
- https://www.forbes.com/sites/quora/2018/07/09/what-are-the-pros-and-cons-of-residential-solar-panels/#3ba658462cd8
- https://www.solarpowerauthority.com/how-much-does-it-cost-to-install-solar-on-an-average-us-house/

- https://www.energy.gov/energysaver/planning-home-solar-electric-system

SIEMENS

Ingenuity for life

Project: Sort by Color

Cadmium Sulfide cells (CdS Cell) are more commonly known as Photo-resistors or Photocells. They form a category of analog sensors that measure the amount of light striking a surface. The less light striking the surface, the greater the resistance of the photo-resistor becomes. This allows a Photo-resistor to be used in a voltage divider circuit where the level of the voltage measured will indicate the quantity of light striking the surface.

Introduction:

Light striking a mirror is reflected and the color appears as it did before striking the mirror. When our eye sees color we are really seeing the light reflecting off the surface of the object. Objects reflect or absorb the light striking them differently. Darker objects reflect ***less*** light and absorb ***more*** light. If no light is reflected, the object appears black to our eye.

Engineers take advantage of this concept in basic ways. We can create paint in colors that people find pleasing. We control light used to illuminate stages for theaters, concerts, and movies. In automation we use reflective light to select colors.

Calibrating sensors is a process necessary for devices used by programmers to detect a specific color based on the amount of voltage created. The programmer can use specific information to cause a specific action in the presence of a certain color. This is applicable when designing a situation where a variety of colors must be differentiated. An example could be an inspection system where only completely finished products are passed through while all others are blocked. This is because the product with an area not finished will cause a different voltage to be produced by the sensor.

Purpose of the Project:

The purpose of the Sort by Color project is to introduce the student to analog sensors and how they might be used to provide input signals. This project will also give students the opportunity to use comparison decision making. Students will apply the design process to solve the problem of how to automate a color sorting system to allow only the correct color through the system.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Science and engineering professionals use data and graphical analysis in making decisions.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The Engineering Design Process is sometimes referred to as the sequential actions of research, design, build, evaluate; then redesign, and communicate.
- Engineering professionals design solutions and communicate the solutions through graphics and pictures.
- Engineers use integrity and ethics when communicating ideas, including citing sources of information.
- In all systems, there is a tradeoff between performance and complexity. Higher complexity is generally associated with higher cost; hence the shortened form of the syllogism is performance versus cost.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.
- Electricity is a form of energy caused by the movement of charged particles. It is often used to transfer energy from one place to another.
- The first law of thermodynamics (conservation of energy and matter) states that output power of a system is always less than the power supplied to the system.
- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.

- "Green Principles" of design are used for eventual disassembly and resource recovery and is referred as Product Lifecycle Management (PLM)
- A Programmable Logic Controller (PLC) is a hardened computer used for industrial automation. PLCs can automate a process, machine function, or even an entire production line.
- The term "Logic" is based upon the mathematical system called Boolean Algebra named after George Boole (Born November 2, 1815-Died December 8, 1864) who was a self-taught English mathematician and philosopher who invented this form of algebra where values are either True or False where rules are created to consistently arrive at desired values.
- The ability to collect data, transform them into information, and use that information to improve an existing process is an enabling skill for Lean manufacturing.
- Applying automated control systems to existing manual processes can dramatically improve quality and reduce the amount of human (manual) time required.
- Electronic sensors detect and transform real-world phenomena into information that is used by computers to control valves, pumps, and other industrial equipment.
- Timers allow programmers to design and control specialized clocks to turn machinery on or off for specific amounts of time.
- Keeping track of events as they occur can be accomplished using logic programs called counters.
- Analog inputs for such things as temperature, pressure, speed, etc., are voltage values that can be converted into a digital value to be stored and used by a computer.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://f1.media.brightcove.com/12/1813624294001/1813624294001_5294871903001_5294854801001.mp4?pubId=1813624294001&videoId=5294854801001
https://www.youtube.com/watch?v=j2XsnnmAL14

Outline:

Documentation
- Engineering Notebook
- Documentation object to be designed

Programmable Logic Controllers (PLC)
- Basic electricity-Multimeter schematics/ Ohms law
- Setup
- Inputs
- Outputs
- Logic
- Timers

Counters
Evaluation
Testing of the ability to sort products by color
Communication
Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Design for Manufacturing

- Understand and apply Statistical Process Control (SPC) to acquire quality control.

Design for Assembly

- Create a management plan that includes quality planning, quality control, quality assurance, and quality improvement for an advanced manufacturing environment.

Automation with Programmable Logic Controllers (PLCs)

- Design and analyze an electrical system to efficiently convert, transform, and transmit electricity to where it is needed.
- Research and specify electrical devices necessary to provide needed power.
- Apply machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.
- Use flow charts and diagrams to apply logic in the design of control programs.

Applying Logic Software (TIA Portal) to Create Problem Solutions

- Design a system of elements that manages power to accomplish a task involving defined movement.
- Design a control system to vary the speed and performance of a motor by utilizing feedback from the system to gain the most efficiency possible.
- Formulate a system to utilize data collection and analysis to maintain and improve product quality and provide adequate confidence that the product will satisfy design requirements.
- Design and analyze the application of machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.

Business of Manufacturing

- Research and evaluate the new approaches of rapid development and deployment of products that saves time and is more efficient.
- Create a management plan including quality planning, quality control, quality assurance and quality improvement for an advance manufacturing environment.

College and Career Readiness Math Standards

Creating Equations

CED.A1 Create equations and inequalities in one variable and use them to solve problems.
CED.A.2 Create equations in two or more variables to represent relationships between quantities
CED.A.3 Represent constraints by equations or inequalities, and by systems of equations and/or inequalities, and interpret solutions as viable or nonviable options in a modeling context
CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Making Inferences & Justifying Conclusions

IC.A.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population.
IC.B.3 Recognize the purposes of and differences among sample surveys, experiments, and observational studies; explain how randomization relates to each.

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.

3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.

9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*

2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards
The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:
1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:
Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 3:
Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 5:
Students will develop an understanding of the effects of technology on the environment.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 14:
Students will develop an understanding of and be able to select and use medical technologies.

STL Standard 16:
Students will develop an understanding of and be able to select and use energy and power technologies.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 18:
Students will develop an understanding of and be able to select and use transportation technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative

assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.
Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Color Sorting of Products

Essential Question:

How do we create a program to sort different colors into bins?

Student Scenario:

You are working with a team responsible for color finishes at Bright Finishes LLC., a firm that applies custom coatings to your customers' products. Recently you have received a complaint that some of the products are not coated properly. With the number of components that you are creating it would be impossible to hire people to look at each one as they come from the finish room before being shipped.

Your team has been charged with coming up with an automated inspection system to look at the parts and identify ones that are not correct. You will have to research a method of determining what constitutes correct color and what should be rejected. Your team will have to apply this to the design and implement a control program on a conveyor system.

The design requirements are as follows:

- The program must sort the products into acceptable and non-acceptable categories.
- The program scans the parts as they pass.
- It must have a safety switch to stop the flow of products.
- The program must be able to sort objects to maintain a continuous flow.

Your team's design will be presented using a working model of the color sorting system controlled by the PLC. The purpose of the system is to increase the accuracy of the deliverables to customers. Greater accuracy will lead to increased customer satisfaction and a continuing business relationship with Bright Finishes LLC.

The research and learning activities are designed to help students:

- Learn the basic principles of PLC control
- Apply analog sensors to monitor environmental conditions
- Apply timers to control the functioning of the conveyor
- Apply understanding of Double Pole Double Throw (DPDT) relays for use in reversing motor control

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design.
- Sketches of the device and planning for programming
- Descriptions of the sensors utilized and where they should be positioned
- Working prototype
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1
Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2
Key Question: How do we get started in the design process?

The teams will be responsible for researching types of analog sensors, PLCs, and Ladder logic. Teams need to research creating comparison statements and where they are used to control the logic of a program.

The student teams discuss possible color sorting control systems including:

- How does an analog sensor work?
- What kinds of sensors might we need to use?
- Where might sensors be located where they will be effective?
- Will the model meet the stated design requirements?
- Are there safety switches in place?
- What are the basic electrical safety issues?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information find tutorials about individual topics and to find out how the software accomplishes basic features. Students can search for design elements they might want to incorporate. This can be accessed from the help menu in the TIA Portal software.

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the color sorting control system. Other tutorials in the resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3-7
Key Question: How do we get started on our individual designs?

Student teams brainstorm needed components of their design and then create their written description of what they want the program to accomplish to add to their design brief to be include with their sketches of the location of sensors. They include operating requirements as well as expected voltage readings. The design plan must also include the statistical data needed to assess performance and how it will be gathered. They then meet with the clients who will need to sign off on the design proposal before programming and system model building begins. The client can be the teacher or an authentic advisor.

Students should work through the tutorials on Analog Inputs, Using Relays to Control Motor Direction and Building Blocks. This will take several days to work through these necessary basics.

Students can reference Introduction to the PLC, Wiring the PLC, Wiring Inputs, Wiring Outputs, Setting up the Programming Environment, Setting up Communication, Introduction to a Project, Writing a First Program and Counters. for specific commands to use in the color sorting control system.

Teams discuss the testing of the color sorting system. The groups decide what components will be tested and how the team will know when their design achieves the test requirements.

Day 8-10
Key Question: How can we begin to design our Color Sorting control system model?

Teams discuss their proposed color sorting systems and how to achieve the design given the approved design brief they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the color sorting device. Components are available in the Do Engineering (https://drive.google.com/open?id=1r_sULTtpb_WBzxLx5kXzaB7kGTn4Rj_h) kit. Next the team divides the work of creating the conveyor (https://drive.google.com/open?id=0B_7sFhPxnoaXU1hrRzI4SmM3VlE), sensors, wiring, and program. They must also decide on sensors, wiring and programing. They utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the color sorting system design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams discuss how the various designs and placement of sensors work and that the designs created will meet the color sorting system requirements and the performance will be within the specifications they established

Day 11-13
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs elements created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team final design. It could be a single design or contain elements of several designs. Once the decision is made the students develop a plan for creating the team prototype using PLC technology. They need to create a design that incorporates their ideas. Once the final plan is completed they will create a prototype program. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin programming and testing to see how they are communicating with the various sensors they selected. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 14-16
Key Question: How do we build and test our designs?

Students assemble their prototype color sorting system. When students encounter problems assembling their prototype they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Once the working prototype is assembled testing can begin to see if the model meets the stated design requirements. Students begin runs to check the accuracy of their systems. They gather data on tests and to show how accurate the system is and how the various functions are performing. Students discuss results of their initial testing and propose improvements to the system.

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Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
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Students discuss the outline of the presentation to their clients. The deliverables will include the prototype, program design and information about the design process and how they solved many of the issues they encountered. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 19
Key Question: How do we convey our ideas?

Students can present their solutions to the class one at a time. Students display the completed color sorting system model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

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Connection Terminals
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CPU
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Dual axis
In_Range
Input
L Terminal
Ladder Logic
Load
Logic
M Terminal
Network
Normally Closed
Normally Open
Organizational Blocks
Output
Phototransistor
Photovoltaic
PIR Sensor
PLC
Power Supply
Power Terminals
Schematic
Set Reset Flip Flop
Single Axis
Switch
Tag Table
Tilt angle
Timers
Wiring

Resources:

CdSCells

- http://www.bristolwatch.com/ele/pd.html
- https://learn.adafruit.com/photocells/overview
- https://acroname.com/examples/reading-photoresistor-using-reflex
- https://www.radio-electronics.com/info/data/resistor/ldr/light_dependent_resistor.php
- https://www.youtube.com/watch?v=QMLjeZ81d_s
- https://www.youtube.com/watch?v=mU3tHvMCGi0https://www.youtube.com/watch?v=bJVg-LTza4s

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

Electricity

- https://www.allaboutcircuits.com/textbook/direct-current/
- https://learn.sparkfun.com/tutorials/alternating-current-ac-vs-direct-current-dc
- https://engineering.mit.edu/engage/ask-an-engineer/whats-the-difference-between-ac-and-dc/
- https://www.school-for-champions.com/science/dc.htm#.W372zehKguU
- http://sinovoltaics.com/learning-center/basics/direct-current-dc-power-definition-and-applications/
- https://whatis.techtarget.com/definition/DC-direct-current
- http://macao.communications.museum/eng/exhibition/secondfloor/MoreInfo/2_3_1_DCCircuit.html
- https://www.khanacademy.org/science/ap-physics-1/ap-circuits-topic/introduction-to-dc-circuits-ap/a/circuit-introduction
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
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- https://www.allaboutcircuits.com/textbook/direct-current/chpt-2/voltage-current-resistance-relate/
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- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-9/analog-and-digital-signals/

Ladder Logic

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- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://library.automationdirect.com/understanding-ladder-logic/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/ladder-diagrams/
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- chttps://unitronicsplc.com/what-is-plc-programmable-logic-controller/
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- http://www.plcdev.com/how_plcs_work
- https://www.elprocus.com/programmable-logic-controllers-and-types-of-plcs/
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- https://www.amci.com/industrial-automation-resources/plc-automation-tutorials/what-plc/
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- https://unitronicsplc.com/what-is-plc-programmable-logic-controller/

SIEMENS

Ingenuity for life

Project: Elevator Control

Introduction:

Elevators have been in use for millennia. Applying power to raise and lower loads made mines more productive, buildings easier to construct, and multistory warehouses possible. Electricity replaced steam as the power source of choice about 130 years ago. The first electric elevator was the brainchild of Werner von Siemens.

Purpose of the Project:

The purpose of the elevator control project is to introduce students to digital logic and how it is involved in decision making using elevator control switches. Student teams apply the design process to solve the problem of how an elevator control system permits motion to the correct location dictated by the user.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.

- Science and engineering professionals use data and graphical analysis in making decisions.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The Engineering Design Process is sometimes referred to as the sequential actions of research, design, build, evaluate; then redesign, and communicate.
- Engineering professionals design solutions and communicate the solutions through graphics and pictures.
- Engineers use integrity and ethics when communicating ideas, including citing sources of information.
- In all systems, there is a tradeoff between performance and complexity. Higher complexity is generally associated with higher cost; hence the shortened form of the syllogism is performance versus cost.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.
- Electricity is a form of energy caused by the movement of charged particles. It is often used to transfer energy from one place to another.
- The first law of thermodynamics (conservation of energy and matter) states that output power of a system is always less than the power supplied to the system.
- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
- “Green Principles” of design are used for eventual disassembly and resource recovery and is referred as Product Lifecycle Management (PLM).
- A Programmable Logic Controller (PLC) is a hardened computer used for industrial automation. PLCs can automate a process, machine function, or even an entire production line.
- The term “Logic” is based upon the mathematical system called Boolean Algebra named after George Boole (Born November 2, 1815-Died December 8, 1864) who was a self-taught English mathematician and philosopher who invented this form of algebra where values are either True or False where rules are created to consistently arrive at desired values.
- The ability to collect data, transform them into information, and use that information to improve an existing process is an enabling skill for Lean manufacturing.
- Applying automated control systems to existing manual processes can dramatically improve quality and reduce the amount of human (manual) time required.
- Electronic sensors detect and transform real-world phenomena into information that is used by computers to control valves, pumps, and other industrial equipment.
- Timers allow programmers to design and control specialized clocks to turn machinery on or off for specific amounts of time.
- Keeping track of events as they occur can be accomplished using logic programs called counters.

- Analog inputs for such things as temperature, pressure, speed, etc., are voltage values that can be converted into a digital value to be stored and used by a computer.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://www.youtube.com/watch?v=se4K5_kfyuY
https://www.youtube.com/watch?v=gPeqw11DjnM

Outline:

- Documentation
  - Engineering Notebook
  - Documentation object to be designed
- Programmable Logic Controllers (PLC)
  - Basic electricity-Multimeter schematics/ Ohms law
  - Setup
  - Inputs
  - Outputs
  - Logic
  - Timers
  - Counters
- Evaluation
  - Testing of the ability to control the elevator
- Communication
  - Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.

- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Design for Manufacturing
- Understand and apply Statistical Process Control (SPC) to acquire quality control.

Design for Assembly
- Create a management plan that includes quality planning, quality control, quality assurance, and quality improvement for an advanced manufacturing environment.

Automation with Programmable Logic Controllers (PLCs)
- Design and analyze an electrical system to efficiently convert, transform, and transmit electricity to where it is needed.
- Research and specify electrical devices necessary to provide needed power.
- Apply machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.
- Use flow charts and diagrams to apply logic in the design of control programs.

Applying Logic Software (TIA Portal) to Create Problem Solutions
- Design a system of elements that manages power to accomplish a task involving defined movement.
- Design a control system to vary the speed and performance of a motor by utilizing feedback from the system to gain the most efficiency possible.
- Formulate a system to utilize data collection and analysis to maintain and improve product quality and provide adequate confidence that the product will satisfy design requirements.
- Design and analyze the application of machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.

Business of Manufacturing
- Research and evaluate the new approaches of rapid development and deployment of products that saves time and is more efficient.
- Create a management plan including quality planning, quality control, quality assurance and quality improvement for an advance manufacturing environment.

College and Career Readiness Math Standards

Creating Equations

CED.A1 Create equations and inequalities in one variable and use them to solve problems.

CED.A.2 Create equations in two or more variables to represent relationships between quantities
CED.A.3 Represent constraints by equations or inequalities, and by systems of equations and/or inequalities, and interpret solutions as viable or nonviable options in a modeling context
CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Create equations that describe numbers or relationships CED
A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Quantities
Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Making Inferences & Justifying Conclusions
IC.A.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population.
IC.B.3 Recognize the purposes of and differences among sample surveys, experiments, and observational studies; explain how randomization relates to each.

Reading Standards for Literacy in History/Social Studies 9-10
Key Ideas and Details
1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.
3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas
7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.
9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity
10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10
Text Types and Purposes
1. Write arguments focused on *discipline-specific content.*

2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:
Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 3:
Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 5:
Students will develop an understanding of the effects of technology on the environment.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 14:
Students will develop an understanding of and be able to select and use medical technologies.

STL Standard 16:
Students will develop an understanding of and be able to select and use energy and power technologies.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 18:
Students will develop an understanding of and be able to select and use transportation technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Elevator Control

Essential Question:

How is a control program designed to allow for the proper control of an elevator?

Student Scenario:

You are working with a team of technicians and programmers at Lifts Inc. Your team is asked to develop a new program to control the elevator at the Albany Supply Warehouse, a company that specializes in appliance sales. The elevator will be used to transport employees and inventory from floor to floor.

Your team must create a model of the section of the warehouse with access to three floors. Each floor will need a call button and a panel for the inside of the elevator to select the desired floor.

The design requirements are as follows:

- The program must read the call buttons.
- The elevator must know what floor it is on.
- The elevator must move in the correct direction.
- It must have a safety switch to stop the elevator in emergencies.
- The elevator must have a door that opens only at the correct floor.

Your team's design will be presented to the CEO of Lifts, Inc. using a working model of the elevator system controlled by the PLC. The company wants an elevator that safely moves the employees and the appliance inventory from floor to floor.

The research and learning activities are designed to help students:

- Learn the basic principles of PLC control
- Apply digital logic to determine the calling floor and current elevator position
- Utilize a closed loop system to identify positions
- Apply understanding of Double Pole Double Throw (DPDT) relays for use in reversing motor control

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design.
- Sketches of the device and planning for programming
- Descriptions of the sensors utilized and where they should be positioned
- Working prototype
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1

Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2

Key Question: How do we get started in the design process?

The teams will be responsible for researching types of analog sensors, PLCs, and Ladder logic. Teams need to research creating comparison statements and where they are used to control the logic of a program.

The student teams discuss possible elevator control systems including:

- What kinds of sensors might we need to use?
- Where might sensors be located where they will be effective?
- Will the model meet the stated design requirements?
- How will our logic work?
- Are there safety switches in place?
- What are the basic electrical safety issues?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information, find tutorials about individual topics, and to find out how the software accomplishes basic features. Students can search for design elements they might want to incorporate. This can be accessed from the help menu in the TIA Portal software.

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the elevator control system. Other tutorials in the resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3-7
Key Question: How do we get started on our individual designs?

First, student teams brainstorm components of their design. Next, a written description of what the program must accomplish. Add this to the team's design brief to be included with the sketches of the location of sensors. Include operating requirements as well as expected logic signals. They then meet with the CEO of Lifts, Inc. who will need to sign off on the design proposal before programming and system model building begins. The client can be the teacher or an authentic advisor.

Students should work through the tutorials on Logic and Decision Making and Designing Programs for Problems.

This will take several days to work through these necessary basics.

Students can reference Analog Inputs, Using Relays to Control Motor Direction Building Blocks. Introduction to the PLC, Wiring the PLC, Wiring Inputs, Wiring Outputs, Setting up the Programming Environment, Setting up Communication, Introduction to a Project, Writing a First Program, PIR Sensor-Motion Detector and Counters. for specific commands to use in the elevator control system.

Teams discuss how their elevator control systems should be tested. The groups decide what components will be tested and how the team will know when their design achieves the test requirements.

Day 8-10
Key Question: How can we begin to design our elevator control system model?

Teams discuss their proposed elevator control systems and how to achieve the design given the approved design brief they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the elevator device and programming scheme. Components are available in the Do Engineering (https://drive.google.com/open?id=1r_sULTtpb_WBzxLx5kXzaB7kGTn4Rj_h) kits. They must also decide on sensors, wiring, and programing. They utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the elevator control system design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams discuss how the various designs and placement of sensors work and that the designs created will meet the elevator control system requirements and the performance will be within the specifications established

Day 11-13
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs elements created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team final design. It could be a single design or contain elements of several designs. Once the decision is made the students develop a plan for creating the team prototype using PLC technology. They need to create a design that incorporates their ideas. Once the final plan is completed they will create a prototype program. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin programming and testing to see how they are communicating with the various sensors they selected. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 14-16
Key Question: How do we build and test our designs?

Students assemble their prototype elevator control system. When students encounter problems assembling their prototype they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Once the working prototype is assembled, testing can begin to see if the model meets the stated design requirements. Students begin runs of the process to check the accuracy of their systems. They gather data on tests to show how accurate the system is and how the various functions are performing. Students discuss results of their initial testing and propose improvements to the system.

Day 17-18
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to the clients. The deliverables will include the prototype, program design, and information about the design process and how they solved many of the issues they encountered. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 19
Key Question: How do we convey our ideas?

Student teams present their solutions to the authentic audience one at a time. Students display the completed elevator control system model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their design.

Vocabulary:

Analog
Closed loop programming
Connection Terminals
Counter
CPU
Digital
DIN Rail
Dual axis
In_Range
Input
L Terminal
Ladder Logic
Load
Logic
M Terminal
Network
Normally Closed
Normally Open
Open Loop programming
Organizational Blocks
Output
Phototransistor
Photovoltaic
PIR Sensor
PLC
Power Supply
Power Terminals
Schematic
Set Reset Flip Flop
Single Axis
Switch
Tag Table
Timers
Wiring

Resources:

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

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- https://engineering.mit.edu/engage/ask-an-engineer/whats-the-difference-between-ac-and-dc/
- https://www.school-for-champions.com/science/dc.htm#.W372zehKguU
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- https://whatis.techtarget.com/definition/DC-direct-current
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- https://www.allaboutcircuits.com/textbook/direct-current/chpt-3/importance-electrical-safety/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
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- https://www.youtube.com/watch?v=088IRtGAWbg
- https://www.youtube.com/watch?v=8T5PlDdltmo

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- https://euroec.by/assets/files/siemens/s71200_easy_book_en-US_en-US.pdf
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://library.automationdirect.com/understanding-ladder-logic/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/ladder-diagrams/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/permissive-interlock-circuits/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/motor-control-circuits/
- http://www.plcacademy.com/ladder-logic-tutorial/
- https://www.techopedia.com/definition/20292/ladder-logic

Logic

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- https://www.allaboutcircuits.com/textbook/digital/chpt-6/digital-logic-functions/
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PLC

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- http://www.plcdev.com/how_plcs_work
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- http://www.plctutor.com/plc-components.html
- http://www.plcdev.com/book/export/html/9
- https://www.amci.com/industrial-automation-resources/plc-automation-tutorials/what-plc/
- https://www.ecmweb.com/content/troubleshooting-plcs
- https://unitronicsplc.com/what-is-plc-programmable-logic-controller/

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Project: Parking Lot Gate Control

Introduction:

It has been estimated that 81.5 million passenger cars will be produced this year. These will join the 1.2 billion already on the world's roads. In the US alone, there are 265 million cars or almost one for every adult. They are essential for modern life style. The issue of where to park these cars in congested areas is reaching a critical point.

Purpose of the Project:

The purpose of the Parking Lot Gate Control project is to introduce students to logic and decision making. Students will apply decision making elements such as State Diagrams and Flow Charts to understand the logic flow in a program. These skills will allow students to define the logic required for events to occur.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Science and engineering professionals use data and graphical analysis in making decisions.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The Engineering Design Process is sometimes referred to as the sequential actions of research, design, build, evaluate; then redesign, and communicate.
- Engineering professionals design solutions and communicate the solutions through graphics and pictures.

- Engineers use integrity and ethics when communicating ideas, including citing sources of information.
- In all systems, there is a tradeoff between performance and complexity. Higher complexity is generally associated with higher cost; hence the shortened form of the syllogism is performance versus cost.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.
- Electricity is a form of energy caused by the movement of charged particles. It is often used to transfer energy from one place to another.
- The first law of thermodynamics (conservation of energy and matter) states that output power of a system is always less than the power supplied to the system.
- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
- “Green Principles” of design are used for eventual disassembly and resource recovery and is referred as Product Lifecycle Management (PLM).
- A Programmable Logic Controller (PLC) is a hardened computer used for industrial automation. PLCs can automate a process, machine function, or even an entire production line.
- The term “Logic” is based upon the mathematical system called Boolean Algebra named after George Boole (Born November 2, 1815-Died December 8, 1864) who was a self-taught English mathematician and philosopher who invented this form of algebra where values are either True or False where rules are created to consistently arrive at desired values.
- The ability to collect data, transform them into information, and use that information to improve an existing process is an enabling skill for Lean manufacturing.
- Applying automated control systems to existing manual processes can dramatically improve quality and reduce the amount of human (manual) time required.
- Electronic sensors detect and transform real-world phenomena into information that is used by computers to control valves, pumps, and other industrial equipment.
- Timers allow programmers to design and control specialized clocks to turn machinery on or off for specific amounts of time.
- Keeping track of events as they occur can be accomplished using logic programs called counters.
- Analog inputs for such things as temperature, pressure, speed, etc., are voltage values that can be converted into a digital value to be stored and used by a computer.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://youtu.be/HG5CBMzPPEY
https://f1.media.brightcove.com/12/1813624294001/1813624294001_4870177341001_cq5-7144884026341300074building-technologies-security-manifest-en.mp4?pubId=1813624294001&videoId=4870162980001

Outline:

- Documentation
  - Engineering Notebook
  - Documentation object to be designed
- Programmable Logic Controllers (PLC)
  - Basic electricity, multimeter, schematics, Ohm's law
  - Setup
  - Inputs
  - Outputs
  - Logic
  - Timers
  - Counters
- Evaluation
  - Testing of the ability to open the gate with the correct combination of inputs
- Communication
  - Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Design for Manufacturing

- Understand and apply Statistical Process Control (SPC) to acquire quality control.

Design for Assembly

- Create a management plan that includes quality planning, quality control, quality assurance, and quality improvement for an advanced manufacturing environment.

Automation with Programmable Logic Controllers (PLCs)

- Design and analyze an electrical system to efficiently convert, transform, and transmit electricity to where it is needed.
- Research and specify electrical devices necessary to provide needed power.
- Apply machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.
- Use flow charts and diagrams to apply logic in the design of control programs.

Applying Logic Software (TIA Portal) to Create Problem Solutions

- Design a system of elements that manages power to accomplish a task involving defined movement.
- Design a control system to vary the speed and performance of a motor by utilizing feedback from the system to gain the most efficiency possible.
- Formulate a system to utilize data collection and analysis to maintain and improve product quality and provide adequate confidence that the product will satisfy design requirements.
- Design and analyze the application of machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.

Business of Manufacturing

- Research and evaluate the new approaches of rapid development and deployment of products that saves time and is more efficient.
- Create a management plan including quality planning, quality control, quality assurance and quality improvement for an advance manufacturing environment.

College and Career Readiness Math Standards

Creating Equations

CED.A1 Create equations and inequalities in one variable and use them to solve problems.

CED.A.2 Create equations in two or more variables to represent relationships between quantities

CED.A.3 Represent constraints by equations or inequalities, and by systems of equations and/or inequalities, and interpret solutions as viable or nonviable options in a modeling context
CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Create equations that describe numbers or relationships CED
A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Quantities
Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Making Inferences & Justifying Conclusions
IC.A.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population.
IC.B.3 Recognize the purposes of and differences among sample surveys, experiments, and observational studies; explain how randomization relates to each.

Reading Standards for Literacy in History/Social Studies 9-10
Key Ideas and Details
1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.
3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas
7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.
9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity
10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10
Text Types and Purposes
1. Write arguments focused on *discipline-specific content.*
2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:

Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 3:
Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 5:
Students will develop an understanding of the effects of technology on the environment.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 14:
Students will develop an understanding of and be able to select and use medical technologies.

STL Standard 16:
Students will develop an understanding of and be able to select and use energy and power technologies.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Parking Lot Control

Essential Question:

How do we create a program to allow a gate to open with the correct inputs?

Student Scenario:

Your company, Parking Solutions, Inc., services parking lots in high demand locations. One of your clients would like their employees to be able to enter a code and open the parking lot gate provided the buttons are pressed in the correct sequence. Your team has been assigned to create a working prototype. The model should have five switches, only four of them will be used in the combination. If the incorrect key or correct keys are pressed out of order the lock must reset and the gate remains closed.

The design requirements are as follows:

- The program must read the switches and the order they are pressed.
- The gate logic must look at the order the switches are pressed and reset if the wrong sequence or keys are pressed.
- The gate should rise after the fourth correct switch is pressed.
- After 15 seconds the gate should automatically close again

Your team's design will be presented using a working model of the gate control system controlled by the PLC. This will result in a gate that responds to the employee's code which opens the gate when the correct combination is entered but remain secure in all other instances.

The research and learning activities are designed to help students:

- Learn the basic principles of PLC control
- Apply digital logic to determine the order and sequences of switches
- Utilize Boolean logic to simplify the parameters
- Apply understanding of Double Pole Double Throw (DPDT) relays for use in reversing motor control

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design
- Sketches of the device and planning for programming
- Descriptions of the sensors utilized and where they should be positioned
- Working prototype
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1

Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2
Key Question: How do we get started in the design process?

The teams will be responsible for researching Boolean logic, flow charts, and state diagrams as they apply to planning ladder logic to be used with PLCs. Teams need to research the use of Set Reset (SR) Flip Flops to create resettable logic needed for this project.

The student teams discuss possible gate control systems including:

- What kinds of logic might we need to use?
- How will we know an incorrect switch is pressed?
- How will our logic work?
- Does the gate close on its own?
- What are the basic electrical safety issues?
- Will the model meet the stated design requirements?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information, find tutorials about individual topics, and to find out how the software accomplishes basic features. Students can search for design elements they might want to incorporate. This can be accessed from the help menu in the TIA Portal software.

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the parking lot gate control system. Other tutorials in the resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3-7
Key Question: How do we get started on our individual designs?

First, student teams brainstorm components of their design. Next, create a written description of what the program must accomplish. Add this to the team's design brief to be included with the sketches of the location of sensors. Include operating requirements as well as expected logic signals. They then meet with the client who will need to sign off on the design proposal before programming and model building begins. The client can be the teacher or an authentic advisor. Students should work through the tutorials on Logic and Decision Making and Designing Programs for Problems.

This will take several days to work through these necessary basics.

Students can reference Analog Inputs, Using Relays to Control Motor Direction Building Blocks. Introduction to the PLC, Wiring the PLC, Wiring Inputs, Wiring Outputs, Setting up the Programming Environment, Setting up Communication, Introduction to a Project, Writing a First Program, PIR Sensor-Motion Detector and Counters for specific commands to use in the Parking Lot Gate control system.

Teams discuss how their parking lot gate control systems should be tested. The groups decide what components will be tested and how the team will know when their design achieves the test requirements.

Day 8-10
Key Question: How can we begin to design our parking lot gate control system model?

Teams discuss their proposed parking lot gate control systems and how to achieve the design consistent with the approved design brief. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the parking lot gate device and programming scheme. Components are available in the Do Engineering (https://drive.google.com/open?id=1r_sULTtpb_WBzxLx5kXzaB7kGTn4Rj_h). They must also decide on sensors, wiring, and programming. The team utilizes the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the parking lot gate control system design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams discuss how the various designs and placement of sensors work and that the designs created will meet the parking lot gate control system requirements and the performance will be within the specifications established.

Day 11-13
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs elements created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team final design. It could be a single design or contain elements of several designs. Once the decision is made the students develop a plan for creating the team prototype using PLC technology. They need to create a design that incorporates their ideas. Once the final plan is completed they will create a prototype program. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin programming and testing to see how they are communicating with the various sensors they selected. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 14-16
Key Question: How do we build and test our designs?

Students assemble their prototype parking lot gate control system. When students encounter problems assembling their prototype they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Once the working prototype is assembled testing can begin to see if the model meets the stated design requirements. Students begin runs of the process to check the accuracy of their systems. They gather data on tests and to show how accurate the system is and how the various functions are performing. Students discuss results of their initial testing and propose improvements to the system.

Day 17-18
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to their client. The deliverables will include the prototype, program design, and information about the design process and how they solved many of the issues they encountered. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 19
Key Question: How do we convey our ideas?

Students can present their solutions to the authentic audience one at a time. Students display the completed parking lot gate control system model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

Analog
And Gates
Boolean Logic
Closed loop programming
Connection Terminals
Counter
CPU
Digital
DIN Rail
Dual axis
Exclusive Or gates
Flow charts
In_Range
Input
L Terminal
Ladder Logic
Load
Logic
M Terminal
Nand gates
Network
Nor gates
Normally Closed
Normally Open
Open Loop programming
Or Gates
Organizational Blocks
Output
Phototransistor
Photovoltaic
PIR Sensor
PLC
Power Supply
Power Terminals
Schematic
Set Reset (SR) Flip Flop
Single Axis
State diagrams
Switch

Tag Table
Tilt angle
Timers
Wiring

Resources:

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

Electricity

- https://www.allaboutcircuits.com/textbook/direct-current/
- https://learn.sparkfun.com/tutorials/alternating-current-ac-vs-direct-current-dc
- https://engineering.mit.edu/engage/ask-an-engineer/whats-the-difference-between-ac-and-dc/
- https://www.school-for-champions.com/science/dc.htm#.W372zehKguU
- http://sinovoltaics.com/learning-center/basics/direct-current-dc-power-definition-and-applications/
- https://whatis.techtarget.com/definition/DC-direct-current
- http://macao.communications.museum/eng/exhibition/secondfloor/MoreInfo/2_3_1_DCCircuit.html
- https://www.khanacademy.org/science/ap-physics-1/ap-circuits-topic/introduction-to-dc-circuits-ap/a/circuit-introduction
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-1/static-electricity/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-2/voltage-current-resistance-relate/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-3/importance-electrical-safety/

- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-9/analog-and-digital-signals/

Ladder Logic

- https://euroec.by/assets/files/siemens/s71200_easy_book_en-US_en-US.pdf
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://library.automationdirect.com/understanding-ladder-logic/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/ladder-diagrams/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/permissive-interlock-circuits/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/motor-control-circuits/
- http://www.plcacademy.com/ladder-logic-tutorial/
- https://www.techopedia.com/definition/20292/ladder-logic

Logic

- http://www.plcdev.com/book/export/html/9
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/digital-logic-functions/
- https://www.i-programmer.info/babbages-bag/235-logic-logic-everything-is-logic.html
- https://academo.org/demos/logic-gate-simulator/
- https://sciencedemos.org.uk/logic_gates.php
- http://www.cburch.com/logisim/

Parking lot gates

- https://www.youtube.com/watch?v=HMROEMSc-Kk
- https://www.youtube.com/watch?v=BrSoELVx2Ss
- https://www.youtube.com/watch?v=tbx54qjVm3A
- https://www.youtube.com/watch?v=B3amVXRmZhI
- https://www.youtube.com/watch?v=t_7MRNkCBnk

PLC

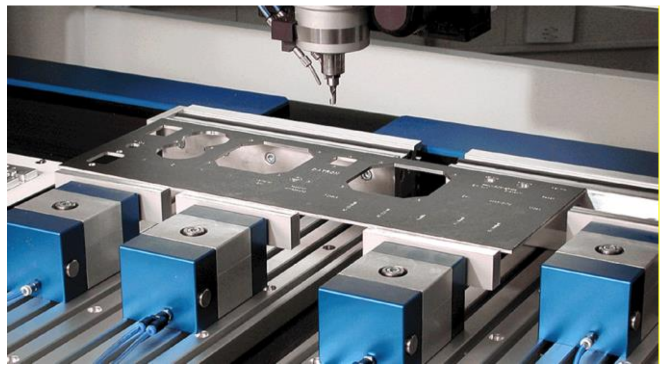
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://www.youtube.com/watch?v=ReTtgzN-Dm
- chttps://unitronicsplc.com/what-is-plc-programmable-logic-controller/
- https://www.industry.usa.siemens.com/automation/us/en/automation-systems/industrial-automation/plc/pages/plc.aspx
- http://www.plcdev.com/how_plcs_work
- https://www.elprocus.com/programmable-logic-controllers-and-types-of-plcs/
- http://www.plctutor.com/plc-components.html
- http://www.plcdev.com/book/export/html/9

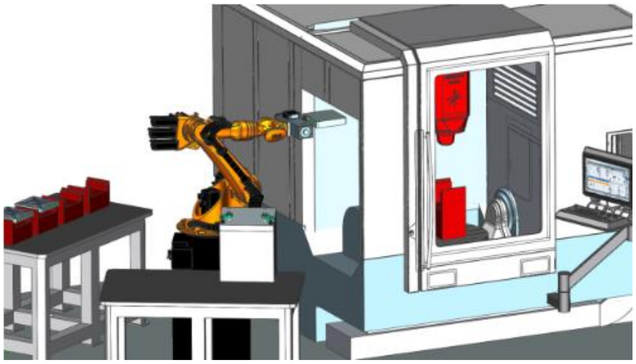
- https://www.amci.com/industrial-automation-resources/plc-automation-tutorials/what-plc/
- https://www.ecmweb.com/content/troubleshooting-plcs
- https://unitronicsplc.com/what-is-plc-programmable-logic-controller/

State Diagrams and Flow Charts

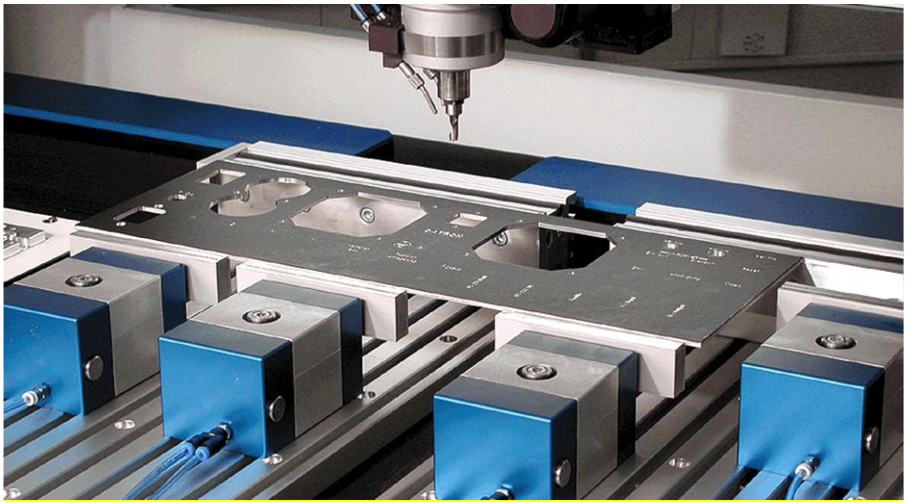
- https://www.lucidchart.com/pages/uml-state-machine-diagram
- https://www.geeksforgeeks.org/unified-modeling-language-uml-state-diagrams/
- http://www.agilemodeling.com/artifacts/stateMachineDiagram.htm
- http://www.cs.unc.edu/~stotts/145/CRC/state.html
- https://www.visual-paradigm.com/guide/uml-unified-modeling-language/what-is-state-machine-diagram/
- https://www.youtube.com/watch?v=L9UCsQxuWmw
- https://www.lucidchart.com/pages/what-is-a-flowchart-tutorial
- http://www.breezetree.com/articles/how-to-flow-chart-in-excel.htm
- https://www.gliffy.com/blog/the-comprehensive-guide-to-flowcharts

Projects Quarter 4

Pneumatics Solenoids, Schematics, Electricity, Hand shaking • Automated Pneumatic Clamping System	
Pneumatics Solenoids, Schematics, Electricity, Hand shaking • Automatic Pneumatic Feeder System	

Pneumatics Solenoids, Schematics, Electricity, Hand shaking • Conveyor Sorting System	
Pneumatics Solenoids, Schematics, Electricity, Hand shaking, Design, CNC and Automation • Automated Workcell for CNC Mill	

Project: Automated Pneumatic Clamping System



Introduction:

Workholding is a term used to describe the hold-down and clamping devices used to keep stock, parts, and product from moving around while machining or other work is performed. A vise or clamps are examples. Automating the clamping process allows for greater accuracy in the machining process creating fewer errors and faster part creation. Frequently pneumatics is used to accomplish this task. By utilizing air pressure to operate clamps, vises or vacuum tables allow for automation of the process. Objects can be placed in the proper location and the movement of vise jaws or clamps locates and secures the parts exactly where intended.

Purpose of the Project:

The purpose of the automated pneumatic clamping system project is to introduce students to logic and decision making. Students will apply decision making elements such as State Diagrams and Flow Charts to design the logic flow in a program. These skills will be used by the students to define the logic required for events to occur.

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Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Science and engineering professionals use data and graphical analysis in making decisions.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
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- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
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- A Programmable Logic Controller (PLC) is a hardened computer used for industrial automation. PLCs can automate a process, machine function, or even an entire production line.
- The term “Logic” is based upon the mathematical system called Boolean Algebra named after George Boole (Born November 2, 1815-Died December 8, 1864) who was a self-taught English mathematician and philosopher who invented this form of algebra where values are either True or False where rules are created to consistently arrive at desired values.
- The ability to collect data, transform them into information, and use that information to improve an existing process is an enabling skill for Lean manufacturing.
- Applying automated control systems to existing manual processes can dramatically improve quality and reduce the amount of human (manual) time required.
- Electronic sensors detect and transform real-world phenomena into information that is used by computers to control valves, pumps, and other industrial equipment.

- Timers allow programmers to design and control specialized clocks to turn machinery on or off for specific amounts of time.
- Keeping track of events as they occur can be accomplished using logic programs called counters.
- Analog inputs for such things as temperature, pressure, speed, etc., are voltage values that can be converted into a digital value to be stored and used by a computer.
- Computer controlled automated systems often use a solenoid valve to open and close a valve to control the flow of a medium such as pressurized gas. A solenoid valve is an electromechanical device where electrical current is used to cause movement.
- The Ideal Gas Law describes the relationship of temperature, pressure, and volume. A subset of this law is called Charles Law which describes how gasses behave when heated. An experiment: fill a small balloon with air and tie off the end. Place the balloon in cold water and watch the size (volume) of the balloon decrease. Then place the balloon in warm water and watch the size (volume) of the balloon increase. Because the volume of a fixed mass of gas is directly proportional to the temperature, the size (volume) of the balloon changes with temperature. In solid vessels the pressure of the gas can be changed to produce movement. In a technology setting, pneumatic cylinders are devices that are controlled by a computer to convert the pressure of compressed gasses to a force acting in a specified direction. This device is often called an actuator.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://www.youtube.com/watch?v=adnxSuVJMH4
https://www.youtube.com/watch?v=_fR3JjSOvY8&fs=1&rel=0&enablejsapi=1&playerapiid=ytPlayerID0EACAAABAAB&wmode=transparent

Outline:

- Documentation
  - Engineering Notebook
  - Documentation object to be designed
- Programmable Logic Controllers (PLC)
  - Basic electricity-Multimeter schematics/ Ohms law
  - Setup
  - Inputs
  - Outputs
  - Logic
  - Timers
  - Counters
- Workcell Creation
  - Pneumatics
  - Solenoids

Schematics
Electricity
Hand shaking

Evaluation

Testing of the ability to clamp a work piece securely and accurately for machining, using the correct combination of inputs

Communication

Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation, and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Reverse Engineering

- Apply design principles which include the accommodation for disassembly and resource recovery.
- Research and apply current business practices that lead to new product development or improvement of products or procedures including the use of rapid development and deployment to be faster to market.
- Analyze the design attributes of an existing product by disassembling it into its parts, use precision measurement tools to create sketches & drawings of the parts, identify the materials and processes used in manufacturing, and create a new and improved design.
- Utilize convergent modeling to capture data and rapidly create new parts to fit existing scans.
- Collaborate with teams to combine models and parametrically create solutions.
- Utilize rapid prototyping/additive manufacturing to create highly complex parts designed in a CAD system.

Design for Manufacturing

- Apply the principles of design for manufacturing, enabling the efficient and effective production of products.
- Develop a logical argument for selecting the tools, machines and labor necessary to produce finished goods from raw materials.
- Create a strategy to increase efficiency and decrease waste by receiving goods only as they are needed in the production process, thereby reducing inventory costs and reducing the impact of water and other natural resource consumption.
- Create a plan for protecting the safety, health and welfare of people engaged in the manufacturing environment.
- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.
- Understand and apply Statistical Process Control (SPC) to acquire quality control.
- Research and apply knowledge of material properties to product design and development.

Design for Assembly

- Apply engineering design of components to assure alignment for assembly.
- Create a management plan that includes quality planning, quality control, quality assurance, and quality improvement for an advanced manufacturing environment.
- Research, construct, and evaluate a plan for an assembly line or work cell.

Computer Numeric Control (CNC) of Machines

- Apply Cartesian Coordinates to create toolpaths for machine tools.
- Research and apply proper cutting tool speeds, feeds, and directions for manufacturing.
- Create simple Numeric Control (NC) part programs using a text editor or a CAM package.
- Analyze NC part program files to identify and correct errors.
- Analyze part geometry to select appropriate cutting tools and fixturing devices needed to create a part using a CNC machine.
- Edit the tool library of a CNC machine program to establish tool offset values.

Applying CAM Software to Problem Solutions

- Design and prepare 3D models with appropriate units for use in toolpath generation.
- Setup a CAM package by editing the material and tool libraries.
- Generate tool paths from a CAD program and edit NC part program files to identify and correct errors.

Automation with Programmable Logic Controllers (PLCs)

- Design and analyze an electrical system to efficiently convert, transform, and transmit electricity to where it is needed.
- Research and specify electrical devices necessary to provide needed power.
- Apply machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.
- Use flow charts and diagrams to apply logic in the design of control programs.

Applying Logic Software (TIA Portal) to Create Problem Solutions

- Design a system of elements that manages power to accomplish a task involving defined movement.
- Design a control system to vary the speed and performance of a motor by utilizing feedback from the system to gain the most efficiency possible.
- Formulate a system to utilize data collection and analysis to maintain and improve product quality and provide adequate confidence that the product will satisfy design requirements.
- Design and analyze the application of machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.

Pneumatics Design and Control

- Construct systems that efficiently utilize a fluid (liquid or gas) under pressure to generate, transmit, and control power.
- Design an integrated system of machines, machine tools, jigs, fixtures, instruments, and control programs to produce needed parts.
- Utilize jigs, fixtures, drill guides, gauges, and other manufacturing and assembly tools.
- Research, construct and evaluate a plan for an assembly line or work cell.
- Identify systems, sub-systems and typical components of an automated manufacturing operation.
- Apply the necessary safety precautions associated with a fully automated system.

Business of Manufacturing

- Research and categorize the activities that a business conducts to make discoveries that can either lead to the development of new products or procedures, or to improve existing products or procedures.
- Research and evaluate the new approaches of rapid development and deployment of products that saves time and is more efficient.
- Review and evaluate the benefits of a plan for an assembly line or work cell.
- Create a strategy to increase efficiency and decrease waste by receiving inventory just in time for the production process to reduce costs and reduce use of natural resources.

- Evaluate the use of production organization, planning, and resources, both human and capital, as well as regulatory requirements, to successfully and efficiently bring a product to market.
- Create a management plan including quality planning, quality control, quality assurance, and quality improvement for an advance manufacturing environment.
- Create a plan for protecting the health and safety of the people engaged in a manufacturing environment.

College and Career Readiness Math Standards

Creating Equations

CED.A1 Create equations and inequalities in one variable and use them to solve problems.

CED.A.2 Create equations in two or more variables to represent relationships between quantities

CED.A.3 Represent constraints by equations or inequalities, and by systems of equations and/or inequalities, and interpret solutions as viable or nonviable options in a modeling context

CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Making Inferences & Justifying Conclusions

IC.A.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population.

IC.B.3 Recognize the purposes of and differences among sample surveys, experiments, and observational studies; explain how randomization relates to each.

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.

3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.

9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*

2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:
1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:
Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 3:
Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 5:
Students will develop an understanding of the effects of technology on the environment.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 14:
Students will develop an understanding of and be able to select and use medical technologies.

STL Standard 16:
Students will develop an understanding of and be able to select and use energy and power technologies.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
[Argumentative_Pursuasive]
[Informational_Explanatory]

Individual Project Rubric:
[Automated Pneumatic Clamping System Rubric]

Essential Question:

How do we design and automate a pneumatic clamping system?

Student Scenario:

You are a member of a design team employed by Workholding Associates. A client of your company has requested a proposal for a design project. Currently, the client's employees mount work blanks on their machines manually for every operation. The company feels the addition of an automated clamping system will save significant operator setup time and improve accuracy. They would like a proposal for designing the system, setup, and training.

Your team will build a prototype clamping system that will automatically locate and hold down the work blank. You can use existing parts or design and print new components to utilize in the new system. You will design, document, and create a program to control the system. You will perform a test to time how long a manual setup takes to determine the time savings. This is important as the company is implementing a lean manufacturing program and this will help them justify the costs.

The design requirements are as follows:

- The prototype must locate the work piece accurately and securely and hold it securely for machining.
- The program must wait for a signal before applying pneumatic pressure.
- Once clamped there must be a pause to simulate the running of the milling machine.
- When the milling machine is done (simulated) the clamps must release and the part must be easily removed.
- A ***required*** sensor must identify when the component is clamped tightly.

Your team's design will be presented using a working model of the pneumatic clamping system controlled by the PLC. This model will demonstrate the speed and accuracy of the clamping system.

The research and learning activities are designed to help students:

- Learn the basics of pneumatics
- Learn the basic principles of PLC control
- Apply digital logic to determine the order and sequences of switches
- Utilize Boolean logic to simplify the parameters

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design.
- Sketches of the device and planning for programming
- Descriptions of the sensors utilized and where they should be positioned
- Working prototype
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1

Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2

Key Question: How do we get started in the design process?

The teams will be responsible for researching pneumatics, cylinders, solenoids, Boolean Logic, flow charts, and state diagrams as they apply to planning ladder logic to be used with PLCs. Teams need to research the use of SR flip flops to create resettable logic needed for this project.

The student teams discuss possible pneumatic clamping control systems including:

- What kinds of logic might we need to use?
- How will we know when it is safe to clamp the part?
- Will the model meet the stated design requirements?
- How will our logic work?

- Does the pneumatic clamping system open when procedure ends?
- What are the basic electrical and pneumatic safety issues?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information, find tutorials about individual topics, and to find out how the software accomplishes basic features. Students can search for design elements they might want to incorporate. This can be accessed from the help menu in the TIA Portal software.

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the automated pneumatic clamping system. Other tutorials in the resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3-7
Key Question: How do we get started on our individual designs?

First student teams brainstorm components of their design. Next create a written description of what the program must accomplish. Add this to the team's design brief to be included with the sketches of the location of sensors. Include operating requirements as well as expected logic signals. They then meet with the client who will need to sign off on the design proposal before programming and automatic clamping model building begins. The client can be the teacher or an authentic advisor.

Students should work through the tutorials on Pneumatics and Control. It will take two days to work through these necessary basics. Have students bring a plastic soda bottle to school for use as a low pressure tank for the pneumatic system they build.

This will take several days to work through these necessary basics.

Students can reference Logic and Decision Making, Designing Programs for Problems, Analog Inputs, Using Relays to Control, Motor Direction, Building Blocks, Introduction to the PLC, Wiring the PLC, Wiring Inputs, Wiring Outputs, Setting up the Programming Environment, Setting up Communication, Introduction to a Project, Writing a First Program, PIR Sensor-Motion Detector and Counters for specific commands to use in the automated pneumatic clamping system.

Teams discuss how their automated pneumatic clamping control systems should be tested. The groups decide what components will be tested and how the team will know when their design achieves the test requirements.

Day 8-10
Key Question: How can we begin to design our automated pneumatic clamping system model?

Teams discuss their proposed automated pneumatic clamping control systems and how to achieve the design given the approved design brief they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the pneumatic clamping device and programming scheme. Components are available in the Do Engineering and the custom pneumatics kits. They must also decide on sensors, wiring, and programming. Students utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the automated pneumatic clamping control system design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams discuss how the various designs and placement of sensors work and that the designs created will meet the automated pneumatic clamping control system requirements and the performance will be within the specifications established. Parts are available in the Do-Engineering kit. (https://drive.google.com/open?id=1r_sULTtpb_WBzxLx5kXzaB7kGTn4Rj_h)

Day 11-13
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs elements created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team's final design. It could be a single design or contain elements of several designs. Once the decision is made the students develop a plan for creating the team prototype using PLC technology. They need to create a design that incorporates their ideas. Once the final plan is completed they will create prototype program. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin programming and testing to see how they are communicating with the various sensors they selected. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 14-16
Key Question: How do we build and test our designs?

Students assemble their prototype automated pneumatic clamping control system. When students encounter problems assembling their prototype they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Once the working prototype is assembled, testing can begin to see if the model meets the stated design requirements. Students begin runs of the process to check the accuracy of their systems. They gather data on tests and to show how accurate the system is and how the various functions are performing. Students discuss results of their initial testing and propose improvements to the system. Remind students of the requirement to show significant time saved and/or accuracy improved using the new system compared to the current manual process.

Day 17-18
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to the client. The deliverables will include the prototype, program design, and information about the design process and how they solved many of the issues they encountered. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 19
Key Question: How do we convey our ideas?

Students can present their solutions to the authentic audience one at a time. Students display the completed automated pneumatic clamping control system model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

Analog
And Gates
Boolean Logic
Closed loop programming
Connection Terminals
Counter
CPU
Cylinder
Digital
DIN Rail
Dual axis
Exclusive Or gates
Flow charts
In_Range
Input
L Terminal
Ladder Logic
Load
Logic
M Terminal
Nand gates
Network
Nor gates
Normally Closed
Normally Open
Open Loop programming
Or Gates
Organizational Blocks
Output
Phototransistor
Photovoltaic
PIR Sensor
PLC
Power Supply
Power Terminals
Schematic
Set Reset Flip Flop
Single Axis
Solenoid
State diagrams
Switch
Tag Table
Tilt angle
Timers
Wiring

Resources:

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

Electricity

- https://www.allaboutcircuits.com/textbook/direct-current/
- https://learn.sparkfun.com/tutorials/alternating-current-ac-vs-direct-current-dc
- https://engineering.mit.edu/engage/ask-an-engineer/whats-the-difference-between-ac-and-dc/
- https://www.school-for-champions.com/science/dc.htm#.W372zehKguU
- http://sinovoltaics.com/learning-center/basics/direct-current-dc-power-definition-and-applications/
- https://whatis.techtarget.com/definition/DC-direct-current
- http://macao.communications.museum/eng/exhibition/secondfloor/MoreInfo/2_3_1_DCCircuit.html
- https://www.khanacademy.org/science/ap-physics-1/ap-circuits-topic/introduction-to-dc-circuits-ap/a/circuit-introduction
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-1/static-electricity/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-2/voltage-current-resistance-relate/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-3/importance-electrical-safety/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-9/analog-and-digital-signals/

Ladder Logic

- https://euroec.by/assets/files/siemens/s71200_easy_book_en-US_en-US.pdf
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://library.automationdirect.com/understanding-ladder-logic/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/ladder-diagrams/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/permissive-interlock-circuits/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/motor-control-circuits/
- http://www.plcacademy.com/ladder-logic-tutorial/
- https://www.techopedia.com/definition/20292/ladder-logic

Logic

- http://www.plcdev.com/book/export/html/9
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/digital-logic-functions/
- https://www.i-programmer.info/babbages-bag/235-logic-logic-everything-is-logic.html
- https://academo.org/demos/logic-gate-simulator/
- https://sciencedemos.org.uk/logic_gates.php
- http://www.cburch.com/logisim/

PLC

- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://www.youtube.com/watch?v=ReTtgzN-Dm
- chttps://unitronicsplc.com/what-is-plc-programmable-logic-controller/
- https://www.industry.usa.siemens.com/automation/us/en/automation-systems/industrial-automation/plc/pages/plc.aspx
- http://www.plcdev.com/how_plcs_work
- https://www.elprocus.com/programmable-logic-controllers-and-types-of-plcs/
- http://www.plctutor.com/plc-components.html
- http://www.plcdev.com/book/export/html/9
- https://www.amci.com/industrial-automation-resources/plc-automation-tutorials/what-plc/
- https://www.ecmweb.com/content/troubleshooting-plcs
- https://unitronicsplc.com/what-is-plc-programmable-logic-controller/

Pneumatic Clamping

- https://www.youtube.com/watch?v=eY5cAYudchw
- https://www.youtube.com/watch?v=5P2pk54wPlo
- https://www.youtube.com/watch?v=snlR6C1ZCo0
- https://www.youtube.com/watch?v=8NKKit18cX8
- https://youtu.be/5P2pk54wPlo
- https://youtu.be/9FGJQ6WRzPY

- https://www.youtube.com/watch?v=Cs0vy42gUkQ
- https://www.youtube.com/watch?v=40WUbK2gCxI
- https://www.datron.com/blog/cnc-workholding-for-milling-machines/

State Diagrams and Flow Charts

- https://www.lucidchart.com/pages/uml-state-machine-diagram
- https://www.geeksforgeeks.org/unified-modeling-language-uml-state-diagrams/
- http://www.agilemodeling.com/artifacts/stateMachineDiagram.htm
- http://www.cs.unc.edu/~stotts/145/CRC/state.html
- https://www.visual-paradigm.com/guide/uml-unified-modeling-language/what-is-state-machine-diagram/
- https://www.youtube.com/watch?v=L9UCsQxuWmw
- https://www.lucidchart.com/pages/what-is-a-flowchart-tutorial
- http://www.breezetree.com/articles/how-to-flow-chart-in-excel.htm
- https://www.gliffy.com/blog/the-comprehensive-guide-to-flowcharts

Project: Automatic Pneumatic Feeder System

Introduction:

Feeders are an important component of automated production. A steady stream of parts allows machinery to run continuously. Feeders are used to deliver components or work pieces in the correct position at the right time to be used by assemblers. These repetitive tasks are handled by machines. People keep track of the process using statistical process control (SPC) and other sampling and testing methods to ensure that the machine is in control and delivering parts within specifications.

Purpose of the Project:

The purpose of the automatic pneumatic feeder system project is to introduce students to logic and decision making. Students will apply decision making elements such as State Diagrams and Flow Charts to design the logic flow in a program. These skills will be used by the students to define the logic required for events to occur.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Science and engineering professionals use data and graphical analysis in making decisions.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The Engineering Design Process is sometimes referred to as the sequential actions of research, design, build, evaluate; then redesign, and communicate.
- Engineering professionals design solutions and communicate the solutions through graphics and pictures.
- Engineers use integrity and ethics when communicating ideas, including citing sources of information.
- In all systems, there is a tradeoff between performance and complexity. Higher complexity is generally associated with higher cost; hence the shortened form of the syllogism is performance versus cost.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.
- Electricity is a form of energy caused by the movement of charged particles. It is often used to transfer energy from one place to another.
- The first law of thermodynamics (conservation of energy and matter) states that output power of a system is always less than the power supplied to the system.
- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
- “Green Principles” of design are used for eventual disassembly and resource recovery and is referred as Product Lifecycle Management (PLM).
- A Programmable Logic Controller (PLC) is a hardened computer used for industrial automation. PLCs can automate a process, machine function, or even an entire production line.
- The term “Logic” is based upon the mathematical system called Boolean Algebra named after George Boole (Born November 2, 1815-Died December 8, 1864) who was a self-taught English mathematician and philosopher who invented this form of algebra where values are either True or False where rules are created to consistently arrive at desired values.
- The ability to collect data, transform them into information, and use that information to improve an existing process is an enabling skill for Lean manufacturing.

- Applying automated control systems to existing manual processes can dramatically improve quality and reduce the amount of human (manual) time required.
- Electronic sensors detect and transform real-world phenomena into information that is used by computers to control valves, pumps, and other industrial equipment.
- Timers allow programmers to design and control specialized clocks to turn machinery on or off for specific amounts of time.
- Keeping track of events as they occur can be accomplished using logic programs called counters.
- Analog inputs for such things as temperature, pressure, speed, etc., are voltage values that can be converted into a digital value to be stored and used by a computer.
- Computer controlled automated systems often use a solenoid valve to open and close a valve to control the flow of a medium such as pressurized gas. A solenoid valve is an electromechanical device where electrical current is used to cause movement.
- The Ideal Gas Law describes the relationship of temperature, pressure, and volume. A subset of this law is called Charles Law which describes how gasses behave when heated. An experiment: fill a small balloon with air and tie off the end. Place the balloon in cold water and watch the size (volume) of the balloon decrease. Then place the balloon in warm water and watch the size (volume) of the balloon increase. Because the volume of a fixed mass of gas is directly proportional to the temperature, the size (volume) of the balloon changes with temperature. In solid vessels the pressure of the gas can be changed to produce movement. In a technology setting, pneumatic cylinders are devices that are controlled by a computer to convert the pressure of compressed gasses to a force acting in a specified direction. This device is often called an actuator.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://f1.media.brightcove.com/12/1813624294001/1813624294001_5371035765001_5371027175001.mp4?pubId=1813624294001&videoId=5371027175001
https://youtu.be/rmJeKpNUpT8?list=PL368BCBB4E866D17F

Outline:

- Documentation
  - Engineering Notebook
  - Documentation object to be designed
- Programmable Logic Controllers (PLC)
  - Basic electricity-Multimeter schematics/ Ohms law
  - Setup
  - Inputs
  - Outputs

Logic
Timers
Counters
Workcell Creation
Pneumatics
Solenoids
Schematics
Electricity
Hand shaking
Evaluation
Testing of the ability to design a feeder system to secure a work piece in the correct location with the desired orientation using the correct combination of inputs

Communication
Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation, and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Reverse Engineering

- Apply design principles which include the accommodation for disassembly and resource recovery.
- Research and apply current business practices that lead to new product development or improvement of products or procedures including the use of rapid development and deployment to be faster to market.
- Analyze the design attributes of an existing product by disassembling it into its parts, use precision measurement tools to create sketches & drawings of

the parts, identify the materials and processes used in manufacturing, and create a new and improved design.
- Utilize convergent modeling to capture data and rapidly create new parts to fit existing scans.
- Collaborate with teams to combine models and parametrically create solutions.
- Utilize rapid prototyping/additive manufacturing to create highly complex parts designed in a CAD system.

Design for Manufacturing
- Apply the principles of design for manufacturing, enabling the efficient and effective production of products.
- Develop a logical argument for selecting the tools, machines and labor necessary to produce finished goods from raw materials.
- Create a strategy to increase efficiency and decrease waste by receiving goods only as they are needed in the production process, thereby reducing inventory costs and reducing the impact of water and other natural resource consumption.
- Create a plan for protecting the safety, health and welfare of people engaged in the manufacturing environment.
- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.
- Understand and apply Statistical Process Control (SPC) to acquire quality control.
- Research and apply knowledge of material properties to product design and development.

Design for Assembly
- Apply engineering design of components to assure alignment for assembly.
- Create a management plan that includes quality planning, quality control, quality assurance, and quality improvement for an advanced manufacturing environment.
- Research, construct, and evaluate a plan for an assembly line or work cell.

Computer Numeric Control (CNC) of Machines
- Apply Cartesian Coordinates to create toolpaths for machine tools.
- Research and apply proper cutting tool speeds, feeds, and directions for manufacturing.
- Create simple Numeric Control (NC) part programs using a text editor or a CAM package.
- Analyze NC part program files to identify and correct errors.

- Analyze part geometry to select appropriate cutting tools and fixturing devices needed to create a part using a CNC machine.
- Edit the tool library of a CNC machine program to establish tool offset values.

Applying CAM Software to Problem Solutions

- Design and prepare 3D models with appropriate units for use in toolpath generation.
- Setup a CAM package by editing the material and tool libraries.
- Generate tool paths from a CAD program and edit NC part program files to identify and correct errors.

Automation with Programmable Logic Controllers (PLCs)

- Design and analyze an electrical system to efficiently convert, transform, and transmit electricity to where it is needed.
- Research and specify electrical devices necessary to provide needed power.
- Apply machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.
- Use flow charts and diagrams to apply logic in the design of control programs.

Applying Logic Software (TIA Portal) to Create Problem Solutions

- Design a system of elements that manages power to accomplish a task involving defined movement.
- Design a control system to vary the speed and performance of a motor by utilizing feedback from the system to gain the most efficiency possible.
- Formulate a system to utilize data collection and analysis to maintain and improve product quality and provide adequate confidence that the product will satisfy design requirements.
- Design and analyze the application of machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.

Pneumatics Design and Control

- Construct systems that efficiently utilize a fluid (liquid or gas) under pressure to generate, transmit, and control power.
- Design an integrated system of machines, machine tools, jigs, fixtures, instruments, and control programs to produce needed parts.
- Utilize jigs, fixtures, drill guides, gauges, and other manufacturing and assembly tools.
- Research, construct and evaluate a plan for an assembly line or work cell.
- Identify systems, sub-systems and typical components of an automated manufacturing operation.
- Apply the necessary safety precautions associated with a fully automated system.

Business of Manufacturing

- Research and categorize the activities that a business conducts to make discoveries that can either lead to the development of new products or procedures, or to improve existing products or procedures.
- Research and evaluate the new approaches of rapid development and deployment of products that saves time and is more efficient.
- Review and evaluate the benefits of a plan for an assembly line or work cell.
- Create a strategy to increase efficiency and decrease waste by receiving inventory just in time for the production process to reduce costs and reduce use of natural resources.
- Evaluate the use of production organization, planning, and resources, both human and capital, as well as regulatory requirements, to successfully and efficiently bring a product to market.
- Create a management plan including quality planning, quality control, quality assurance, and quality improvement for an advance manufacturing environment.
- Create a plan for protecting the health and safety of the people engaged in a manufacturing environment.

College and Career Readiness Math Standards

Creating Equations

CED.A1 Create equations and inequalities in one variable and use them to solve problems.
CED.A.2 Create equations in two or more variables to represent relationships between quantities
CED.A.3 Represent constraints by equations or inequalities, and by systems of equations and/or inequalities, and interpret solutions as viable or nonviable options in a modeling context
CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Making Inferences & Justifying Conclusions

IC.A.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population.
IC.B.3 Recognize the purposes of and differences among sample surveys, experiments, and observational studies; explain how randomization relates to each.

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.

3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.

9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*

2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards
The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:
1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:
Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 3:
Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 5:
Students will develop an understanding of the effects of technology on the environment.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.
STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 14:
Students will develop an understanding of and be able to select and use medical technologies.

STL Standard 16:
Students will develop an understanding of and be able to select and use energy and power technologies.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:
Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Automatic Pneumatic Feeder System

Essential Question:

How can we design a system to automatically deliver a part using pneumatic and other components?

Student Scenario:

You are a member of a design team employed by Automated Feeders. A client of your company, Workholding Associates, has requested a proposal for a design of an automated feeder system to save time and improve accuracy. Currently, the client's employees mount work blanks on their machines manually for every operation. They wish to subcontract the feeder design to Automated Feeders.

Your team will build a prototype feeder system that will automatically position the work blank properly. You can use existing parts or design and print new components to utilize in the prototype feeder system. You will design, document, and create a program to control the system. You will perform a test to time how long a manual setup takes to determine the time savings. This is important as the company is implementing a lean manufacturing program and this will help them justify the costs.

The design requirements are as follows:

- The prototype must feed the blank in the correct position.
- The program must wait for a signal before feeding the next part.
- Once the feeder delivers the part it should clear out of the way and pause while sending a signal to the automated feeder system.
- When the milling machine is done and the automated clamping system releases a signal for the next part should be delivered to the correct position.
- The system must have a sensor to identify the presence of parts in the feeder.

Your team's design will be presented using a working model of the pneumatic feeder system controlled by the PLC. This demonstrates the ability to automatically deliver a part to the correct location.

The research and learning activities are designed to help students:

- Learn the basics of pneumatics
- Learn the basic principles of PLC control
- Apply digital logic to determine the order and sequences of switches
- Utilize Boolean logic to simplify the parameters

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design
- Sketches of the device and planning for programming
- Descriptions of the sensors utilized and where they should be positioned
- Working prototype
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1

Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2

Key Question: How do we get started in the design process?

The teams will be responsible for researching pneumatics, cylinders, solenoids Boolean Logic, flow charts, and state diagrams as they apply to planning ladder logic to be used with PLCs. Teams need to research the use of SR flip flops to create resettable logic needed for this project. Teams should research types of feeder systems.

The student teams discuss possible pneumatic feeder control systems including:

- What kinds of logic might we need to use?
- How will we know when it is safe to deliver the part
- Will the model meet the stated design requirements?
- How will our logic work?
- Does the pneumatic feeder system return to its home position when through?
- What are the basic electrical and pneumatic safety issues?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information find tutorials about individual topics and to find out how the software accomplishes basic features. Students can search for design elements they might want to incorporate. This can be accessed from the help menu in the TIA Portal software.

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the automatic pneumatic feeder system. Other tutorials in the resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3-7
Key Question: How do we get started on our individual designs?

First, student teams brainstorm components of their design. Next create a written description of what the program must accomplish. Add this to the team's design brief. Include operating requirements as well as expected logic signals. They then meet with the client who will need to sign off on the design proposal before programming and model building begins. The client can be the teacher or an authentic advisor.

Students should work through the tutorials on Pneumatics and Control. It will take two days to work through these necessary basics. Have students bring a plastic soda bottle to school for use as a low pressure tank for the pneumatic system they build.

This will take several days to work through these necessary basics.

Students can reference Logic and Decision Making, Designing Programs for Problems, Analog Inputs, Using Relays to Control Motor Direction, Building

Blocks, Introduction to the PLC, Wiring the PLC, Wiring Inputs, Wiring Outputs, Setting up the Programming Environment, Setting up Communication, Introduction to a Project, Writing a First Program, PIR Sensor-Motion Detector and Counters for specific commands to use in the automated pneumatic clamping system.

Teams discuss how their automatic pneumatic feeder control system should be tested. The groups decide which components will be tested and how the team will know when their design achieves the test requirements.

Day 8-10
Key Question: How can we begin to design our automatic pneumatic feeder system model?

Teams discuss their proposed automatic pneumatic feeder control system and how to achieve the design given the approved design brief they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the pneumatic feeder device and programming scheme. Components are available in the Do Engineering and the custom pneumatics kits. A set of instructions for a block feeder can be found in the Do-Engineering manual page 48 to provide some ideas. They must also decide on sensors, wiring, and programing. They utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the automatic pneumatic feeder control system design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams discuss how the various designs and placement of sensors work and that the designs created will meet the automatic pneumatic feeder control system requirements and the performance will be within the specifications they established

Day 11-13
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs elements created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team's final design. It could be a single design or contain elements of several designs. Once the decision is made the students develop a plan for creating the team prototype using PLC technology. They need to create a design that incorporates their ideas. Once the final plan is completed they will create prototype program. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin programming and testing to see how they are communicating with the various sensors they selected. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 14-16
Key Question: How do we build and test our designs?

Students assemble their prototype automatic pneumatic feeder control system. When students encounter problems assembling their prototype they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Once the working prototype is assembled testing can begin to see if the model meets the stated design requirements. Students begin runs of the process to check the accuracy of their systems. They gather data on tests and to show how accurate the system is and how the various functions are performing. Students discuss results of their initial testing and propose improvements to the system. Remind students of the requirement to show significant time saved and/or accuracy improved using the new system compared to the current manual process.

Day 17-18
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to the client. The deliverables will include the prototype, program design and information about the design process and how they solved many of the issues they encountered. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 19
Key Question: How do we convey our ideas?

Students can present their solutions to the class one at a time. Students display the completed automatic pneumatic feeder control system model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

Analog
And Gates
Boolean Logic
Closed loop programming
Connection Terminals
Counter
CPU
Cylinder
Digital
DIN Rail
Dual axis
Exclusive Or gates
Feeders
Flow charts
In_Range
Input
L Terminal
Ladder Logic
Load
Logic
M Terminal
Nand gates
Network
Nor gates
Normally Closed
Normally Open
Open Loop programming
Or Gates
Organizational Blocks
Output
Phototransistor
Photovoltaic
PIR Sensor
PLC
Power Supply
Power Terminals
Schematic
Set Reset Flip Flop
Single Axis
Solenoid
State diagrams
Switch
Tag Table

Tilt angle
Timers
Wiring

Resources:

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

Electricity

- https://www.allaboutcircuits.com/textbook/direct-current/
- https://learn.sparkfun.com/tutorials/alternating-current-ac-vs-direct-current-dc
- https://engineering.mit.edu/engage/ask-an-engineer/whats-the-difference-between-ac-and-dc/
- https://www.school-for-champions.com/science/dc.htm#.W372zehKguU
- http://sinovoltaics.com/learning-center/basics/direct-current-dc-power-definition-and-applications/
- https://whatis.techtarget.com/definition/DC-direct-current
- http://macao.communications.museum/eng/exhibition/secondfloor/MoreInfo/2_3_1_DCCircuit.html
- https://www.khanacademy.org/science/ap-physics-1/ap-circuits-topic/introduction-to-dc-circuits-ap/a/circuit-introduction
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-1/static-electricity/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-2/voltage-current-resistance-relate/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-3/importance-electrical-safety/

- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-9/analog-and-digital-signals/

Ladder Logic

- https://euroec.by/assets/files/siemens/s71200_easy_book_en-US_en-US.pdf
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://library.automationdirect.com/understanding-ladder-logic/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/ladder-diagrams/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/permissive-interlock-circuits/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/motor-control-circuits/
- http://www.plcacademy.com/ladder-logic-tutorial/
- https://www.techopedia.com/definition/20292/ladder-logic

Logic

- http://www.plcdev.com/book/export/html/9
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/digital-logic-functions/
- https://www.i-programmer.info/babbages-bag/235-logic-logic-everything-is-logic.html
- https://academo.org/demos/logic-gate-simulator/
- https://sciencedemos.org.uk/logic_gates.php
- http://www.cburch.com/logisim/

Part Feeders

- https://www.youtube.com/watch?v=KpkC4GmBsW8
- https://www.youtube.com/watch?v=UkdEN30762E
- https://www.youtube.com/watch?v=pQQSk3Ujc0I
- https://www.youtube.com/watch?v=xD5ifTDFtRQ
- https://youtu.be/B13ffPEv1q4
- https://www.youtube.com/watch?v=c4jgr8xz25Q
- https://www.feedall.com/feeders-conveyors/billet-feeders/manual-load-billet-feeder/
- https://www.youtube.com/watch?v=pjEN88IMFvc
- https://www.youtube.com/watch?v=LCN2LSjeRBM
- https://www.wrabacon.com/automated-systems/tray-stackers.html
- https://youtu.be/wa_fMM5N1rw
- https://youtu.be/3UPVjuvRDcM
- https://youtu.be/Xy7tGAF8UmU
- https://www.youtube.com/watch?v=B3Q3Wtx7STY
- https://www.youtube.com/watch?v=Vm_Tfnwq3MQ
- http://www.autoindtech.com/up210-upstacker.html

PLC

- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://www.youtube.com/watch?v=ReTtgzN-Dm
- chttps://unitronicsplc.com/what-is-plc-programmable-logic-controller/
- https://www.industry.usa.siemens.com/automation/us/en/automation-systems/industrial-automation/plc/pages/plc.aspx
- http://www.plcdev.com/how_plcs_work
- https://www.elprocus.com/programmable-logic-controllers-and-types-of-plcs/
- http://www.plctutor.com/plc-components.html
- http://www.plcdev.com/book/export/html/9
- https://www.amci.com/industrial-automation-resources/plc-automation-tutorials/what-plc/
- https://www.ecmweb.com/content/troubleshooting-plcs
- https://unitronicsplc.com/what-is-plc-programmable-logic-controller/

Pneumatic Clamping

- https://www.youtube.com/watch?v=eY5cAYudchw
- https://www.youtube.com/watch?v=5P2pk54wPlo
- https://www.youtube.com/watch?v=snlR6C1ZCo0
- https://www.youtube.com/watch?v=8NKKit18cX8
- https://youtu.be/5P2pk54wPlo
- https://youtu.be/9FGJQ6WRzPY
- https://www.youtube.com/watch?v=Cs0vy42gUkQ
- https://www.youtube.com/watch?v=40WUbK2gCxI
- https://www.datron.com/blog/cnc-workholding-for-milling-machines/

State Diagrams and Flow Charts

- https://www.lucidchart.com/pages/uml-state-machine-diagram
- https://www.geeksforgeeks.org/unified-modeling-language-uml-state-diagrams/
- http://www.agilemodeling.com/artifacts/stateMachineDiagram.htm
- http://www.cs.unc.edu/~stotts/145/CRC/state.html
- https://www.visual-paradigm.com/guide/uml-unified-modeling-language/what-is-state-machine-diagram/
- https://www.youtube.com/watch?v=L9UCsQxuWmw
- https://www.lucidchart.com/pages/what-is-a-flowchart-tutorial
- http://www.breezetree.com/articles/how-to-flow-chart-in-excel.htm
- https://www.gliffy.com/blog/the-comprehensive-guide-to-flowcharts

Project: Conveyor Sorting System

Introduction:

Conveyors are an integral component of automated systems. They move components to where they are needed. FedEx, DHL and UPS all utilize conveyors that manage to sort packages on the fly so they all arrive at the correct location. Sensors read data on the fly and components redirect the path of the objects being sorted.

Purpose of the Project:

The purpose of the conveyor sorting system project is to introduce logic and decision making. Students will apply decision making elements such as State Diagrams and Flow Charts to design the logic flow in a program. These skills will be used by the student teams to define the logic required for events to occur. Students learn that automation allows for the increased production that makes modern life possible.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Science and engineering professionals use data and graphical analysis in making decisions.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The Engineering Design Process is sometimes referred to as the sequential actions of research, design, build, evaluate; then redesign, and communicate.
- Engineering professionals design solutions and communicate the solutions through graphics and pictures.
- Engineers use integrity and ethics when communicating ideas, including citing sources of information.
- In all systems, there is a tradeoff between performance and complexity. Higher complexity is generally associated with higher cost; hence the shortened form of the syllogism is performance versus cost.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.
- Electricity is a form of energy caused by the movement of charged particles. It is often used to transfer energy from one place to another.
- The first law of thermodynamics (conservation of energy and matter) states that output power of a system is always less than the power supplied to the system.
- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
- “Green Principles” of design are used for eventual disassembly and resource recovery and is referred as Product Lifecycle Management (PLM).
- A Programmable Logic Controller (PLC) is a hardened computer used for industrial automation. PLCs can automate a process, machine function, or even an entire production line.
- The term “Logic” is based upon the mathematical system called Boolean Algebra named after George Boole (Born November 2, 1815-Died December 8, 1864) who was a self-taught English mathematician and philosopher who invented this form of algebra where values are either True or False where rules are created to consistently arrive at desired values.
- The ability to collect data, transform them into information, and use that information to improve an existing process is an enabling skill for Lean manufacturing.
- Applying automated control systems to existing manual processes can dramatically improve quality and reduce the amount of human (manual) time required.
- Electronic sensors detect and transform real-world phenomena into information that is used by computers to control valves, pumps, and other industrial equipment.
- Timers allow programmers to design and control specialized clocks to turn machinery on or off for specific amounts of time.

- Keeping track of events as they occur can be accomplished using logic programs called counters.
- Analog inputs for such things as temperature, pressure, speed, etc., are voltage values that can be converted into a digital value to be stored and used by a computer.
- Computer controlled automated systems often use a solenoid valve to open and close a valve to control the flow of a medium such as pressurized gas. A solenoid valve is an electromechanical device where electrical current is used to cause movement.
- The Ideal Gas Law describes the relationship of temperature, pressure, and volume. A subset of this law is called Charles Law which describes how gasses behave when heated. An experiment: fill a small balloon with air and tie off the end. Place the balloon in cold water and watch the size (volume) of the balloon decrease. Then place the balloon in warm water and watch the size (volume) of the balloon increase. Because the volume of a fixed mass of gas is directly proportional to the temperature, the size (volume) of the balloon changes with temperature. In solid vessels the pressure of the gas can be changed to produce movement. In a technology setting, pneumatic cylinders are devices that are controlled by a computer to convert the pressure of compressed gasses to a force acting in a specified direction. This device is often called an actuator.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://youtu.be/7BKoKTgUBIo
https://www.youtube.com/watch?v=3EeRsUbIZqE

Outline:

- Documentation
  - Engineering Notebook
  - Documentation object to be designed
- Programmable Logic Controllers (PLC)
  - Basic electricity-Multimeter schematics/ Ohms law
  - Setup
  - Inputs
  - Outputs
  - Logic
  - Timers
  - Counters
- Workcell Creation
  - Pneumatics
  - Solenoids
  - Schematics
  - Electricity
  - Hand shaking
- Evaluation

Testing of the design of a prototype conveyor sorting system that will automatically detect a specific color and move it into the correct bin

Communication

Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation, and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.
- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Reverse Engineering

- Apply design principles which include the accommodation for disassembly and resource recovery.
- Research and apply current business practices that lead to new product development or improvement of products or procedures including the use of rapid development and deployment to be faster to market.
- Analyze the design attributes of an existing product by disassembling it into its parts, use precision measurement tools to create sketches & drawings of the parts, identify the materials and processes used in manufacturing, and create a new and improved design.
- Utilize convergent modeling to capture data and rapidly create new parts to fit existing scans.
- Collaborate with teams to combine models and parametrically create solutions.
- Utilize rapid prototyping/additive manufacturing to create highly complex parts designed in a CAD system.

Design for Manufacturing

- Apply the principles of design for manufacturing, enabling the efficient and effective production of products.

- Develop a logical argument for selecting the tools, machines and labor necessary to produce finished goods from raw materials.
- Create a strategy to increase efficiency and decrease waste by receiving goods only as they are needed in the production process, thereby reducing inventory costs and reducing the impact of water and other natural resource consumption.
- Create a plan for protecting the safety, health and welfare of people engaged in the manufacturing environment.
- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.
- Understand and apply Statistical Process Control (SPC) to acquire quality control.
- Research and apply knowledge of material properties to product design and development.

Design for Assembly
- Apply engineering design of components to assure alignment for assembly.
- Create a management plan that includes quality planning, quality control, quality assurance, and quality improvement for an advanced manufacturing environment.
- Research, construct, and evaluate a plan for an assembly line or work cell.

Computer Numeric Control (CNC) of Machines
- Apply Cartesian Coordinates to create toolpaths for machine tools.
- Research and apply proper cutting tool speeds, feeds, and directions for manufacturing.
- Create simple Numeric Control (NC) part programs using a text editor or a CAM package.
- Analyze NC part program files to identify and correct errors.
- Analyze part geometry to select appropriate cutting tools and fixturing devices needed to create a part using a CNC machine.
- Edit the tool library of a CNC machine program to establish tool offset values.

Applying CAM Software to Problem Solutions
- Design and prepare 3D models with appropriate units for use in toolpath generation.
- Setup a CAM package by editing the material and tool libraries.
- Generate tool paths from a CAD program and edit NC part program files to identify and correct errors.

Automation with Programmable Logic Controllers (PLCs)

- Design and analyze an electrical system to efficiently convert, transform, and transmit electricity to where it is needed.
- Research and specify electrical devices necessary to provide needed power.
- Apply machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.
- Use flow charts and diagrams to apply logic in the design of control programs.

Applying Logic Software (TIA Portal) to Create Problem Solutions

- Design a system of elements that manages power to accomplish a task involving defined movement.
- Design a control system to vary the speed and performance of a motor by utilizing feedback from the system to gain the most efficiency possible.
- Formulate a system to utilize data collection and analysis to maintain and improve product quality and provide adequate confidence that the product will satisfy design requirements.
- Design and analyze the application of machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.

Pneumatics Design and Control

- Construct systems that efficiently utilize a fluid (liquid or gas) under pressure to generate, transmit, and control power.
- Design an integrated system of machines, machine tools, jigs, fixtures, instruments, and control programs to produce needed parts.
- Utilize jigs, fixtures, drill guides, gauges, and other manufacturing and assembly tools.
- Research, construct and evaluate a plan for an assembly line or work cell.
- Identify systems, sub-systems and typical components of an automated manufacturing operation.
- Apply the necessary safety precautions associated with a fully automated system.

Business of Manufacturing

- Research and categorize the activities that a business conducts to make discoveries that can either lead to the development of new products or procedures, or to improve existing products or procedures.
- Research and evaluate the new approaches of rapid development and deployment of products that saves time and is more efficient.
- Review and evaluate the benefits of a plan for an assembly line or work cell.
- Create a strategy to increase efficiency and decrease waste by receiving inventory just in time for the production process to reduce costs and reduce use of natural resources.

- Evaluate the use of production organization, planning, and resources, both human and capital, as well as regulatory requirements, to successfully and efficiently bring a product to market.
- Create a management plan including quality planning, quality control, quality assurance, and quality improvement for an advance manufacturing environment.
- Create a plan for protecting the health and safety of the people engaged in a manufacturing environment.

College and Career Readiness Math Standards

Creating Equations

CED.A1 Create equations and inequalities in one variable and use them to solve problems.

CED.A.2 Create equations in two or more variables to represent relationships between quantities

CED.A.3 Represent constraints by equations or inequalities, and by systems of equations and/or inequalities, and interpret solutions as viable or nonviable options in a modeling context

CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Making Inferences & Justifying Conclusions

IC.A.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population.

IC.B.3 Recognize the purposes of and differences among sample surveys, experiments, and observational studies; explain how randomization relates to each.

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.
3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.

9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*

2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council’s Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:
1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:
Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:
Students will develop an understanding of the core concepts of technology.

STL Standard 3:
Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 5:
Students will develop an understanding of the effects of technology on the environment.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 14:
Students will develop an understanding of and be able to select and use medical technologies.

STL Standard 16:
Students will develop an understanding of and be able to select and use energy and power technologies.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 18:
Students will develop an understanding of and be able to select and use transportation technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Conveyor sorting System Rubric

Essential Question:
How do we create a continuous sorting machine that separates components automatically?

Student Scenario:
You are a member of a design team employed by Conveyor Sorters, Inc. A client of your company has requested a proposal for the installation of a single conveyor system for all the parts of various machines used in their facility. The conveyor system will be required to select the proper parts to deliver to different stations. The customer wants a working prototype to demonstrate the practicality of using such a system. They would like 99% accuracy from the system. Your boss has asked your team to design the prototype and use different color disks to represent the work pieces. You will be required to have three different colors to sort into bins.

Your team will build a prototype conveyor sorting system that will automatically detect the color and move it to drop in the correct bin. You can use existing parts or design and print new components to utilize in the prototype conveyor system. You will design, document and create a program to control the system. You will perform a test to determine how accurate your system will be. This is important as the company is implementing a lean manufacturing program and this will help them justify the costs.

The design requirements are as follows:

- The prototype must move the disk to the correct position and deposit it into the correct bin.
- The program must have on/off capability so the operator can shut down the system if needed.
- The conveyor must move continuously.
- A ***required*** sensor must identify the color of parts in the conveyor sorting system.

Your team's design will be presented using a working model of the pneumatic conveyor sorting system controlled by the PLC. This demonstrates the ability to automatically deliver a stream of parts to the correct location.

The research and learning activities are designed to help students:

- Learn the basics of pneumatics
- Learn the basic principles of PLC control
- Apply digital logic to determine the order and sequences of switches
- Utilize Boolean logic to simplify the parameters

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design
- Sketches of the device and planning for programming
- Descriptions of the sensors utilized and where they should be positioned
- Working prototype
- Engineering report of the design process
- Presentation for the authentic audience

Daily Plan:

Day 1
Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2
Key Question: How do we get started in the design process?

The teams will be responsible for researching pneumatics, cylinders, solenoids, Boolean Logic, flow charts, and state diagrams as they apply to planning ladder logic to be used with PLCs. Teams need to research the use of SR flip flops to create resettable logic needed for this project. Teams should research types of conveyor sorting systems.

The student teams discuss possible pneumatic conveyor sorting control systems including:

- What kinds of logic might we need to use?
- How will we know if we are meeting the goal of 99% success rate?
- Will the model meet the stated design requirements?
- How will our logic work?
- Does the pneumatic conveyor sorting system work continuously?
- What are the basic electrical and pneumatic safety issues?

The teacher should remind students about the extensive help and tutorial systems built into the software. This help system can be used to get general background information find tutorials about individual topics and to find out how the software accomplishes basic features. Students can search for design elements they might want to incorporate. This can be accessed from the help menu in the TIA Portal software.

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the color sorting control system. Other tutorials in the resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3-7
Key Question: How do we get started on our individual designs?

First, student teams brainstorm components of their design. Next create a written description of what the program must accomplish. Add this to the team's design brief to be included with the sketches of the location of sensors. Include operating requirements as well as expected logic signals. They then meet with the client who will need to sign off on the design proposal before programming and model building begins. The client can be the teacher or an authentic advisor.

Students should work through the tutorials on Pneumatics and Control.
This will take two days to work through these necessary basics. Have students bring a plastic soda bottle to school for use in the system.

Students can reference Logic and Decision Making, Designing Programs for Problems, Analog Inputs, Using Relays to Control, Motor Direction, Building Blocks, Introduction to the PLC, Wiring the PLC, Wiring Inputs, Wiring Outputs, Setting up the Programming Environment, Setting up Communication, Introduction to a Project, Writing a First Program, PIR Sensor-Motion Detector and Counters for specific commands to use in the automated pneumatic clamping system.

Teams discuss how their conveyor sorting control system should be tested. The groups decide which components will be tested and how the team will know when their design achieves the test requirements.

Day 8-10
Key Question: How can we begin to design our conveyor sorting system model?

Teams discuss their proposed conveyor sorting control systems and how to achieve the design given the approved design brief they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the pneumatic conveyor sorting device and programming scheme. Components are available in the Do Engineering and the custom pneumatics kits. A set of instructions for a conveyor can be found at https://drive.google.com/open?id=0B_7sFhPxnoaXU1hrRzI4SmM3VlE. They must also decide on sensors, wiring, and programming. They utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the conveyor sorting control system design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams discuss how the various designs and placement of sensors work and that the designs created will meet the conveyor sorting control system requirements and the performance will be within the specifications they established

Day 11-13
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs elements created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team final design. It could be a single design or contain elements of several designs. Once the decision is made the students develop a plan for creating the team prototype using PLC technology. They need to create a design that incorporates their ideas. Once the final plan is completed they will create a prototype program. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin programming and testing to see how they are communicating with the various sensors they selected. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 14-16
Key Question: How do we build and test our designs?

Students assemble their prototype conveyor sorting control system. When students encounter problems assembling their prototype they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Once the working prototype is assembled testing can begin to see if the model meets the stated design requirements. Students begin runs of the process to check the accuracy of their systems. They gather data on tests and to show how accurate the system is and how the various functions are performing. Students discuss results of their initial testing and propose improvements to the system.

Day 17-18
Key Question: How do we organize our thoughts in a presentation to the authentic audience?

The student teams discuss and finish any changes that are needed.
The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to the client. The deliverables will include the prototype, program design, and information about the design process, and how they solved many of the issues encountered. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 19
Key Question: How do we convey our ideas?

Students can present their solutions to the class one at a time. Students display the completed conveyor sorting control system model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs.

Vocabulary:

Analog
And Gates
Boolean Logic

Closed loop programming
Connection Terminals
Counter
CPU
Cylinder
Digital
DIN Rail
Dual axis
Exclusive Or gates
Feeders
Flow charts
In_Range
Input
L Terminal
Ladder Logic
Load
Logic
M Terminal
Nand gates
Network
Nor gates
Normally Closed
Normally Open
Open Loop programming
Or Gates
Organizational Blocks
Output
Phototransistor
Photovoltaic
PIR Sensor
PLC
Power Supply
Power Terminals
Schematic
Set Reset Flip Flop
Single Axis
Solenoid
State diagrams
Switch
Tag Table
Tilt angle
Timers
Wiring

Resources:

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

Conveyor Sorting Systems

- https://www.youtube.com/watch?v=KpkC4GmBsW8
- https://www.youtube.com/watch?v=UkdEN30762E
- https://www.youtube.com/watch?v=i8Dny3rNvmI
- https://www.youtube.com/watch?v=w8j7vk2K2L0
- https://www.youtube.com/watch?v=wFqU8-dL_Nw
- https://www.youtube.com/watch?v=SMEQgGcl1ik
- https://www.youtube.com/watch?v=arxroyWkdX8
- https://www.youtube.com/watch?v=zv38u6Hnqag
- https://www.youtube.com/watch?v=OKl_rwTGpng
- https://www.youtube.com/watch?v=tSEHDBSynVo
- https://www.youtube.com/watch?v=q9y_COwHb3s
- https://www.youtube.com/watch?v=BVId0pzACQ4
- https://www.youtube.com/watch?v=vN9XRIAys38
- https://www.youtube.com/watch?v=ZAHTr0giZmw
- https://www.youtube.com/watch?v=udRYxhS4-Ow

Electricity

- https://www.allaboutcircuits.com/textbook/direct-current/
- https://learn.sparkfun.com/tutorials/alternating-current-ac-vs-direct-current-dc
- https://engineering.mit.edu/engage/ask-an-engineer/whats-the-difference-between-ac-and-dc/
- https://www.school-for-champions.com/science/dc.htm#.W372zehKguU
- http://sinovoltaics.com/learning-center/basics/direct-current-dc-power-definition-and-applications/

- https://whatis.techtarget.com/definition/DC-direct-current
- http://macao.communications.museum/eng/exhibition/secondfloor/MoreInfo/2_3_1_DCCircuit.html
- https://www.khanacademy.org/science/ap-physics-1/ap-circuits-topic/introduction-to-dc-circuits-ap/a/circuit-introduction
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-1/static-electricity/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-2/voltage-current-resistance-relate/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-3/importance-electrical-safety/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-9/analog-and-digital-signals/

Ladder Logic

- https://euroec.by/assets/files/siemens/s71200_easy_book_en-US_en-US.pdf
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://library.automationdirect.com/understanding-ladder-logic/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/ladder-diagrams/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/permissive-interlock-circuits/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/motor-control-circuits/
- http://www.plcacademy.com/ladder-logic-tutorial/
- https://www.techopedia.com/definition/20292/ladder-logic

Logic

- http://www.plcdev.com/book/export/html/9
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/digital-logic-functions/
- https://www.i-programmer.info/babbages-bag/235-logic-logic-everything-is-logic.html
- https://academo.org/demos/logic-gate-simulator/
- https://sciencedemos.org.uk/logic_gates.php
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PLC

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- https://www.youtube.com/watch?v=ReTtgzN-Dm
- chttps://unitronicsplc.com/what-is-plc-programmable-logic-controller/

- https://www.industry.usa.siemens.com/automation/us/en/automation-systems/industrial-automation/plc/pages/plc.aspx
- http://www.plcdev.com/how_plcs_work
- https://www.elprocus.com/programmable-logic-controllers-and-types-of-plcs/
- http://www.plctutor.com/plc-components.html
- http://www.plcdev.com/book/export/html/9
- https://www.amci.com/industrial-automation-resources/plc-automation-tutorials/what-plc/
- https://www.ecmweb.com/content/troubleshooting-plcs
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State Diagrams and Flow Charts

- https://www.lucidchart.com/pages/uml-state-machine-diagram
- https://www.geeksforgeeks.org/unified-modeling-language-uml-state-diagrams/
- http://www.agilemodeling.com/artifacts/stateMachineDiagram.htm
- http://www.cs.unc.edu/~stotts/145/CRC/state.html
- https://www.visual-paradigm.com/guide/uml-unified-modeling-language/what-is-state-machine-diagram/
- https://www.youtube.com/watch?v=L9UCsQxuWmw
- https://www.lucidchart.com/pages/what-is-a-flowchart-tutorial
- http://www.breezetree.com/articles/how-to-flow-chart-in-excel.htm
- https://www.gliffy.com/blog/the-comprehensive-guide-to-flowcharts

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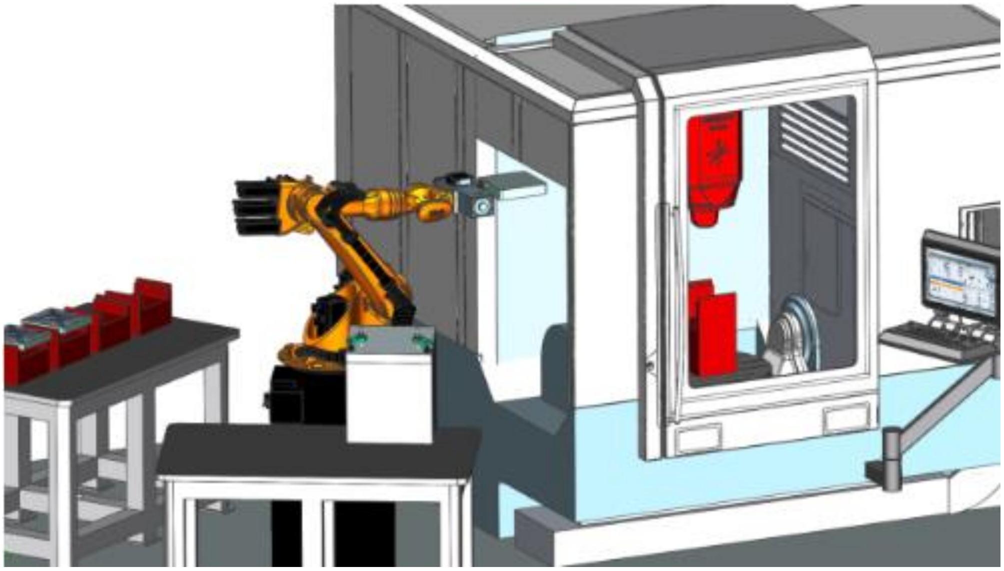


Project: Automated Work Cell for CNC Mill

Introduction:

Work cells are design to optimize the amount of goods produced. They bring together people and equipment with efficiently designed processes. This limits the amount of wasted time and effort moving product and results in higher quality in addition to increased productivity. Many aspects of the design are examined; such as how do the materials arrive, is there a smooth flow of people, operations and finished goods, and are there bottlenecks that can be avoided?

Purpose of the Project:

The automated work cell project combines all the projects in this course by designing a way to manufacture a product. The automated work cell applies logic and decision making. Students will apply decision making elements such as State Diagrams and Flow Charts to design the logic flow in a program. They will also examine how materials will arrive, automate placement and clamping of the materials, and how to safely increase the productivity of the mill.

Concepts:

- Creating technical solutions requires the use of mathematical analysis, scientific inquiry, and engineering design.
- Science and engineering professionals use data and graphical analysis in making decisions.
- Modern design requires the ability to generate, process, and transfer information digitally using appropriate technologies.
- The Engineering Design Process is sometimes referred to as the sequential actions of research, design, build, evaluate; then redesign, and communicate.
- Engineering professionals design solutions and communicate the solutions through graphics and pictures.
- Technological knowledge and abilities can be used to design, construct, use, and evaluate products and systems that satisfy human and environmental needs.
- Technological solutions, patents, and/or new designs are of little social value unless they are promoted, sold, or marketed in some way to the end user.
- An Engineering Notebook is used to keep detailed records of the design and development process.
- Engineers sometimes communicate through a white paper that describes a problem and offers a solution.
- Engineers use integrity and ethics when communicating ideas, including citing sources of information.
- Results of experimental research in science and engineering are submitted by the person(s) conducting the studies, to professional journals where they are peer reviewed prior to publication. Reviewers are highly regarded professionals with accepted credentials in their field.
- Nature has many methodologies allowing organisms to adapt to and excel in their ecosystems. Designers use biomimicry to take advantage of those adaptations in the creation of products to fit particular needs.
- In all systems, there is a tradeoff between performance and complexity. Higher complexity is generally associated with higher cost; hence the shortened form of the syllogism is performance versus cost.
- Designing mechanical systems requires the knowledge and application of simple machines to manage and transform power and forces into required motion.
- Simple and compound machines have mechanical advantages that can be used to solve real-world problems.
- Mathematical formulas are used to analyze the amount of force necessary to provide to a mechanism to overcome losses due to inefficiency of the system.
- Converting one form of energy to another is not a 1:1 ratio; some energy is lost to conversion inefficiencies such as friction, heat to the environment, and other factors.
- Engineering features are the collection of design components that allow for the assembly of components. These might include bosses, spot faces, snap fittings and joints, counter sinks, counter bores, and other elements that allow for assembly.

- Electricity is a form of energy caused by the movement of charged particles. It is often used to transfer energy from one place to another.
- Newton's laws represent the relationship between force, mass, velocity, and acceleration which can be used to predict power captured and converted by products such as a wind turbines.
- The first law of thermodynamics (conservation of energy and matter) states that output power of a system is always less than the power supplied to the system.
- Mathematical models of physical phenomena, such as heat transfer in liquids, can be used to design an automated system that will outperform any manual system.
- Computer controlled actions, such as moving an object on or off an automated assembly line, use pneumatics, a branch of physics and technology that focuses on the mechanical properties of gases.
- The Ideal Gas Law describes the relationship of temperature, pressure, and volume. A subset of this law is called Charles Law which describes how gasses behave when heated. An experiment: fill a small balloon with air and tie off the end. Place the balloon in cold water and watch the size (volume) of the balloon decrease. Then place the balloon in warm water and watch the size (volume) of the balloon increase. Because the volume of a fixed mass of gas is directly proportional to the temperature, the size (volume) of the balloon changes with temperature. In solid vessels the pressure of the gas can be changed to produce movement. In a technology setting, pneumatic cylinders are devices that are controlled by a computer to convert the pressure of compressed gasses to a force acting in a specified direction. This device is often called an actuator.
- Additive manufacturing produces models by adding thin layers of material, one after the other to produce a model.
- The design of mechanisms requires the use of dimension tolerances to assure that component parts work together effectively with minimum power losses.
- "Green Principles" of design are used for eventual disassembly and resource recovery and is referred as Product Lifecycle Management (PLM)
- Convergent modeling is the process of analyzing a component to determine how much material can be removed from the original design and meet the stress requirements specified.
- Design for manufacturing involves the analysis of the design and how the design can be changed to allow for rapid and efficient manufacturing processes.
- Design for assembly involves analysis and changes to the design to make the assembly of the product as efficient as possible.
- CNC machine tool technology uses Cartesian Coordinates to position and control tooling to produce accurate models.
- G-code is the name given to numerical control programs that are used to control all types of computerized machinery.
- Speeds and Feeds is a machining term that refers to the rate that material is removed to acquire a finished part. Speed refers to either the speed of the moving material or the speed of the cutter or both at the same time. Feed is the rate of material removal. The relationship between speed and feed can vary

depending on the desired surface finish. Usually initial cuts remove more material leaving a rough finish and a finish cut removes less material with a slower feed rate leaving a smooth finished surface.

- Tooling is a term that describes many aspects of the cutters, jigs, fixtures, hold down devices, and other accessories used in the process of material removal.
- Verification is the process used to confirm the program tool path to assure the machining operation will occur properly and without damage to the tool, part or machine.
- Post processors have programs that interpret the intent of CAM software and turn the desired operations into G-code to control the CNC machines.
- A Programmable Logic Controller (PLC) is a hardened computer used for industrial automation. PLCs can automate a process, machine function, or even an entire production line.
- The term "Logic" is based upon the mathematical system called Boolean Algebra named after George Boole (Born November 2, 1815-Died December 8, 1864) who was a self-taught English mathematician and philosopher who invented this form of algebra where values are either True or False where rules are created to consistently arrive at desired values.
- The ability to collect data, transform them into information, and use that information to improve an existing process is an enabling skill for Lean manufacturing.
- Applying automated control systems to existing manual processes can dramatically improve quality and reduce the amount of human (manual) time required.
- Electronic sensors detect and transform real-world phenomena into information that is used by computers to control valves, pumps, and other industrial equipment.
- Timers allow programmers to design and control specialized clocks to turn machinery on or off for specific amounts of time.
- Keeping track of events as they occur can be accomplished using logic programs called counters.
- Analog inputs for such things as temperature, pressure, speed, etc., are voltage values that can be converted into a digital value to be stored and used by a computer.
- Computer controlled automated systems often use a solenoid valve to open and close a valve to control the flow of a medium such as pressurized gas. A solenoid valve is an electromechanical device where electrical current is used to cause movement.
- Automated manufacturing systems rely on a mechanical system called a conveyor to move material from one place to another using a continuous belt.
- Materials have inherent properties making them more suitable for specific applications.
- Selecting materials for use in a product requires knowledge of material properties and characterization, based upon manufacturing processes selected, chemical

composition, internal defects, temperature, previous loading, dimensions, and other factors.

Siemens Real World Application Videos:

The following videos are related to the technologies in this project as they are used now and in the future.

https://youtu.be/1pNw58cFLo8
https://www.youtube.com/watch?v=9AX_5insUVg

Outline:

- Documentation
  - Engineering Notebook
  - Documentation object to be designed
- Programmable Logic Controllers (PLC)
  - Basic electricity-Multimeter schematics/ Ohms law
  - Setup
  - Inputs
  - Outputs
  - Logic
  - Timers
  - Counters
- Work cell Creation
  - Pneumatics
  - Solenoids
  - Schematics
  - Electricity
  - Hand shaking
- Evaluation
  - Testing of the organization of the Work cell and the impact is has on the finished product
- Communication
  - Presentation of design solutions

Standards:

Career and Technical Standards

Engineering Design Process

- Maintain an Engineering Notebook for research, prototype creation, documentation, and daily reflections.
- Apply engineering design and problem solving as an iterative process incorporating science, mathematics, and engineering to optimally convert resources to meet a design solution.
- Communicate design solutions utilizing effective technical writing skills including correct spelling, proper grammar, and accurate technical vocabulary.
- Prepare a quantitative plan for the successful completion of a project.

- Assume leadership responsibility for collaborative team actions and decisions related to the successful completion of a project.
- Evaluate the needs and costs of resources necessary for the completion of a project.
- Prepare and communicate model documentation to include such details as product analysis, size, materials, assembly details, installation and service requirements.

Reverse Engineering

- Apply design principles which include the accommodation for disassembly and resource recovery.
- Research and apply current business practices that lead to new product development or improvement of products or procedures including the use of rapid development and deployment to be faster to market.
- Analyze the design attributes of an existing product by disassembling it into its parts, use precision measurement tools to create sketches & drawings of the parts, identify the materials and processes used in manufacturing, and create a new and improved design.
- Utilize convergent modeling to capture data and rapidly create new parts to fit existing scans.
- Collaborate with teams to combine models and parametrically create solutions.
- Utilize rapid prototyping/additive manufacturing to create highly complex parts designed in a CAD system.

Design for Manufacturing

- Apply the principles of design for manufacturing, enabling the efficient and effective production of products.
- Develop a logical argument for selecting the tools, machines and labor necessary to produce finished goods from raw materials.
- Create a strategy to increase efficiency and decrease waste by receiving goods only as they are needed in the production process, thereby reducing inventory costs and reducing the impact of water and other natural resource consumption.
- Create a plan for protecting the safety, health and welfare of people engaged in the manufacturing environment.
- Create technical drawings having proper dimensional tolerances and limits necessary for components to fit as designed.
- Use appropriate instruments accurately to make precision measurements required by plan specification to achieve required dimensions, shapes, location of centers, parallel surfaces and other component attributes.
- Understand and apply Statistical Process Control (SPC) to acquire quality control.
- Research and apply knowledge of material properties to product design and development.

Design for Assembly

- Apply engineering design of components to assure alignment for assembly.
- Create a management plan that includes quality planning, quality control, quality assurance, and quality improvement for an advanced manufacturing environment.
- Research, construct, and evaluate a plan for an assembly line or work cell.

Computer Numeric Control (CNC) of Machines

- Apply Cartesian Coordinates to create toolpaths for machine tools.
- Research and apply proper cutting tool speeds, feeds, and directions for manufacturing.
- Create simple Numeric Control (NC) part programs using a text editor or a CAM package.
- Analyze NC part program files to identify and correct errors.
- Analyze part geometry to select appropriate cutting tools and fixturing devices needed to create a part using a CNC machine.
- Edit the tool library of a CNC machine program to establish tool offset values.

Applying CAM Software to Problem Solutions

- Design and prepare 3D models with appropriate units for use in toolpath generation.
- Setup a CAM package by editing the material and tool libraries.
- Generate tool paths from a CAD program and edit NC part program files to identify and correct errors.

Automation with Programmable Logic Controllers (PLCs)

- Design and analyze an electrical system to efficiently convert, transform, and transmit electricity to where it is needed.
- Research and specify electrical devices necessary to provide needed power.
- Apply machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.
- Use flow charts and diagrams to apply logic in the design of control programs.

Applying Logic Software (TIA Portal) to Create Problem Solutions

- Design a system of elements that manages power to accomplish a task involving defined movement.
- Design a control system to vary the speed and performance of a motor by utilizing feedback from the system to gain the most efficiency possible.
- Formulate a system to utilize data collection and analysis to maintain and improve product quality and provide adequate confidence that the product will satisfy design requirements.
- Design and analyze the application of machine control systems, sensory feedback, and information processing to increase productivity in manufacturing.

Pneumatics Design and Control

- Construct systems that efficiently utilize a fluid (liquid or gas) under pressure to generate, transmit, and control power.
- Design an integrated system of machines, machine tools, jigs, fixtures, instruments, and control programs to produce needed parts.
- Utilize jigs, fixtures, drill guides, gauges, and other manufacturing and assembly tools.
- Research, construct and evaluate a plan for an assembly line or work cell.
- Identify systems, sub-systems and typical components of an automated manufacturing operation.
- Apply the necessary safety precautions associated with a fully automated system.

Business of Manufacturing

- Research and categorize the activities that a business conducts to make discoveries that can either lead to the development of new products or procedures, or to improve existing products or procedures.
- Research and evaluate the new approaches of rapid development and deployment of products that saves time and is more efficient.
- Review and evaluate the benefits of a plan for an assembly line or work cell.
- Create a strategy to increase efficiency and decrease waste by receiving inventory just in time for the production process to reduce costs and reduce use of natural resources.
- Evaluate the use of production organization, planning, and resources, both human and capital, as well as regulatory requirements, to successfully and efficiently bring a product to market.
- Create a management plan including quality planning, quality control, quality assurance, and quality improvement for an advance manufacturing environment.
- Create a plan for protecting the health and safety of the people engaged in a manufacturing environment.

College and Career Readiness Math Standards

Creating Equations

CED.A1 Create equations and inequalities in one variable and use them to solve problems.

CED.A.2 Create equations in two or more variables to represent relationships between quantities

CED.A.3 Represent constraints by equations or inequalities, and by systems of equations and/or inequalities, and interpret solutions as viable or nonviable options in a modeling context

CED.A.4 Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Create equations that describe numbers or relationships CED

A.4. Rearrange formulas to highlight a quantity of interest, using the same reasoning as in solving equations

Quantities

Q.A.1Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Making Inferences & Justifying Conclusions

IC.A.1 Understand statistics as a process for making inferences about population parameters based on a random sample from that population.
IC.B.3 Recognize the purposes of and differences among sample surveys, experiments, and observational studies; explain how randomization relates to each.

Reading Standards for Literacy in History/Social Studies 9-10

Key Ideas and Details

1. Cite specific textual evidence to support analysis of primary and secondary sources, attending to such features as the date and origin of the information.
3. Analyze in detail a series of events described in a text; determine whether earlier events caused later ones or simply preceded them.

Integration of Knowledge and Ideas

7. Integrate quantitative or technical analysis (e.g., charts, research data) with qualitative analysis in print or digital text.
9. Compare and contrast treatments of the same topic in several primary and secondary sources.

Range of Reading and Level of Text Complexity

10. By the end of grade 10, read and comprehend science/technical texts in the grades 9–10 text complexity band independently and proficiently.

Writing Standards for Literacy in History/Social Studies, Science, and Technical Subjects 9-10

Text Types and Purposes

1. Write arguments focused on *discipline-specific content.*
2. Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.

Production and Distribution of Writing

4. Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.

Research to Build and Present Knowledge

7. Conduct short as well as more sustained research projects to answer a question (including a self-generated question) or solve a problem; narrow or broaden the inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

8. Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.

Range of Writing

10. Write routinely over extended time frames (time for reflection and revision) and shorter time frames (a single sitting or a day or two) for a range of discipline-specific tasks, purposes, and audiences.

Next Generation Science Standards

The projects engage students in the scientific and engineering practices taken from the National Research Council's Framework for K-12 Science Education, Practices, Crosscutting Concepts, and Core Ideas. This is the document upon which the NGSS are based.

These practices are used for two reasons: 1) they parallel the design process utilized in each project, and 2) they serve as the foundation of the NGSS.

The eight science and engineering practices are:

1. Asking questions and defining problems
2. Developing and using models
3. Planning and carrying out investigations
4. Analyzing and interpreting data
5. Using mathematics and computational thinking
6. Constructing explanations and designing solutions
7. Engaging in argument from evidence
8. Obtaining, evaluating, and communicating information

Standards for Technological Literacy

STL Standard 1:

Students will develop an understanding of the characteristics and scope of technology.

STL Standard 2:

Students will develop an understanding of the core concepts of technology.

STL Standard 3:
Students will develop an understanding of the relationships among technologies and the connections between technology and other fields of study.

STL Standard 4:
Students will develop an understanding of the cultural, social, economic, and political effects of technology.

STL Standard 5:
Students will develop an understanding of the effects of technology on the environment.

STL Standard 7:
Students will develop an understanding of the influence of technology on history.

STL Standard 8:
Students will develop an understanding of the attributes of design.

STL Standard 9:
Students will develop an understanding of engineering design.

STL Standard 10:
Students will develop an understanding of the role of troubleshooting, research and development, invention and innovation, and experimentation in problem solving.

STL Standard 11:
Students will develop the abilities to apply the design process.

STL Standard 12:
Students will develop the abilities to use and maintain technological products and systems.

STL Standard 13:
Students will develop the abilities to assess the impact of products and systems.

STL Standard 14:
Students will develop an understanding of and be able to select and use medical technologies.

STL Standard 16:
Students will develop an understanding of and be able to select and use energy and power technologies.

STL Standard 17:
Students will develop an understanding of and be able to select and use information and communication technologies.

STL Standard 19:
Students will develop an understanding of and be able to select and use manufacturing technologies.

STL Standard 20:
Students will develop an understanding of and be able to select and use construction technologies.

Assessment:

Assessment is both formative and summative. It is an integral part of high quality instruction. During the course of a project one of the instructor's main functions is to work with student groups, keeping track of progress and providing formative assessment using feedback and promoting reflection about the design process. The focus should be on lifetime learning and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimentation, testing, and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality. Rubrics should be shared with students at the beginning of a project to clarify any misconceptions before beginning their work. Students can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks:
Argumentative_Pursuasive
Informational_Explanatory

Individual Project Rubric:
Automated work cell Rubric

Essential Question:

How can we create a system to automatically feed and control a manufacturing process to produce a component?

Student Scenario:

You are a member of a production design team for Metal Arts, Inc. The company wants to implement a new work area for doing small runs of parts for clients. The plan is to interview clients, design the parts, using design for manufacturing principles, create the tool path, and then process the parts through an efficient work cell. The goal is to use lean manufacturing principles to deliver the materials just as they are needed.

Your team will research the issue and design and create a prototype work cell that will automatically position the work blank properly. You can use existing parts or design and print new components to utilize in the prototype automated work cell system. You will design, document, and create a program to control the system. You will perform a test to time how long it takes to determine takt time to know exactly how many parts could be created in a day. Your team will study the results and see if there is any way to reduce the amount of time it takes. This is important as the company is implementing a lean manufacturing program and this will help them justify the costs.

The design requirements are as follows:

- The prototype must feed the blank in the correct position.
- The program must wait for a signal before automatically clamping the part.
- The clamping system must send a signal to the mill to begin the milling process.
- When the milling machine is done a signal should be sent to the automated clamping system to release the part.
- After the part is removed a signal is sent to the feeder and conveyor systems to deliver the next blank.

Your team's design will be presented using a working model of the work cell controlled by the PLC. This demonstrates the ability to of the work cell to create the parts quickly. The presentation will also document the design process used to design the work cell.

The research and learning activities are designed to help students:

- Learn the basics of pneumatics
- Learn the basic principles of PLC control
- Apply digital logic to determine the order and sequences of switches
- Utilize Boolean logic to simplify the parameters
- Design logic to control multiple components of the work cell

Deliverables:

- Engineering Notebook with reflections, research notes, bibliography, and other processes used in the design.
- Sketches of the device and planning for programming
- Descriptions of the sensors utilized and where they should be positioned
- Working prototype
- Engineering report of the design process
- Study of the lean principles and how they were applied in the design
- Presentation for the authentic audience

Daily Plan:

Day 1

Key Question: What are the expectations of the project?

Introduce students to the project by providing them with the Essential Question and the scenario.

Review and discuss with your students the Design Process, Engineering Notebook and Design Documentation requirements. Discuss the Problem Statement, Design Brief, Testing Protocol, and Management Plan. Review the elements of a good Engineering Report with the students. These were all covered in the *Siemens Engineering Design* course in the first project titled *Introduction to the Engineering Design Process* and may be reviewed as needed. All Siemens curricular projects are grounded in the engineering design process and students must develop a reliance on this proven procedure.

Have the students form teams of two. Allow the students sufficient time to discuss the problem. Students begin by brainstorming ideas in their Engineering Notebooks. The teacher will provide a list of vocabulary terms that students will need to research on their own. The teams can divide the list of terms among team members and share their definitions. All team members are responsible to know all definitions.

Day 2

Key Question: How do we get started in the design process?

The teams will be responsible for researching pneumatics, cylinders, solenoids, Boolean Logic, flow charts, and state diagrams as they apply to planning ladder logic to be used with PLCs. Teams need to research the use of SR flip flops to create resettable logic needed for this project. Teams should research types of work cells and how lean principles are employed in their design.

The student teams discuss possible features for their work cells including:

- What kind of part will we design?
- What design for assembly components do we need to include?
- Is our tool path efficient?
- Will we need a tool change?
- What kinds of logic might we need to use to allow different systems to be controlled from one place?
- How will we know when it is safe to deliver the part to the next stage?
- Will the work cell model meet the stated design requirements?
- How will our logic work?
- Does the work cell return to its home position when through and wait for the next part to be delivered?
- What are the basic electrical and pneumatic safety issues?
- What kind of emergency stop will be needed?

- How will we know how many parts we create?

The teacher should remind students about the extensive help and tutorial systems built into the TIA Portal software. Students can also use sites for Solid Edge and Solid Edge CAM Pro. Countershttps://docs.plm.automation.siemens.com/tdoc/se/110/se_help/#uid:index and https://docs.plm.automation.siemens.com/tdoc/nx/11.0.1/nx_help#uid:xid1128418:index_mfgmilling.

These help systems can be used to get general background information find tutorials about individual topics and to find out how the software accomplishes basic features. Students can search for design elements they might want to incorporate. This can be accessed from the help menu in the TIA Portal software.

Students can enter terms and view a tutorial for creating certain features. Students can reference specific terms from the vocabulary list for specific commands to be used in the design of the color sorting control system. Other tutorials in the Resources section are available for student use.

Remind students to record research notes and sources as well as reflections on the day in the Engineering Notebook.

Day 3-7

Key Question: How do we get started on our individual designs?

First, student teams brainstorm components of their design. Next create a written description of what the program must accomplish. Add this to the team's design brief to be included with their sketches of the location of equipment parts and necessary sensors. They include operating requirements as well as expected logic signals. They then meet with the supervisor who will need to sign off on the design proposal before programming and model building begins. The supervisor can be the teacher or an authentic advisor.

The students will be designing a work cell and will need to identify all the necessary pieces. Each component will need a program and a way of communicating with all the other components. This will take some time to design and the teacher should guide students to where they can find answers.

Students can reference Pneumatics and Control, Logic and Decision Making, Designing Programs for Problems, Analog Inputs, Using Relays to Control Motor Direction, Building Blocks, Introduction to the PLC, Wiring the PLC, Wiring Inputs, Wiring Outputs, Setting up the Programming Environment, Setting up Communication, Introduction to a Project, Writing a First Program, PIR Sensor-Motion Detector, Learning CNC, Generative Design, Fits and Tolerances, Basic 3D Commands, Creating Drawing Views, Introduction Assembly Modeling, Analysis in Solid Edge and Working with Bodies specific commands to use in the automated work cell.

Teams discuss how their automated work cell systems should be tested. The groups decide what components will be tested and how the team will know when their design achieves the test requirements.

Day 8-11
Key Question: How can we begin to design our automated work cell model?

Teams discuss their proposed work cells and how to achieve the design given the approved design brief they presented. They work together to brainstorm ideas and begin to narrow their vision of their solution. Next the team divides the work of creating the work cell and programming scheme. Components are available in the Do Engineering kits (https://drive.google.com/open?id=1r_sULTtpb_WBzxLx5kXzaB7kGTn4Rj_h). They must also decide on sensors, wiring, and programming. They utilize the division of work in the creation of the project management plan.

Students record sketches and reflections in the Engineering Notebook. Once the students have a solution to the work cell design, they need to determine how the design will meet the requirements. This means students must consider how the design will be tested before building.

Teams discuss how the various designs and placement of sensors work and that the designs created will meet the work cell requirements and the performance will be within the specifications they established

Day 12-16
Key Question: How can we put our new designs together?

Student teams conduct meetings to review all designs elements created so far. They look at the criteria and testing protocols created. They discuss which design they wish to use as the team final design. It could be a single design or contain elements of several designs. Once the decision is made the students develop a plan for creating the team prototype using PLC technology. They need to create a design that incorporates their ideas. Once the final plan is completed they will create a prototype program. The teams discuss the final testing of their prototypes and how that will be achieved.

Students create the final plans and begin programming and testing to see how they are communicating with the various sensors they selected. Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Day 17-22
Key Question: How do we build and test our designs?

Students assemble their prototype work cell. When students encounter problems assembling their prototype they must discuss how they will resolve the issue and change the design.

Students record any changes in their designs and enter reflections in their Engineering Notebooks.

Once the working prototype is assembled testing can begin to see if the model meets the stated design requirements. Students begin runs of the process to check the accuracy of their systems. They gather data on tests and to show how accurate the system is and how the various functions are performing. Students discuss results of their initial testing and propose improvements to the system.

Day 23-26
Key Question: How do we organize our thoughts in a presentation to the class (authentic audience)?

The student teams discuss and finish any changes that are needed. Students run their work cells and gather data. They refine their research on the lean components they were hoping to achieve. The teacher will discuss with the teams how to optimally present their ideas.

Students discuss the outline of the presentation to the supervisor. The deliverables will include the prototype, program design and information about the design process, and how they solved many of the issues they encountered. The students should be required to write the introduction, provide results including graphics, and form a conclusion including an acknowledgement section reporting the source of information. Students decide how to divide the work to create a team report.

Day 27
Key Question: How do we convey our ideas?

Students can present their solutions to the authentic audience one at a time. Students display the completed work cell model and demonstrate how it functions. Students discuss changes they would consider if they had time to create another iteration of their design.

In the end, all students can reflect on their work by giving and receiving feedback on how they could possibly improve their designs

Vocabulary:

Analog
And Gates
Boolean Logic
Closed loop programming

Connection Terminals
Counter
CPU
Cylinder
Design for Manufacturing
Digital
DIN Rail
Dual axis
Exclusive Or gates
Feeders
Flow charts
Handshaking
In_Range
Input
L Terminal
Ladder Logic
Lean Manufacturing
Load
Logic
M Terminal
Nand gates
Network
Nor gates
Normally Closed
Normally Open
Open Loop programming
Or Gates
Organizational Blocks
Output
Phototransistor
Photovoltaic
PIR Sensor
PLC
Power Supply
Power Terminals
Schematic
Set Reset Flip Flop
Single Axis
Six Sigma
Solenoid
State diagrams
Switch
Tag Table
Takt time
Tilt angle
Timers

Wiring
Work Cell

Resources:

Conveyor Sorting Systems

- https://www.youtube.com/watch?v=KpkC4GmBsW8
- https://www.youtube.com/watch?v=UkdEN30762E
- https://www.youtube.com/watch?v=i8Dny3rNvml
- https://www.youtube.com/watch?v=w8j7vk2K2L0
- https://www.youtube.com/watch?v=wFqU8-dL_Nw
- https://www.youtube.com/watch?v=SMEQgGcl1ik
- https://www.youtube.com/watch?v=arxroyWkdX8
- https://www.youtube.com/watch?v=zv38u6Hnqag
- https://www.youtube.com/watch?v=OKl_rwTGpng
- https://www.youtube.com/watch?v=tSEHDBSynVo
- https://www.youtube.com/watch?v=q9y_COwHb3s
- https://www.youtube.com/watch?v=BVId0pzACQ4
- https://www.youtube.com/watch?v=vN9XRIAys38
- https://www.youtube.com/watch?v=ZAHTr0giZmw
- https://www.youtube.com/watch?v=udRYxhS4-Ow
- https://www.youtube.com/watch?v=XO7fvrdTCgs

CNC Machining

- https://www.youtube.com/watch?v=2u7OH43NEUo
- https://www.youtube.com/watch?v=txCMvRF4Bm8
- https://www.youtube.com/watch?v=uE-49w6JtTk
- https://www.youtube.com/watch?v=sxs9j8Ydc8E
- https://www.youtube.com/watch?v=WjkMKHN8Zd0
- https://www.youtube.com/watch?v=kHjCvL3X6xc
- https://www.youtube.com/watch?v=nAdBW-A4hbI
- https://mecsoft.com/blog/understanding-climb-vs-conventional-milling/
- http://www.shars.com/products/cutting/end-mills
- https://www.mmsonline.com/articles/cnc-intro-the-key-concepts-of-computer-numerical-control
- http://www.mmsonline.com/articles/key-cnc-concept-1the-fundamentals-of-cnc

Cutting Tools and Workholding

- https://www.youtube.com/watch?v=ckzK-LbeZmY
- http://www.youtube.com/watch?v=J1VtofzVG24&list=PLDB7440122C72886B&inde=6
- http://www.youtube.com/watch?v=6uB2FsUvuE4
- http://www.youtube.com/watch?v=r7-eEj_qq5M&list=PLDB7440122C72886B&index=5

Engineering Notebook:

- http://www.wisegeek.com/what-is-an-engineering-notebook.htm
- https://www.firstinspires.org/sites/default/files/uploads/resource_library/ftc/engineering-notebook-guidelines.pdf
- https://www.asme.org/career-education/articles/early-career-engineers/my-engineers-notebook-jenn-t-dandrea

Engineering Reports

- http://web.mit.edu/me-ugoffice/communication/technical-writing.pdf
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/writing_engineering_reports.html
- https://www.youtube.com/playlist?list=PLDAAF7A8FD5CD582C&feature=plcp
- https://owl.purdue.edu/owl/subject_specific_writing/writing_in_engineering/mechanical_engineering_writing_enhancement_program/report_writing.html
- https://owl.purdue.edu/owl/subject_specific_writing/professional_technical_writing/technical_reports_and_report_abstracts/reports_proposals_and_technical_papers.html

Electricity

- https://www.allaboutcircuits.com/textbook/direct-current/
- https://learn.sparkfun.com/tutorials/alternating-current-ac-vs-direct-current-dc
- https://engineering.mit.edu/engage/ask-an-engineer/whats-the-difference-between-ac-and-dc/
- https://www.school-for-champions.com/science/dc.htm#.W372zehKguU
- http://sinovoltaics.com/learning-center/basics/direct-current-dc-power-definition-and-applications/
- https://whatis.techtarget.com/definition/DC-direct-current
- http://macao.communications.museum/eng/exhibition/secondfloor/MoreInfo/2_3_1_DCCircuit.html
- https://www.khanacademy.org/science/ap-physics-1/ap-circuits-topic/introduction-to-dc-circuits-ap/a/circuit-introduction
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-1/static-electricity/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-2/voltage-current-resistance-relate/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-3/importance-electrical-safety/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-5/what-are-series-and-parallel-circuits/
- https://www.allaboutcircuits.com/textbook/direct-current/chpt-9/analog-and-digital-signals/

G-Code

- https://makezine.com/2016/10/24/get-to-know-your-cnc-how-to-read-g-code/
- https://reprap.org/wiki/G-code
- https://machmotion.com/blog/gcode-the-stuff-that-dreams-are-made-of
- https://www.cnccookbook.com/g-code-m-code-reference-list-cnc-mills/
- https://nraynaud.github.io/webgcode/
- https://camotics.org/
- http://www.editcnc.com/GandMcodes.html

Ladder Logic

- https://euroec.by/assets/files/siemens/s71200_easy_book_en-US_en-US.pdf
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://library.automationdirect.com/understanding-ladder-logic/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/ladder-diagrams/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/permissive-interlock-circuits/
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/motor-control-circuits/
- http://www.plcacademy.com/ladder-logic-tutorial/
- https://www.techopedia.com/definition/20292/ladder-logic

Lean

- https://www.process.st/lean-manufacturing-principles/
- https://www.leanproduction.com/
- http://shinkamanagement.com/introduction-to-lean-manufacturing/
- https://youtu.be/7GfGMhfcSBU
- https://www.youtube.com/watch?v=P_4s2dnAncs
- https://youtu.be/8EXS9wR0VRc
- https://www.youtube.com/watch?v=ZdHGTCXcJQU
- https://www.processexcellencenetwork.com/lean-six-sigma-business-performance/articles/12-essential-lean-concepts-and-tools
- http://asq.org/learn-about-quality/lean/overview/overview.html

Logic

- http://www.plcdev.com/book/export/html/9
- https://www.allaboutcircuits.com/textbook/digital/chpt-6/digital-logic-functions/
- https://www.i-programmer.info/babbages-bag/235-logic-logic-everything-is-logic.html
- https://academo.org/demos/logic-gate-simulator/
- https://sciencedemos.org.uk/logic_gates.php
- http://www.cburch.com/logisim/

Part Feeders

- https://www.youtube.com/watch?v=1-oNjN-TvgI

- https://www.youtube.com/watch?v=nIoXYeWAUp4
- https://www.youtube.com/watch?v=KpkC4GmBsW8
- https://www.youtube.com/watch?v=UkdEN30762E
- https://www.youtube.com/watch?v=pQQSk3Ujc0I
- https://www.youtube.com/watch?v=xD5ifTDFtRQ
- https://youtu.be/B13ffPEv1q4
- https://www.youtube.com/watch?v=c4jgr8xz25Q
- https://www.feedall.com/feeders-conveyors/billet-feeders/manual-load-billet-feeder/
- https://www.youtube.com/watch?v=pjEN88IMFvc
- https://www.youtube.com/watch?v=LCN2LSjeRBM
- https://www.wrabacon.com/automated-systems/tray-stackers.html
- https://youtu.be/wa_fMM5N1rw
- https://youtu.be/3UPVjuvRDcM
- https://youtu.be/Xy7tGAF8UmU
- https://www.youtube.com/watch?v=B3Q3Wtx7STY
- https://www.youtube.com/watch?v=Vm_Tfnwq3MQ
- http://www.autoindtech.com/up210-upstacker.html

PLC

- https://www.allaboutcircuits.com/textbook/digital/chpt-6/programmable-logic-controllers-plc/
- https://www.youtube.com/watch?v=ReTtgzN-Dm
- chttps://unitronicsplc.com/what-is-plc-programmable-logic-controller/
- https://www.industry.usa.siemens.com/automation/us/en/automation-systems/industrial-automation/plc/pages/plc.aspx
- http://www.plcdev.com/how_plcs_work
- https://www.elprocus.com/programmable-logic-controllers-and-types-of-plcs/
- http://www.plctutor.com/plc-components.html
- http://www.plcdev.com/book/export/html/9
- https://www.amci.com/industrial-automation-resources/plc-automation-tutorials/what-plc/
- https://www.ecmweb.com/content/troubleshooting-plcs
- https://unitronicsplc.com/what-is-plc-programmable-logic-controller/

Pneumatic Clamping

- https://www.youtube.com/watch?v=eY5cAYudchw
- https://www.youtube.com/watch?v=5P2pk54wPlo
- https://www.youtube.com/watch?v=snlR6C1ZCo0
- https://www.youtube.com/watch?v=8NKKit18cX8
- https://youtu.be/5P2pk54wPlo
- https://youtu.be/9FGJQ6WRzPY
- https://www.youtube.com/watch?v=Cs0vy42gUkQ
- https://www.youtube.com/watch?v=40WUbK2gCxI

- https://www.datron.com/blog/cnc-workholding-for-milling-machines/

State Diagrams and Flow Charts

- https://www.lucidchart.com/pages/uml-state-machine-diagram
- https://www.geeksforgeeks.org/unified-modeling-language-uml-state-diagrams/
- http://www.agilemodeling.com/artifacts/stateMachineDiagram.htm
- http://www.cs.unc.edu/~stotts/145/CRC/state.html
- https://www.visual-paradigm.com/guide/uml-unified-modeling-language/what-is-state-machine-diagram/
- https://www.youtube.com/watch?v=L9UCsQxuWmw
- https://www.lucidchart.com/pages/what-is-a-flowchart-tutorial
- http://www.breezetree.com/articles/how-to-flow-chart-in-excel.htm
- https://www.gliffy.com/blog/the-comprehensive-guide-to-flowcharts

Work cells

- https://online.kettering.edu/news/2016/08/15/lean-manufacturing-and-work cells-what-you-need-know
- https://www.moresteam.com/presentations/download/work cell_design.pdf
- http://www.strategosinc.com/cellular_manufacturing.htm
- http://www.six-sigma-material.com/Work cells.html
- https://ottomotors.com/blog/work cell-design-lean-manufacturing
- https://www.youtube.com/watch?v=6UKxxU3ukoQ
- http://www.driveyoursuccess.com/2012/06/manufacturing-work-cell-optimization-design-layout-and-analysis.html
- http://www.strategosinc.com/celldesign.htm
- http://www.webpages.uidaho.edu/mindworks/Lean/Lecture%20Notes/ME%20410%20Lecture%20Slides%2007%20Cell%20Design.pdf
- https://www.youtube.com/watch?v=xV1WG-aS1GQ
- https://www.youtube.com/watch?v=1_wwUMwHoEA

Activities

The activities are arranged in the order of the curriculum. They can be accessed from this page to make it easier for students to have them on their computers and easier to locate.

[PIR Motion Sensor]
[Logic and Decision Making]
[Designing Programs]
[Analog Inputs]
[Pneumatics and Control]

Creating Sketches for 3D Modeling

The power of 3D CAD modeling systems is the ability to create a digital prototype that behaves similarly to an actual model. Digital prototyping provides a tool to quickly try a variety of materials and shapes to discover how the design should change to meet certain parameters.

The analysis will only be as accurate as the 3D model. 3D models begin with an accurate 2D image or profile. When creating 3D models we are really building a mathematical database which is using advanced formula to capture our intent and creating visualizations for us. Once the model is created we can digitally apply materials to see how the object will behave under applied forces, temperature, electrical current, and a host of other factors. This ability saves a lot of time in the design of new products. Later we can export the 3D models to a printer to create objects from what we design. This allows designers to try parts together and spot problems before designing an entire manufacturing run.

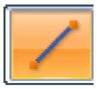
Since the models begin as sketches, it is important to create the sketches as accurately as possible. This section is about the creation of sketches as well as defining them as completely as possible. A fully defined sketch cannot change its shape orientation or position. The term “fully constrained” is used when that condition is met. Geometry is constrained in two basic ways. The first is geometric relationships. Geometric relationships control the orientation of an element with respect to another element or reference plane and the relationships enforce the rules you want your initial sketch to follow. These rules might include parallel lines, perpendicular lines or axes, tangent or concentric circles, etc. Having the geometric relationship defined can simplify your work. For example, you can define a tangent relationship between a line and an arc. If the adjoining elements change, the tangent relationship does not. Geometric relationships control how a sketch changes during editing.

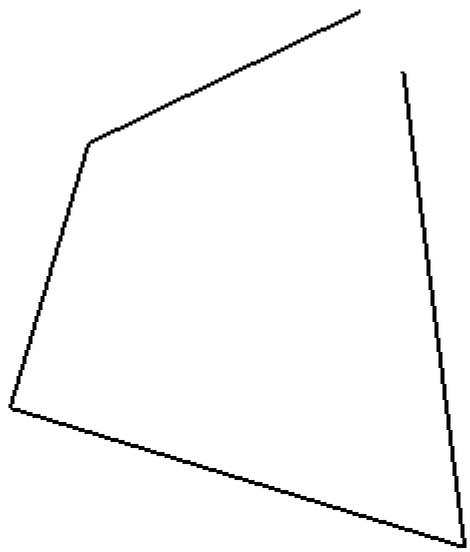
The second way geometry is constrained is establishing dimensional relationships. A dimension assigns and maintains a dimensional value to an individual element or establishes a relationship between multiple elements. A label, consisting of text, lines, and arrows, represents dimensions graphically. The combination of geometric relationships and dimensions accurately depict a sketch.

The exercises below will concentrate on learning how to describe a sketch. It is important to remember there is no one right way to create or establish the relationships in a sketch.

Sketch 1

Begin a new Solid Edge part.

Use the Line  command from the Sketching section of the ribbon and create the shape shown below.



Use your Esc key to exit the sketching command.

Place the cursor over a corner. Left click (hold) and drag the shape around. Notice that you can move each corner, even to the point of changing its shape.

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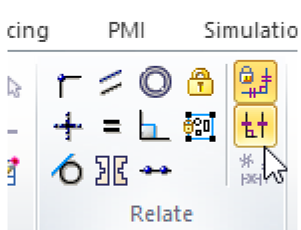
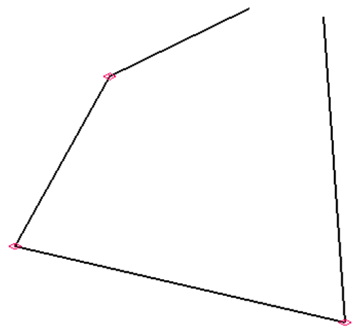
Relationships:

To see which relationships are working on your sketch, click on the Show Relationship handles on the Relate section of the ribbon.

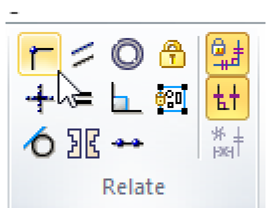


This will show which relationships exist in the drawing. In the picture below, a red square at each corner indicates the lines are meeting at the corner.



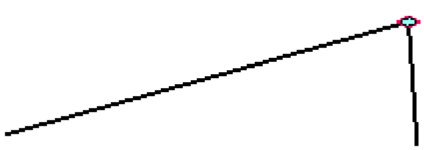
The first step is to complete the shape.

Select Connect from the Relate section of the ribbon.

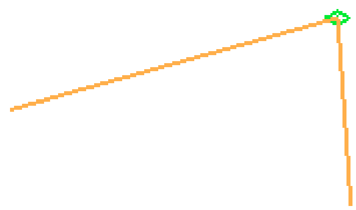


Select the endpoint of one line. You will see the endpoint mark appear on the screen.

Then select the endpoint of the other line. The two endpoints now make up a corner and the connect relationship handle appears.



If any handles appear other than the squares on the corner, delete them. To delete a relationship, highlight the individual handle, right click and select delete. Be sure the handle is highlighted. A common mistake is to erase the line and not the handle. Use the Ctrl key and the Z (Ctrl Z) at the same time to undo the last action if changes are necessary.

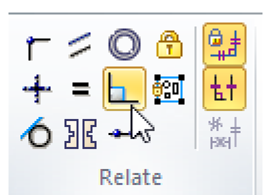


Adding More Relationships:

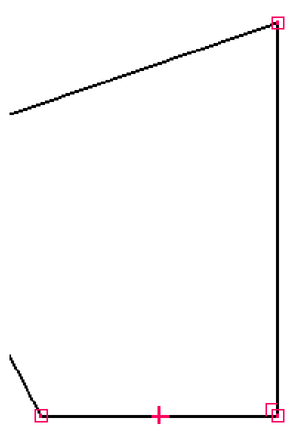
Choose Horizontal/Vertical from the Relate section of the ribbon. Click on the bottom line of your sketch.

The line should now be horizontal and you will see a + in the middle of the line. This shows there is an additional relationship present. If you double click on a line you should be able to drag the line to different locations. The bottom line will always be horizontal no matter where you move it.

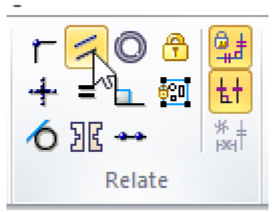
Add a Perpendicular relationship between the bottom line and the line on the right by selecting perpendicular from the relate section of the ribbon.



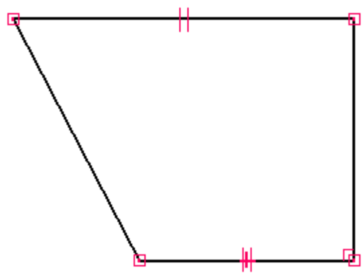
Now the line on the right shows a perpendicular relationship to the bottom line.



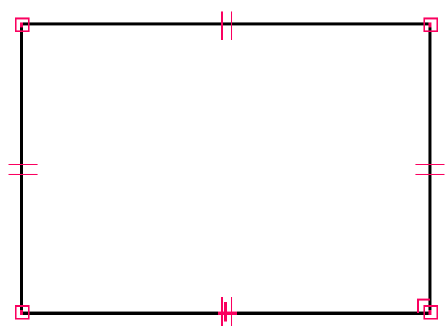
Add a Parallel relationship between the bottom line and the top line.



This adds the parallel marking to the bottom and top lines.



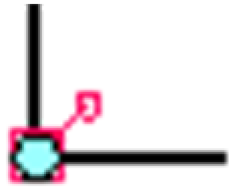
Select a relationship to make the line on the left a vertical line. There are a few you can use. Select one that will allow you to add the relationship to make the shape a rectangle.



This is now a rectangle that cannot be dragged into any other shape other than a rectangle. You can move it around the screen and change the relationship between the sides.

We can fix a point on the rectangle so it cannot move. Select the Lock from the Relate section of the ribbon.

Select the lower left corner of the rectangle. You will see something that looks like a pin appear. You will not be able to drag the corner.



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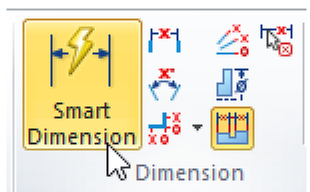
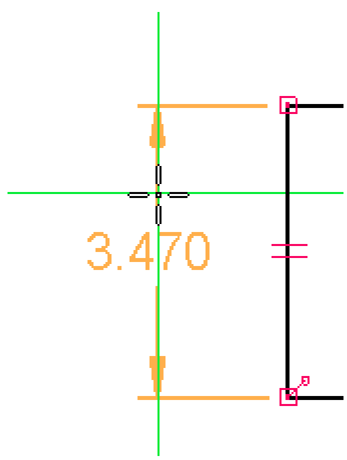
Adding Dimensions:
We can use dimensional relationships to further define the shape. The dimensions work in concert with the geometric relationships. Select Smart Dimension from the Dimension section of the ribbon.

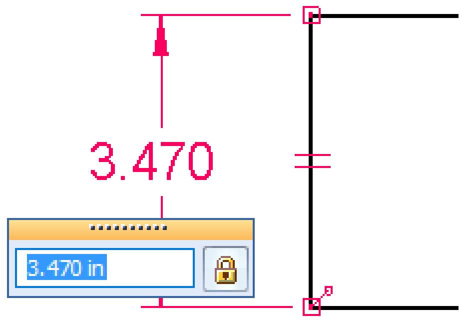


Select the vertical line on the left. Move the mouse off the line and see a dimension appear and follow your mouse.



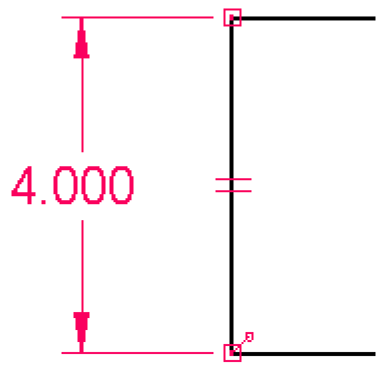
Left click to place the dimension on the screen.

A dialog box will open and allow you to enter in a value.

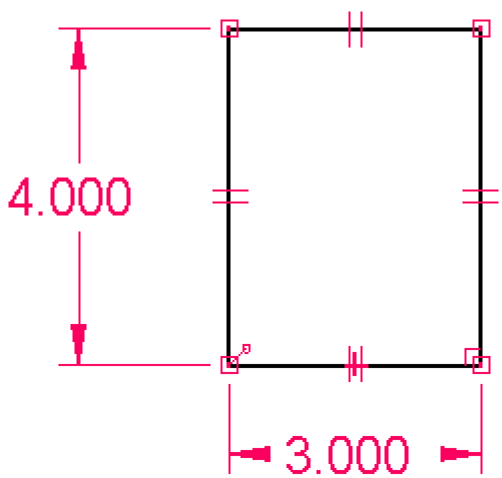


Enter the value 4 and hit the enter key.

See the sketch change shape and the dimension change to 4.



Now select the bottom line and change the dimension to 3.



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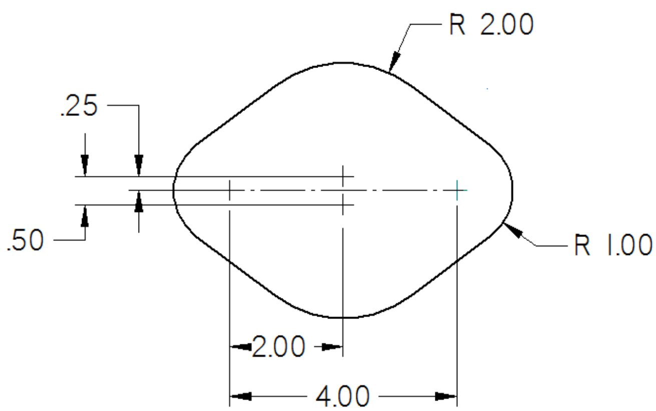
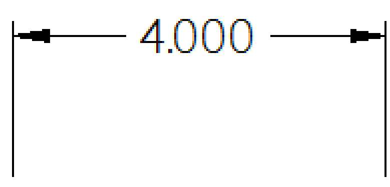
Sketch 2

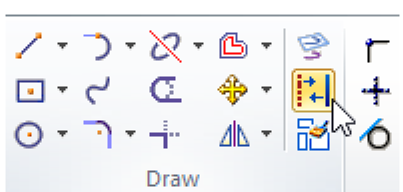
Begin a new Solid Edge part. We will be creating a sketch to resemble the one below.



In a complex shape designers will frequently utilize geometry to aid in the construction. Study the drawing above. You will see the centers of the round ends are spaced 4 apart. Begin by drawing a line segment. Add a dimension so it is exactly 4 long.



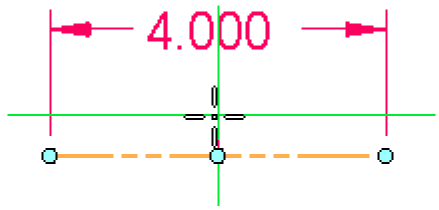
Since this line is only used for construction and will not be part of the sketch we will change the line into a construction line. Highlight the line by clicking on it. Select Construction from the Draw section of the ribbon.



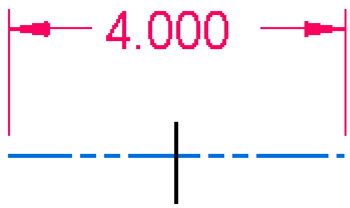
The line changes character. It now is made from two short dashes followed by a long dash. This tells experience designers this is a line used to set up needed geometry.

The centers for the curves at the top and bottom of the shape will be .25 above and below the center and centered.

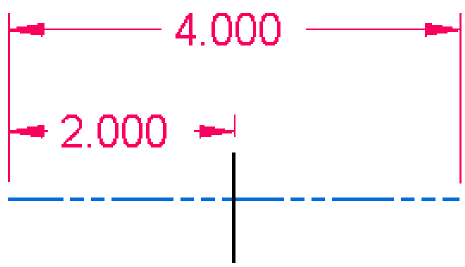
Select the Line command and come close to the existing construction line. The line will indicate where the center is.



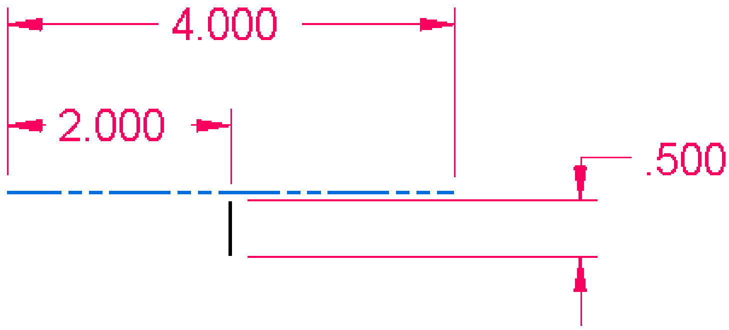
Draw a line through the center.



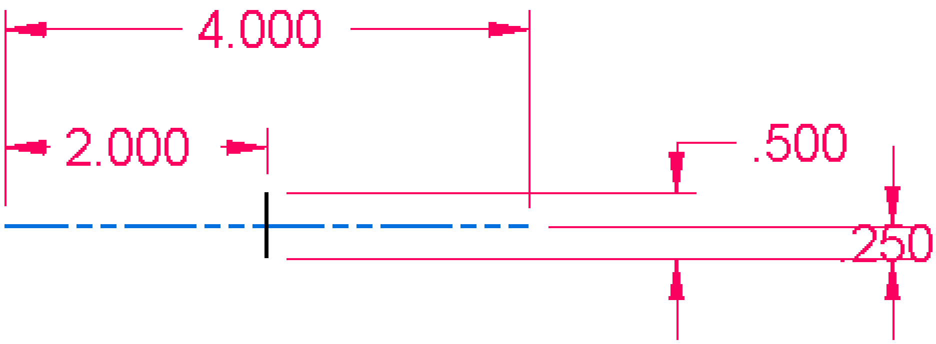
Select Distance Between from the dimension section of the ribbon. Select the end of the horizontal line and then the vertical line you just drew. Place the dimension below the 4 but above the line.



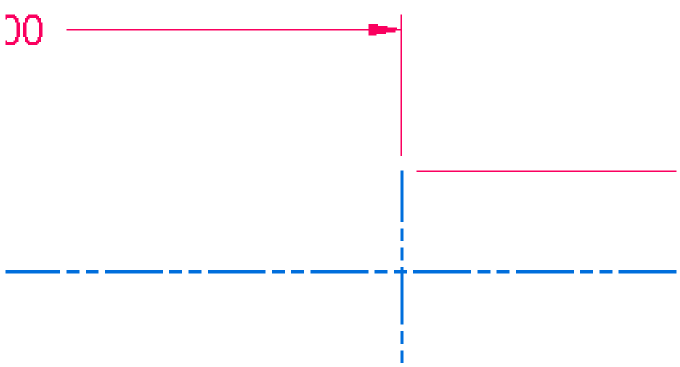
If you drew the line through the center point the program assumed you wanted a bisector so the dimension should be accurate. If it is not you should change it. We need to be sure the line is ½ long with the endpoints .25 on either side of the center line.



Add the .25 dimension from the end point of the line and the horizontal line.



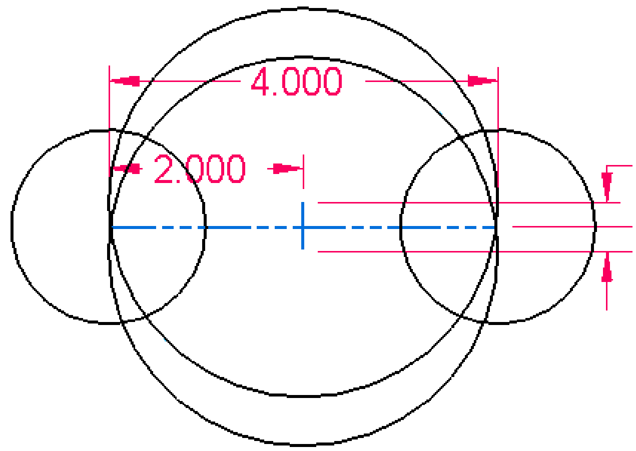
Convert the vertical line into a construction line. It is a small line so you might not see that it is a construction line until you zoom in.



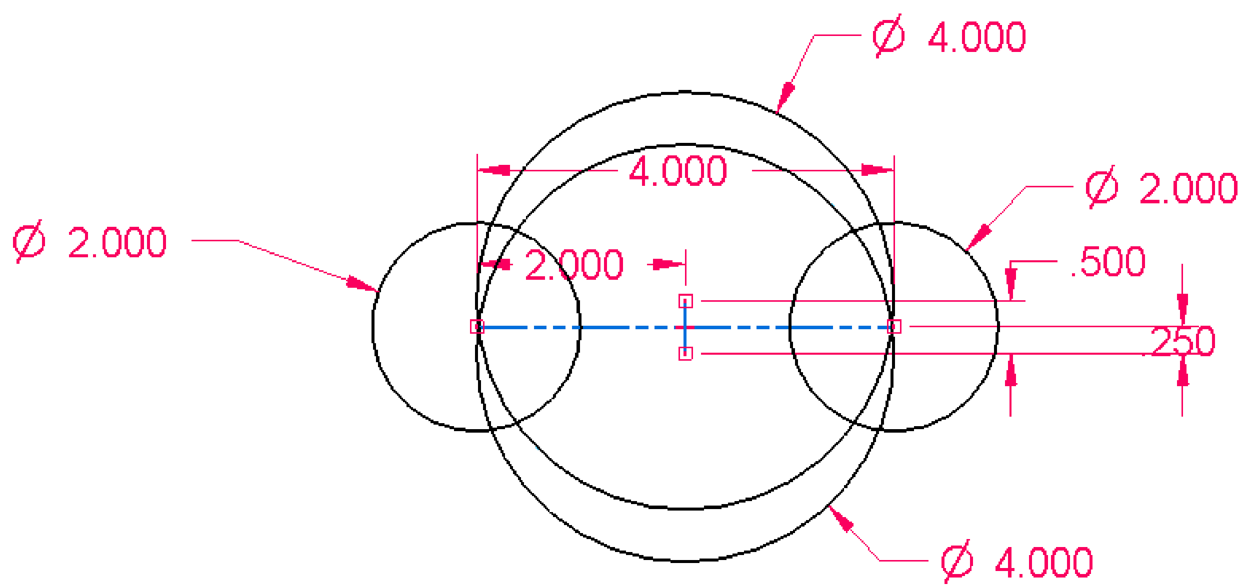
Select the Circle tool from the Draw section of the ribbon.

In the dialog box enter 2 for the radius of the circle. Click on each end of the vertical line to place the circle at the above and below the line. They will overlap. Hit the escape key to exit the circle command.

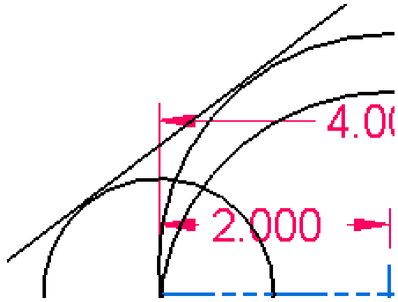
Repeat the process using the radius of one inch to place the circles at each end of the horizontal line.



Use the smart dimension tool to add dimensions to each circle. This will prevent them from changing size later.

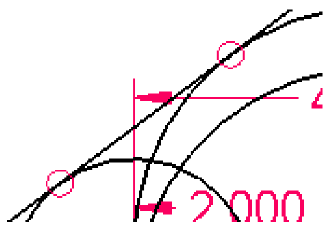


We now create a line that is tangent to each circle. Select the line command. Sketch a line from the circle on the left to the top circle. Don’t worry if the line isn’t tangent. We will add that relationship to be sure it is what we want.

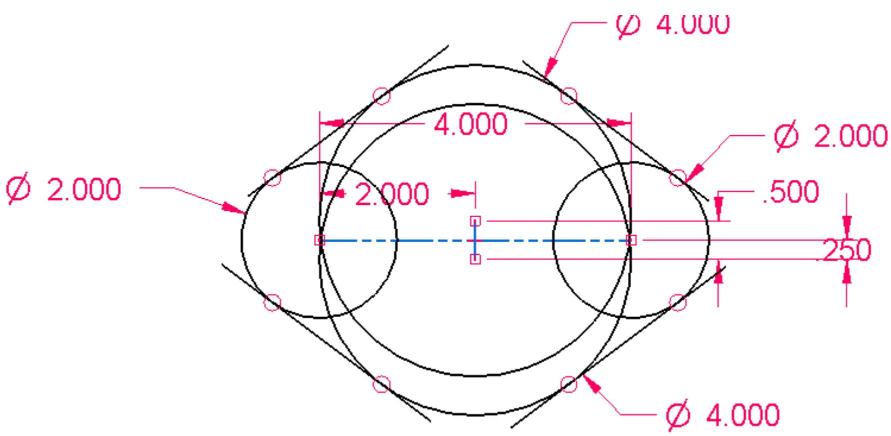


From the Relate section of the ribbon highlight the Tangent relationship.

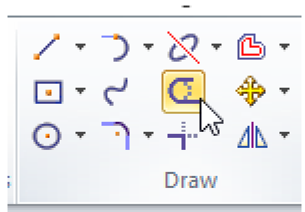
Select the line and then the circle on the left. Then select the line and the top circle. The line might not move much but it will show the tangent handle.



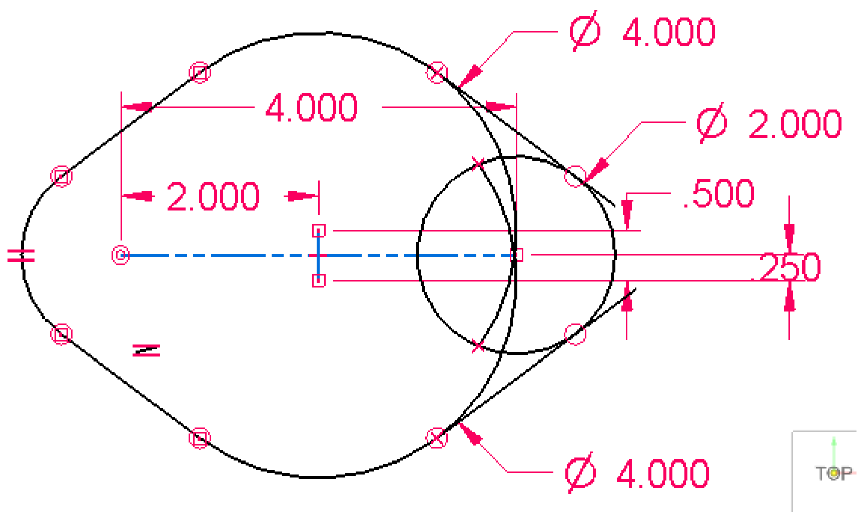
Repeat the process for each line and circle.



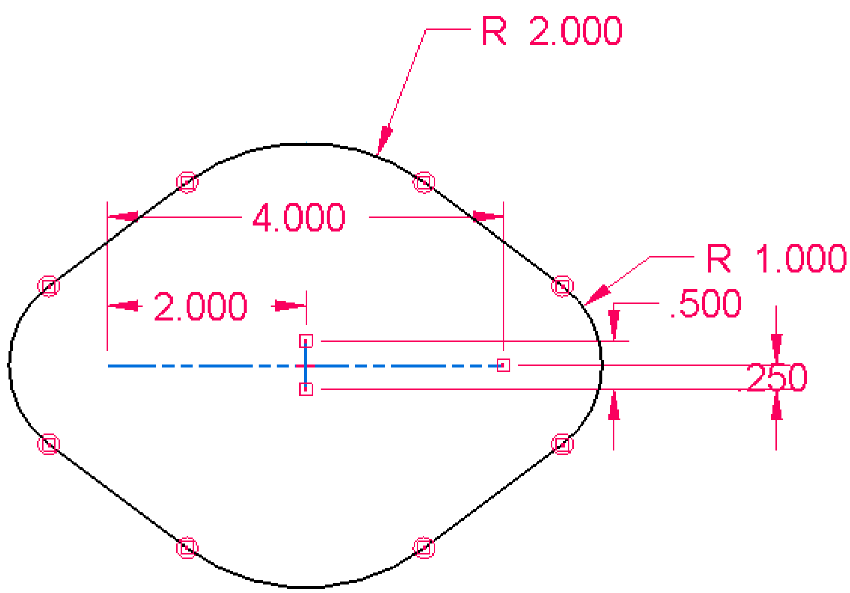
Now use the trim command found in the draw section of the ribbon.



Select the parts of the geometry not needed. Use the Ctrl Z combination as a shortcut for Undo if necessary.



The finished sketch should resemble the one below.



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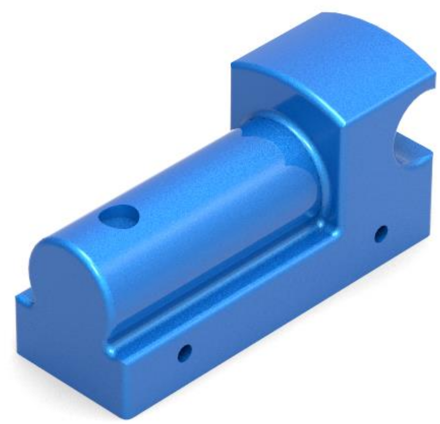
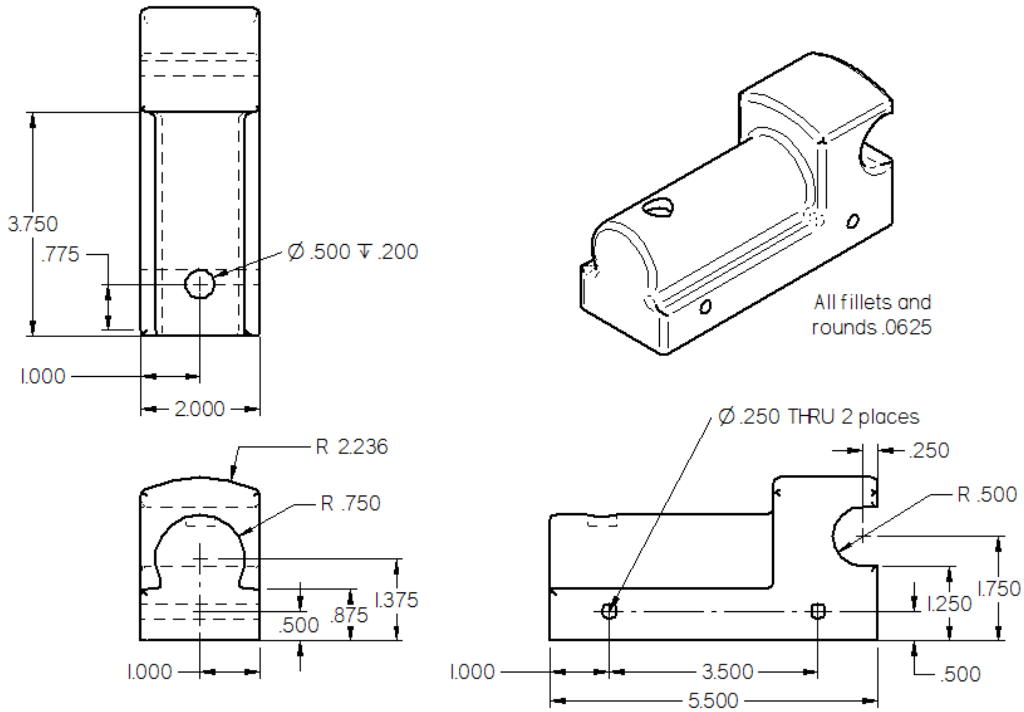
Basic 3D Commands

Creating parts in a 3D solid modeling software program follows set procedures. Any 3D shape begins with a 2D shape and then the shape is translated into a solid model. In a previous exercise you used a 2D shape and extruded it. The extrusion process uses the original shape and copies it in a third dimension. A circle becomes a rod. A square becomes a rectangular prism. There are other ways to create 3D shapes. These exercises are designed to introduce some of them and to provide a sense of how various shapes can be combined to produce what is needed. The following exercises demonstrate one way of creating the shapes. There is no one correct way.

Extrusions

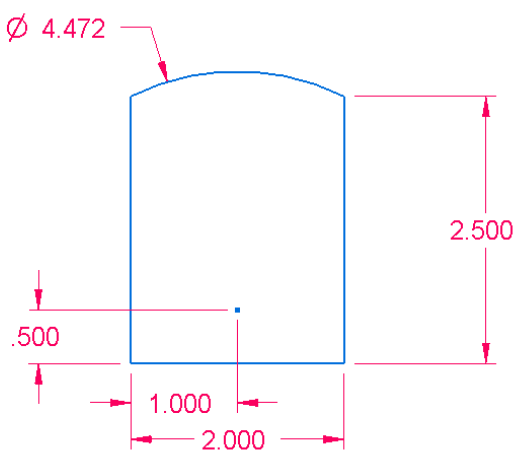


Geometric Requirements

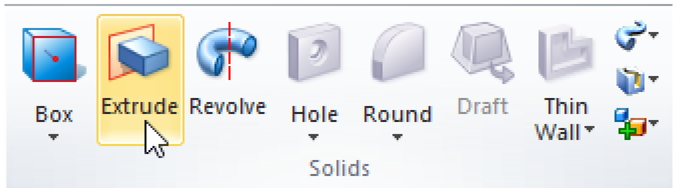


Instructions:

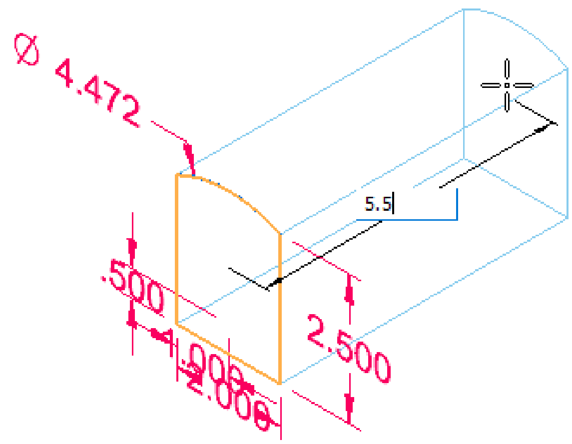
Begin with a new part file. Create a sketch similar to the one shown below of a train body.



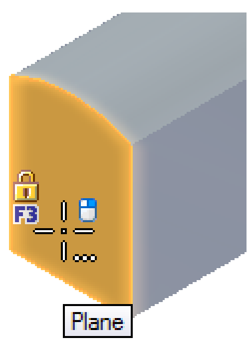
Extrusions:
Select the Extrude tool from the Solids section of the Home ribbon. Select F1 to display the Help menu.



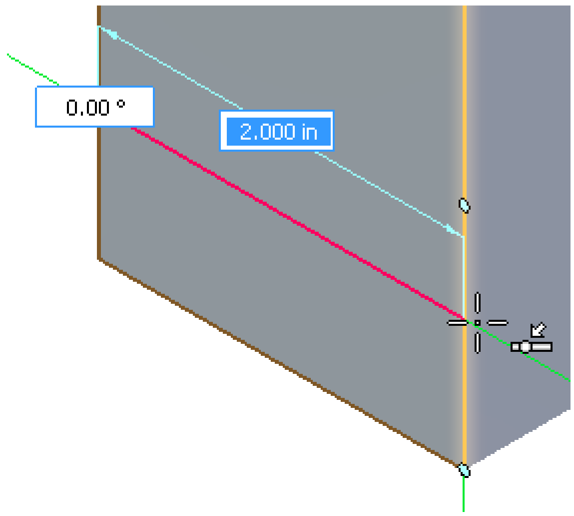
Use Face for the selection and select your sketch. Extrude a distance of 5.5.



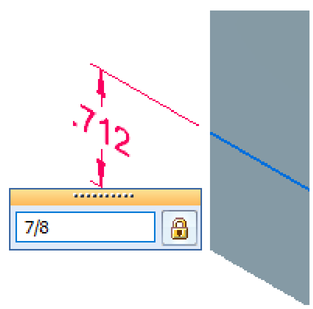
Next draw a line across the front of the train body. Select the line tool and hover over the front of the train body. When it highlights use the (F3) key to lock on the front of the train.



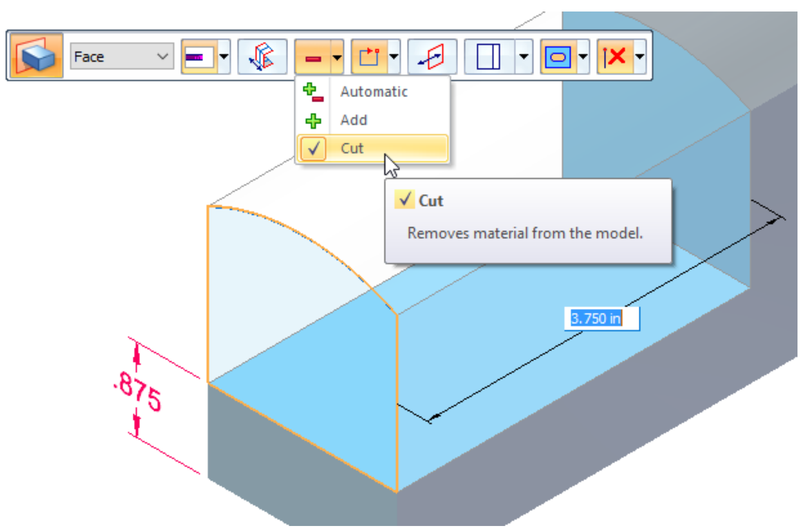
Look for the handle that indicates the cursor is on the line.



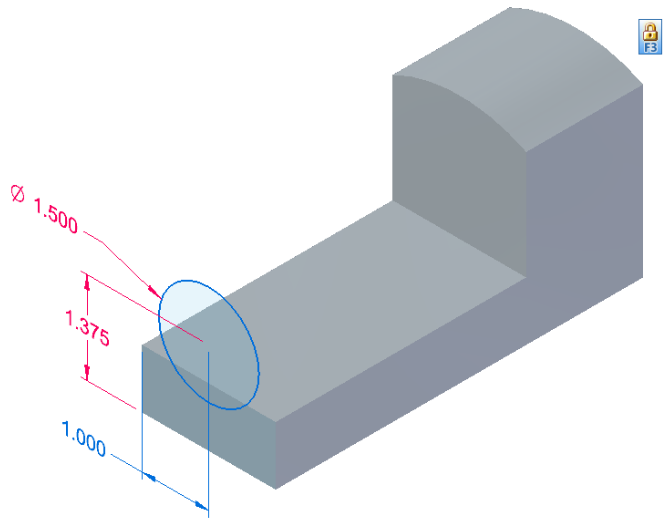
Dimension the line 7/8 from the bottom line.



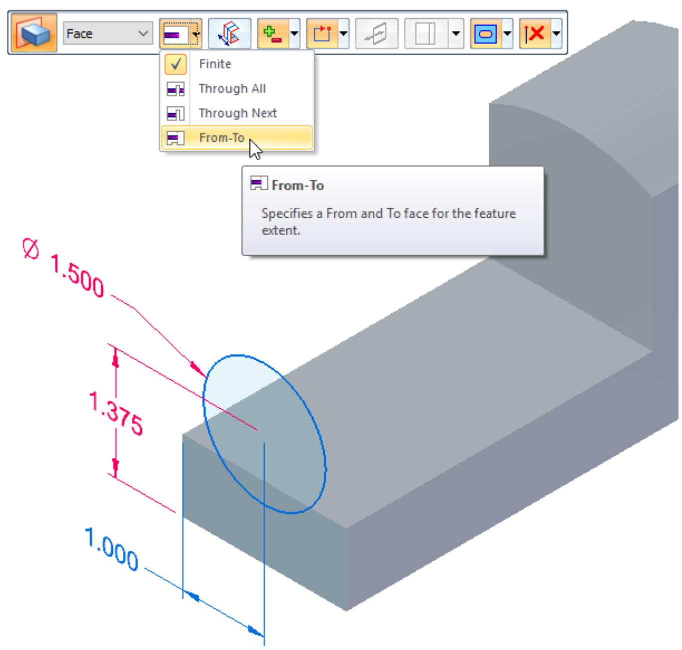
Use extents for the limits and cut (minus sign) for the operation. Use 3.75 for the distance.



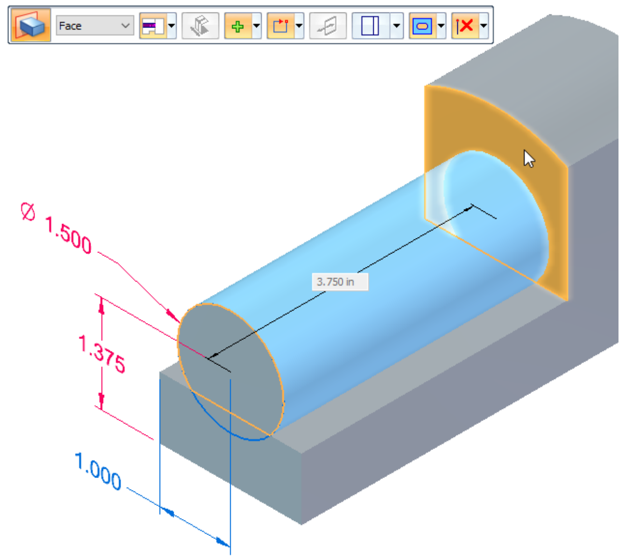
Sketch a circle on the front of the train body. Be sure to use F3 to lock the plane on the front. Add dimensions to the circle center as follows: 1" from the side and 1.375 from the bottom. Set the diameter to 1.5.



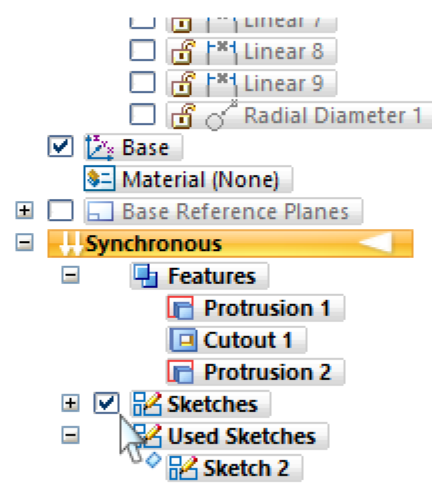
Extrude the sketch. Use Join for the operation and From-To for the extents. This will enable the selection of the starting and stopping point of the extrusion.



Highlight the upper part of the circle. Right click to accept. When prompted select the vertical surface behind the sketch.



The computer will then extend the shape and stop at the surface. Don't worry that the sketch moves. On the left side of the screen in the synchronous section of the tree uncheck the sketches to hide the sketch.



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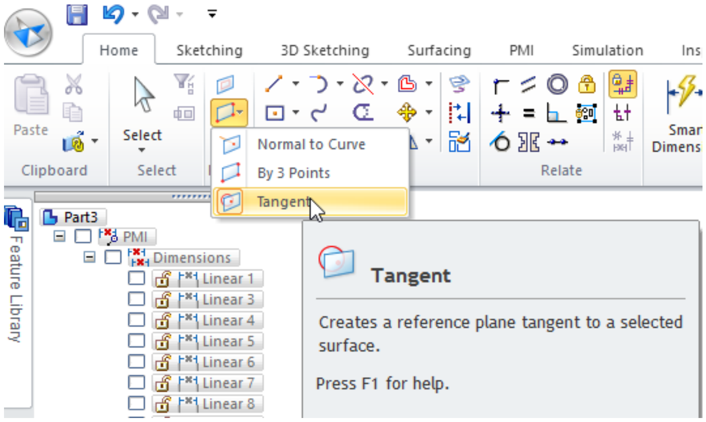
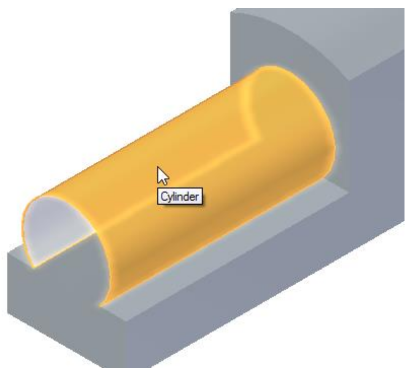
Creating a Plane:

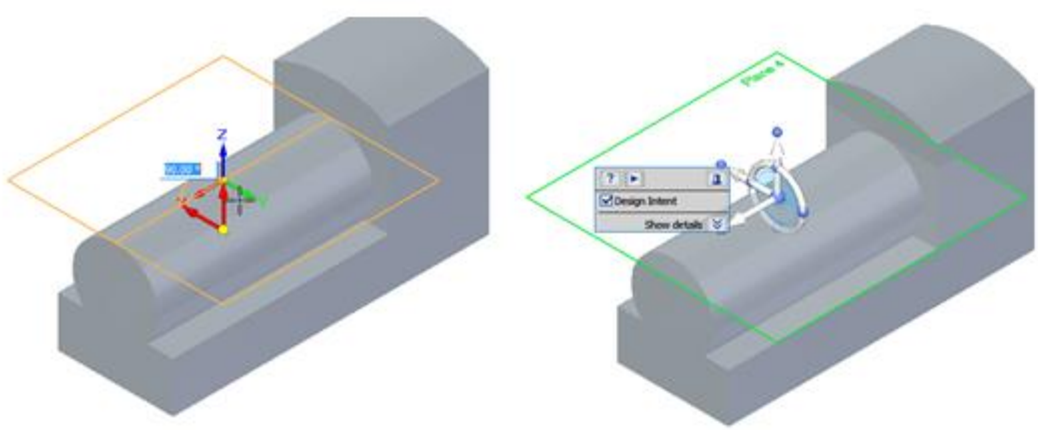
There are instances when a sketch must be created where there is no existing solid face. To get the sketch where it is needed, we create a plane. From the Home ribbon, select Tangent from the Planes section. Select F1 to see the Help section on creating a tangent plane.



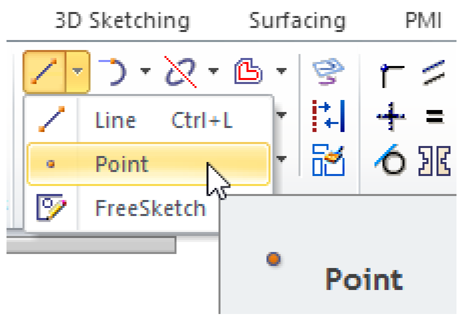
Select the cylinder on the front of the train body.



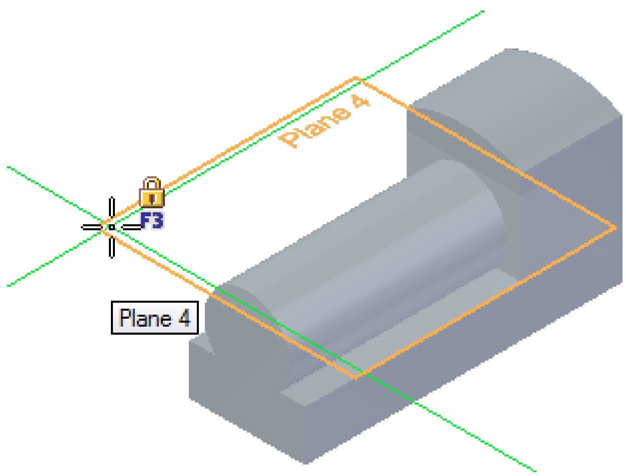
Set the angle to 90 degrees. Click on the top of the cylinder to keep the plane on the top.



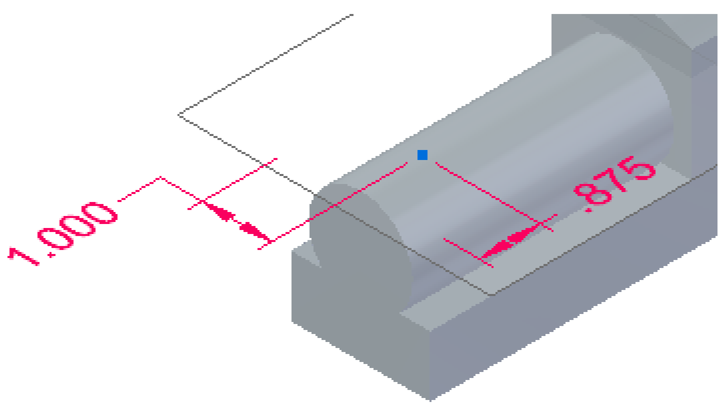
Use the Point command found under the Line command in the Draw section of the ribbon.



Hover over the edge of the plane until it highlights and lock the drawing plane using the F3 key.



Once you lock the plane in place, switch to the top view.
Click to place the point close to where you want it. Dimension the Hole Center 7/8 inch from the front of the train and 1 inch from the side.



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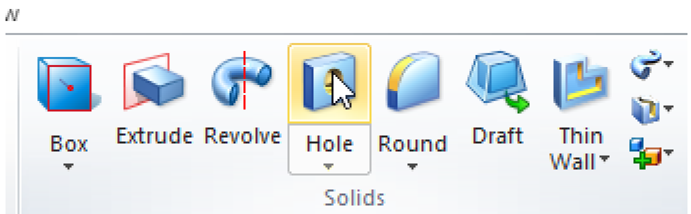
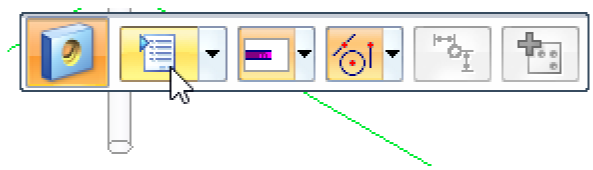
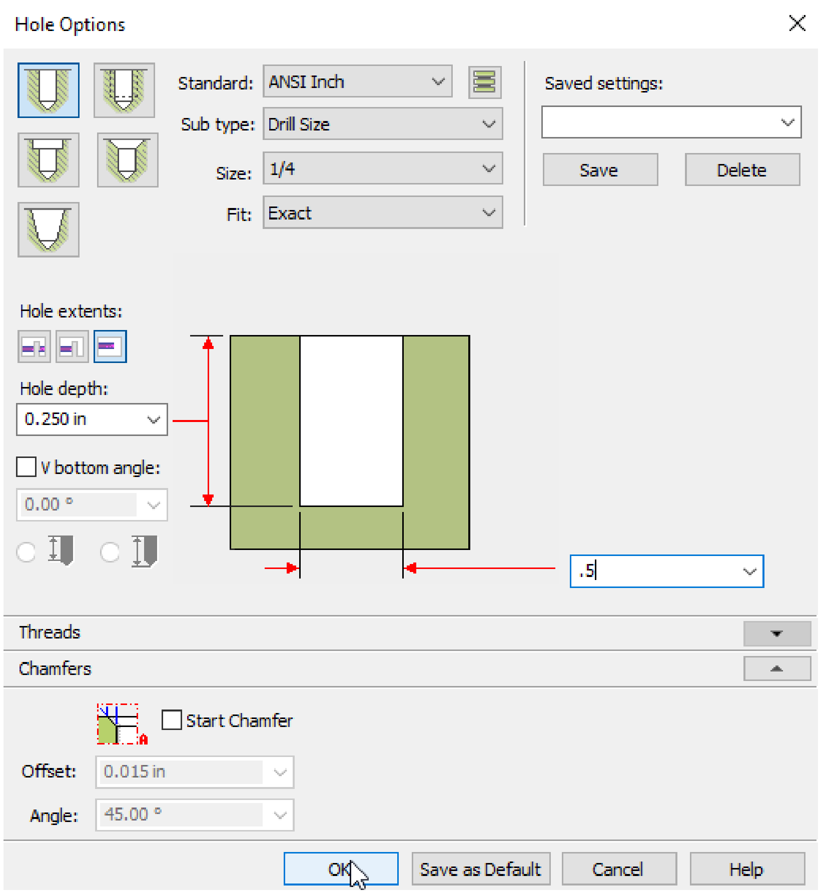
Hole:
Select Hole from the Solids area of the ribbon.



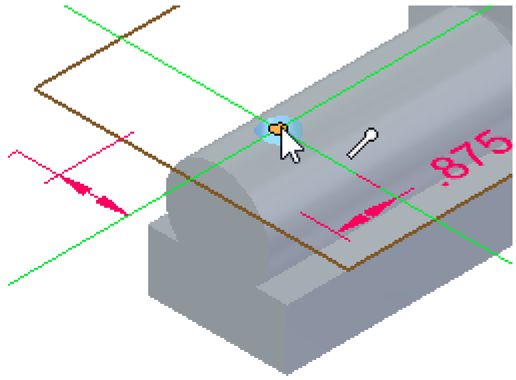
F1 will provide a lot of information about creating various types of holes.

From the Hole dialog box select the settings option.

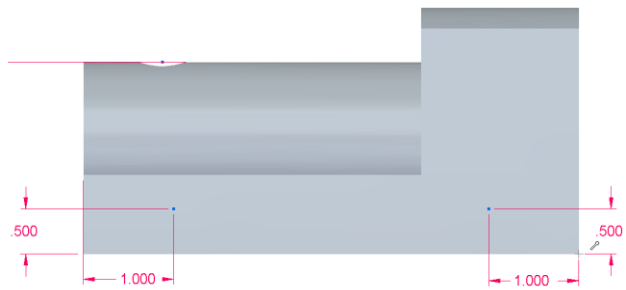




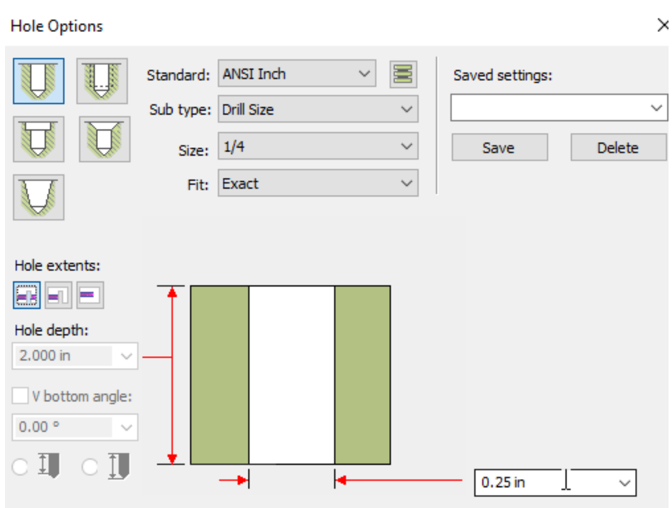
Set the hole depth to .25 and the diameter to .5. Select OK and click on the point drawn.



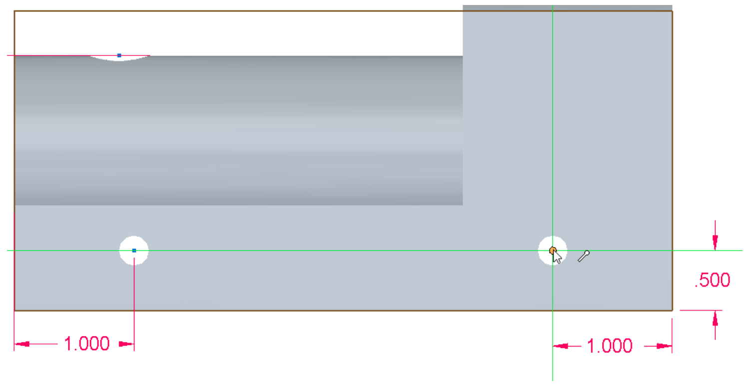
Change the view to the side of the train body and place two points. Dimension the points ½ inch from the bottom and 1" from each end. The measurements will be critical when assembling your train. Be sure it is dimensioned correctly.



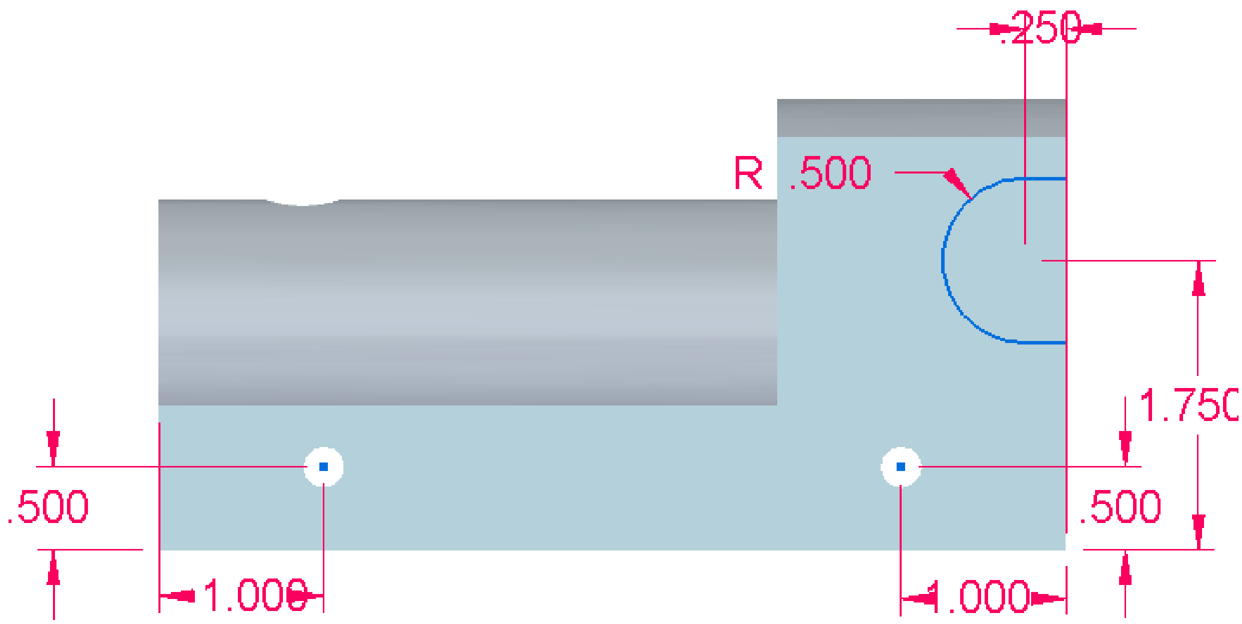
Use the hole command and make the holes .25 in diameter and Through all for the extents.



Place a hole on each point created. Be sure the handle indicates that the hole is correctly placed.



Sketch the notch for the back of the train body. Extrude the sketch using Cut for an option and Through all for the termination.



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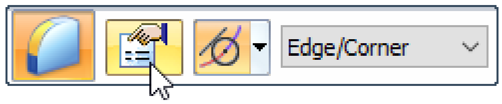
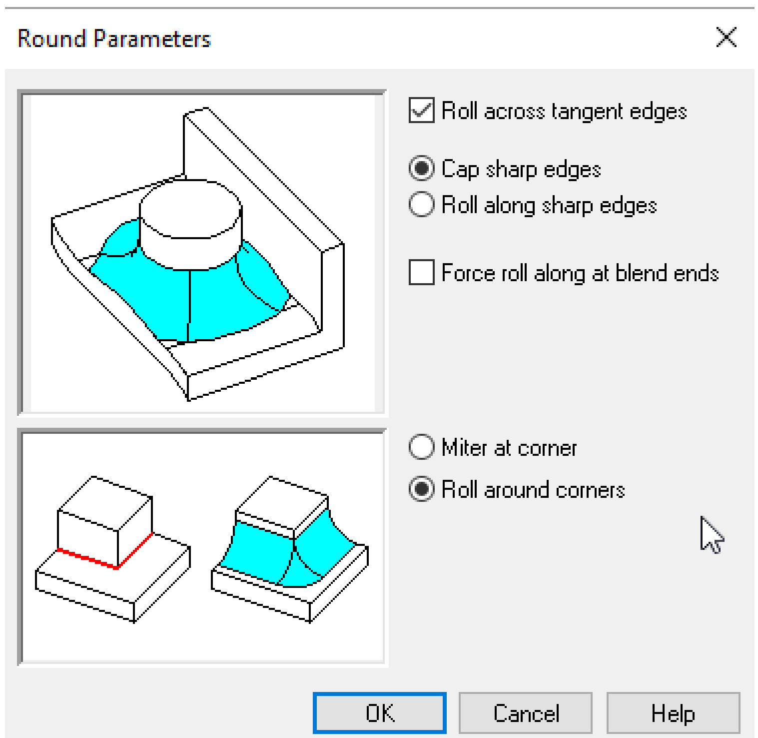
Fillets and Rounds:

Fillets and rounds are used to connect planes smoothly with an arc that is tangent to the surfaces. An inside corner is a fillet and an outside corner is called a round. In actual application fillets and rounds help reduce the stress on an object as square corners are prone to breaking and chipping. Software frequently uses the same term for both operations although engineers know the important difference between the two. For more information, select the Round command from the Solids section of the ribbon and press F1 to access the help menu.

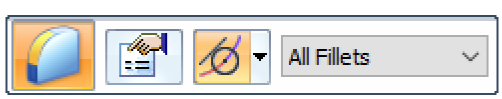
In the Round dialog box select the icon for Parameters.



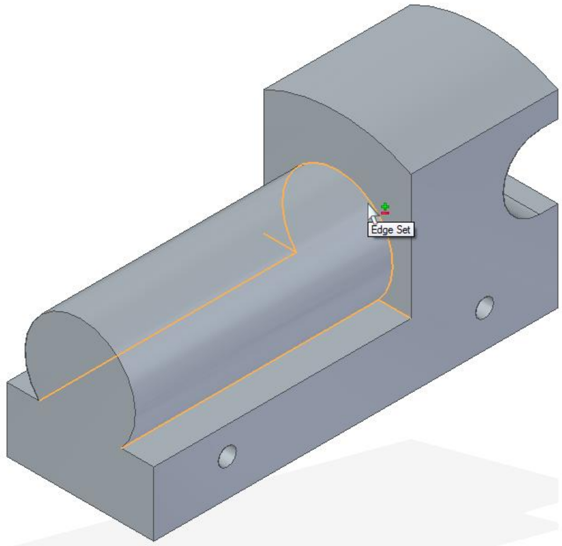
Select the following options for the Round command.



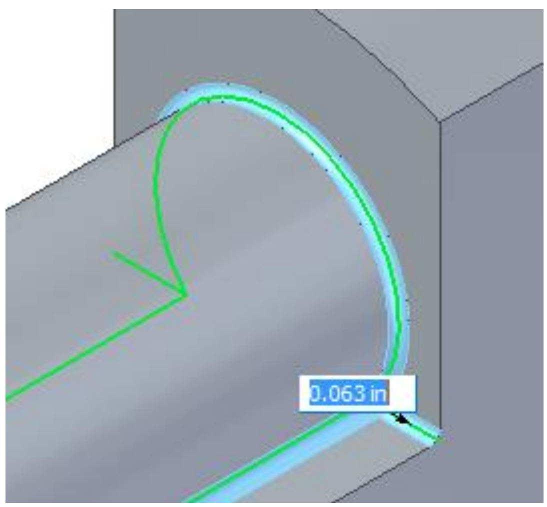
Select All Fillets for an option.



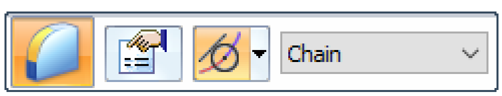
This command will find all the elements that are connected together that would get a fillet.



Use .0625 for the radius of the round.

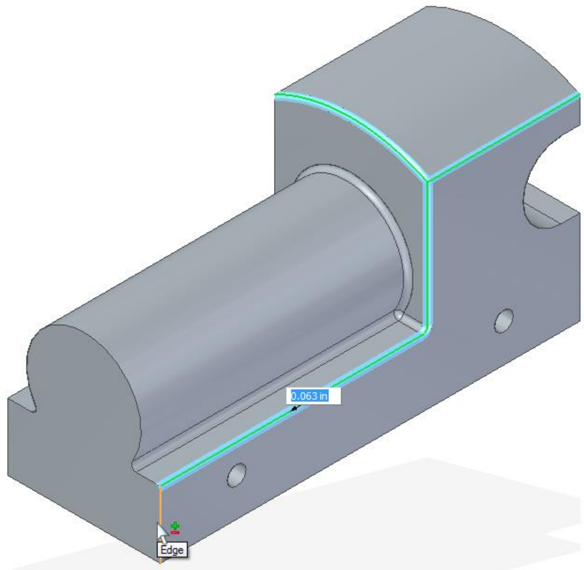


Return to the Round dialog box and select Chain for an option. This will select all lines that are connected. We want to round all the corners but not the holes for the wheels.



Select all the lines that make up the edges of the train engine.

As you select the lines the rounds will appear.



Set the radius to .0625.
Save your file

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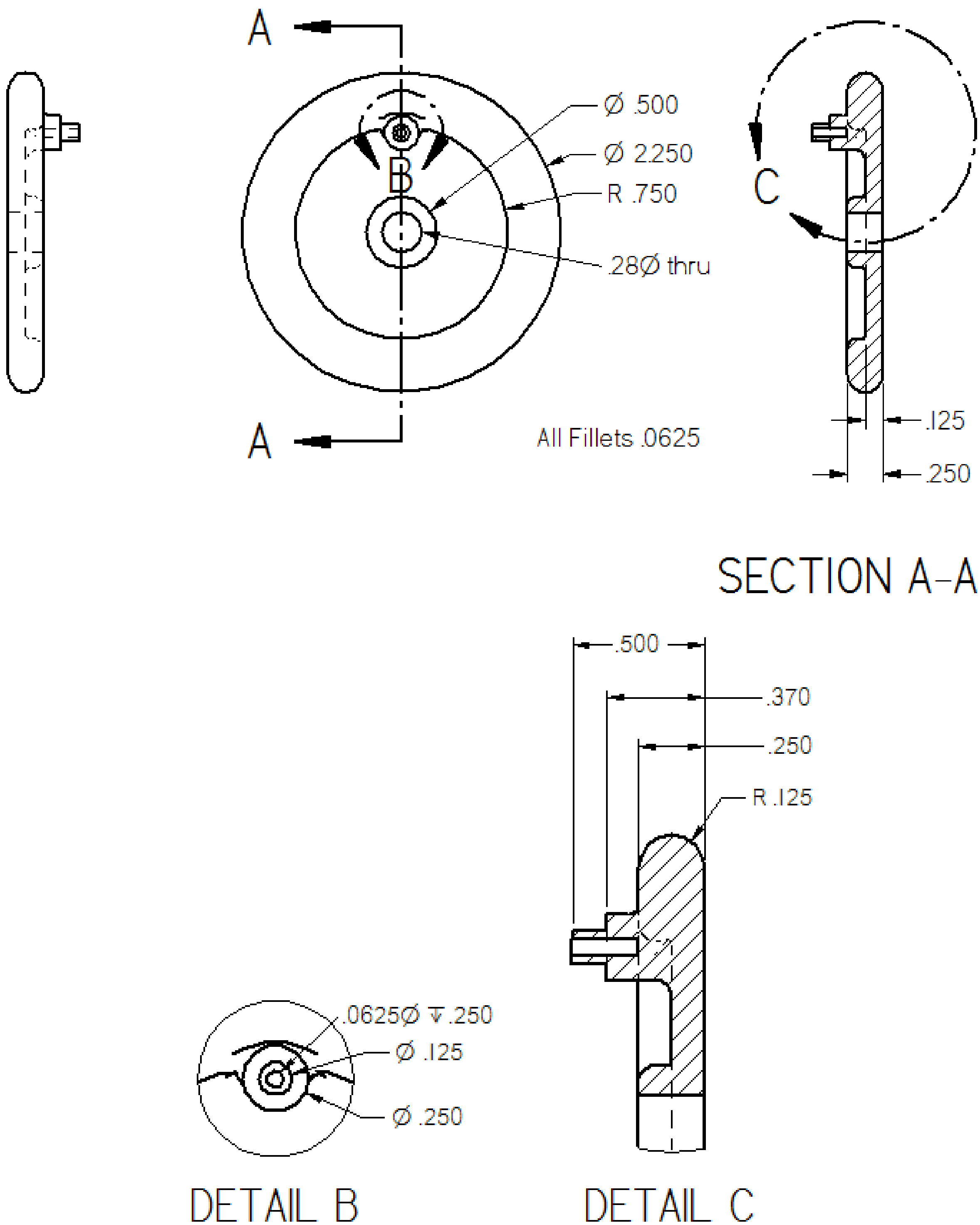
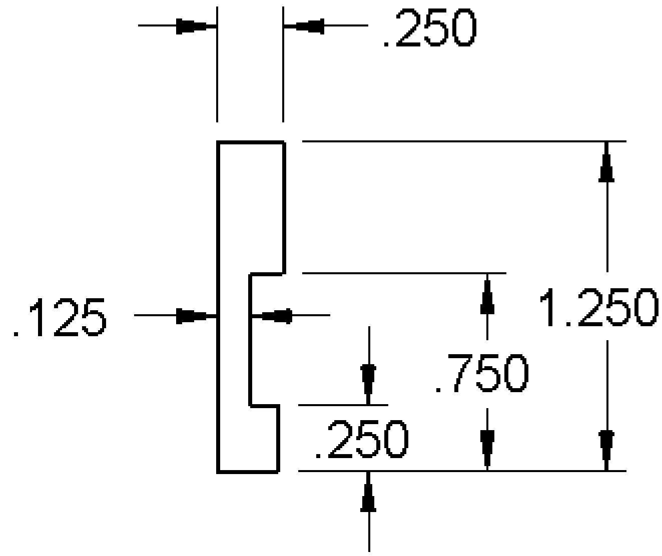
Wheel

Geometric Requirements:

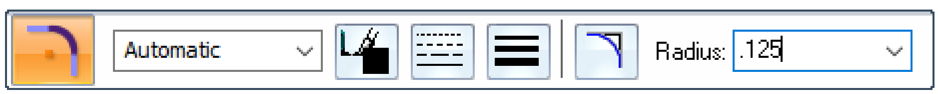


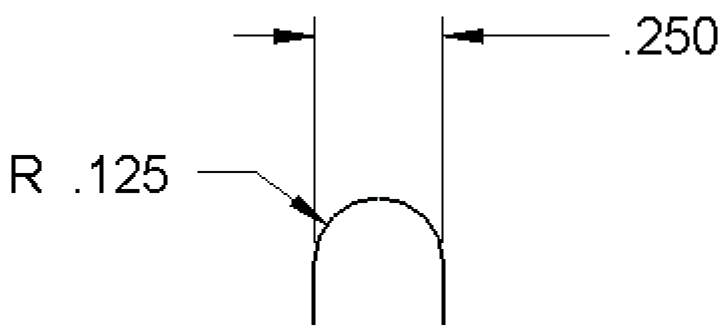
Create the sketch

Begin with a new part file. Create a sketch similar to the one below.

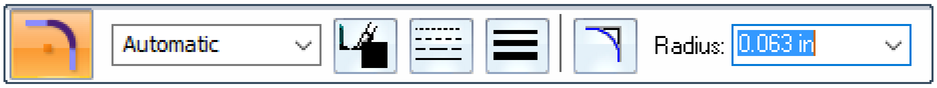


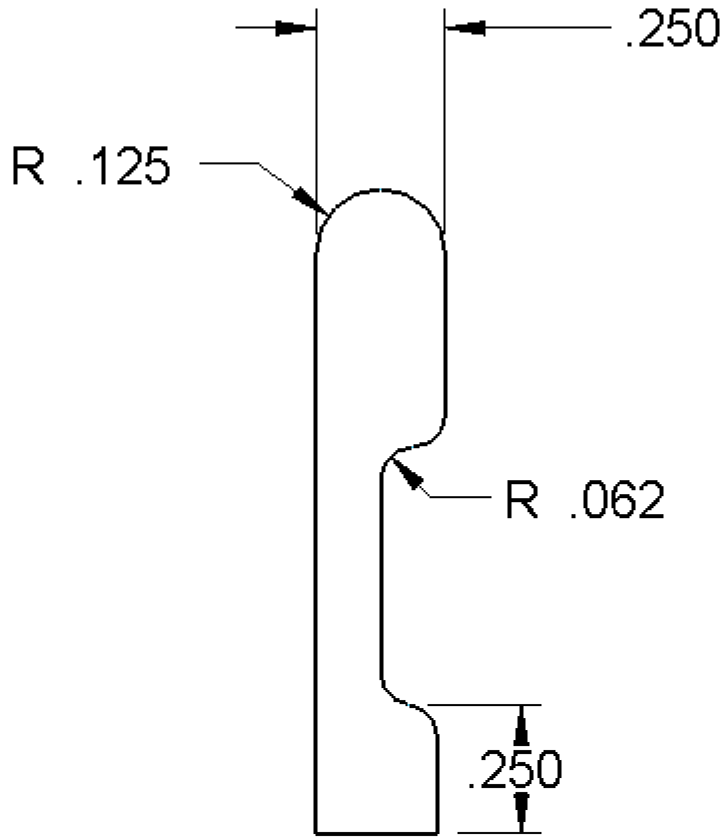
Use the Fillet tool from the Draw area of the ribbon to round the top of the wheel. Use a radius of .125





Reset the radius to .0625 and round the other corners except for the bottom line of the sketch.





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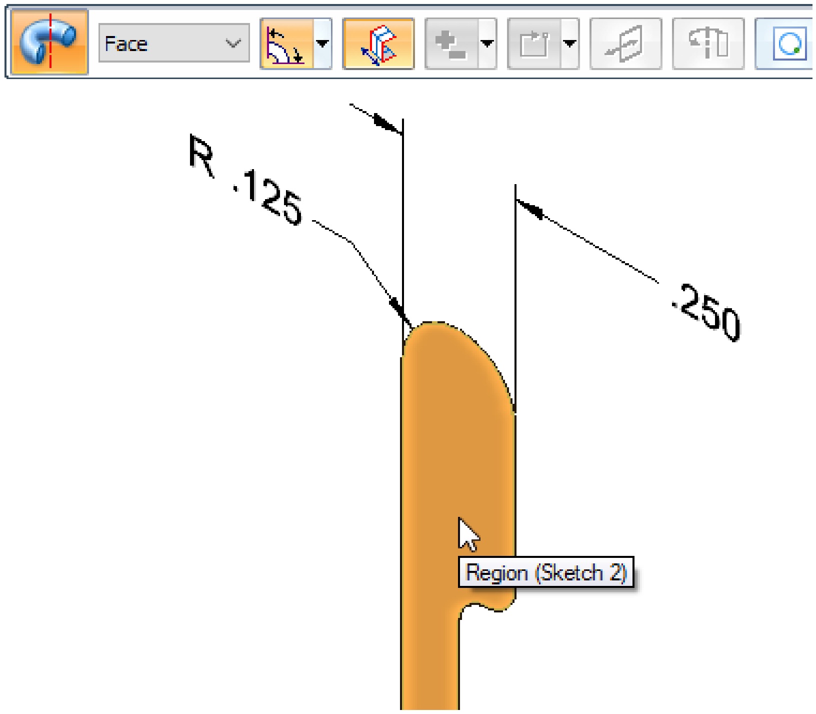
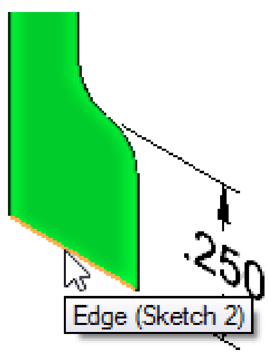
Revolve:
When a curve of a plane created by a collection of curves is rotated around an axis the resulting solid shape is called a revolution. Mathematicians call this a solid of revolution. CAD programs call the command Revolve. It allows for the creation of a solid shape from what is drawn by spinning the shape around an axis. For more information, select the Revolve command and press the F1 key.

Place the view into a 3D view. Select Revolve from the Solids section of the Home ribbon. Set the selection style to Face.

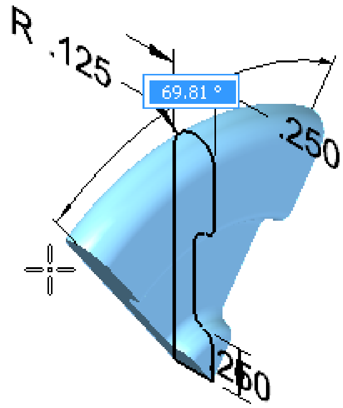


Highlight the sketch and right click to accept.

The prompt will ask for the axis of revolution. Select the very bottom line of the sketch. This should cause the shape to revolve around that line.



The shape should begin to revolve. Enter 360 in the box to create the complete wheel.



The resulting shape is the blank for the wheel.

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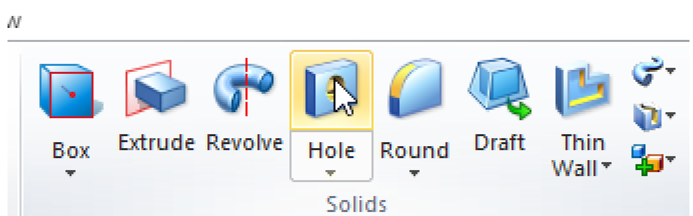
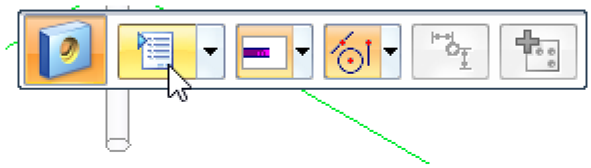
Hole:

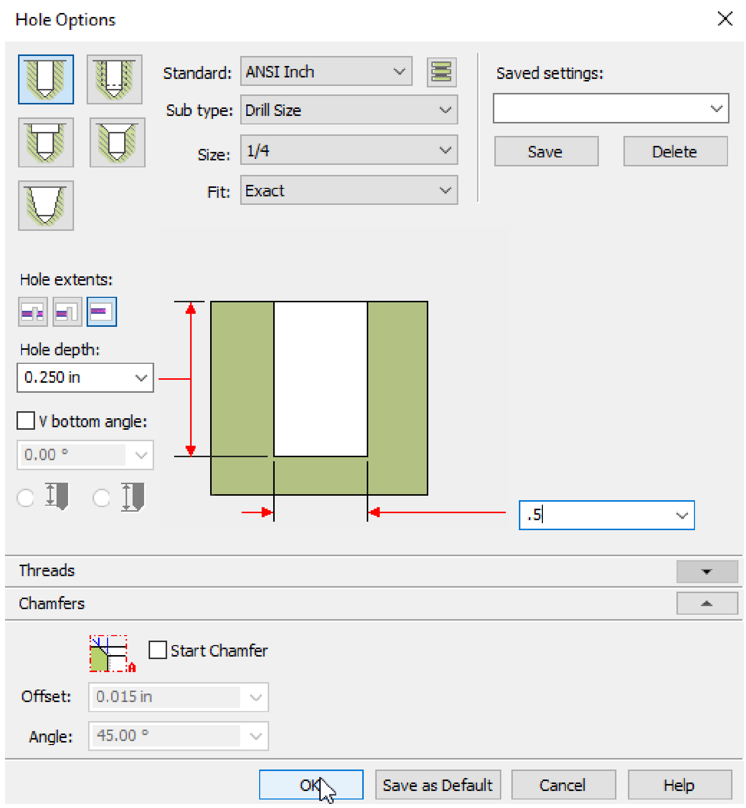
Select Hole from the Solids area of the ribbon.



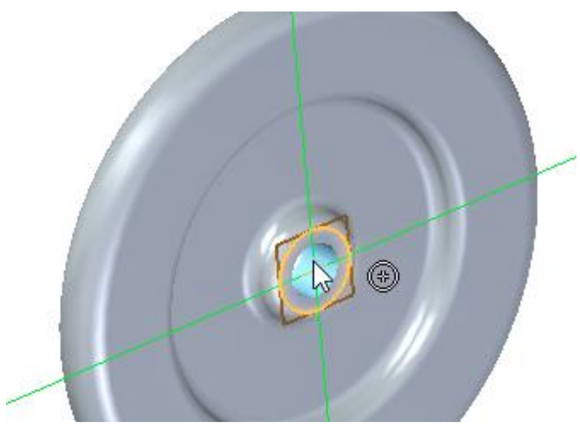
F1 will provide a lot of information about creating various types of holes.

From the Hole dialog box select the settings option.





Select the Hole command from the Solids area of the ribbon. In the Hole dialog box, set the diameter to .25 and the extents to Through all. Hover over the center of the wheel and select the F3 key to lock the plane. Look for the center relationship and place the hole in the center of the wheel.



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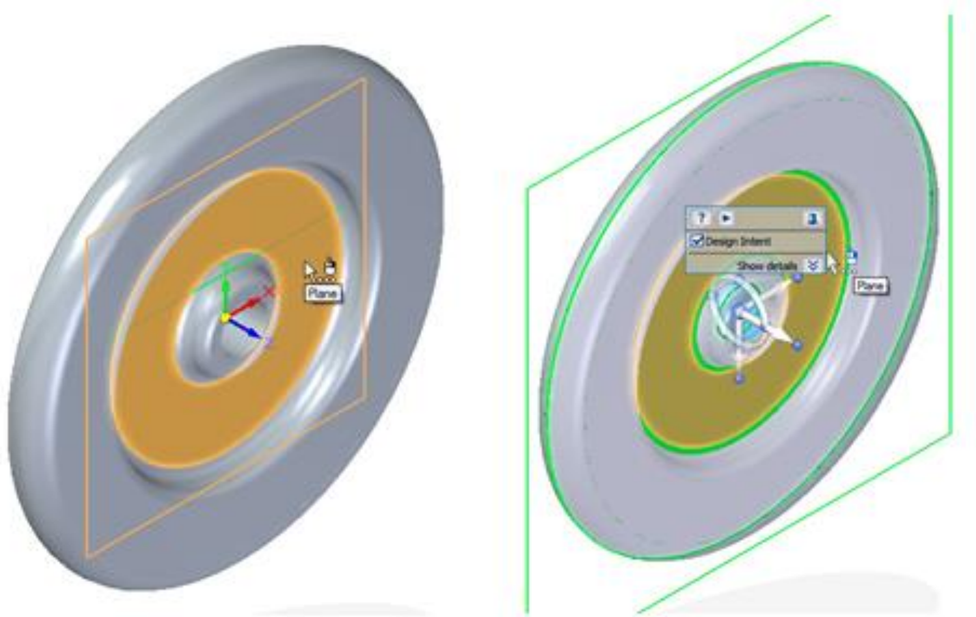
Live Section:

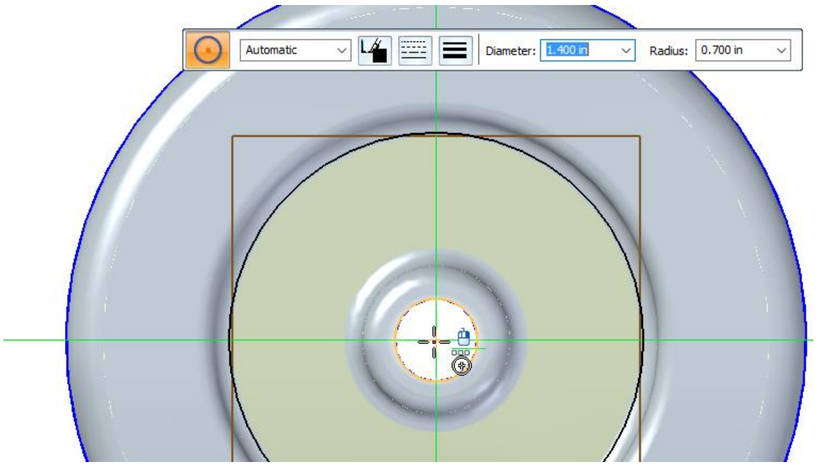
A Live Section sets a plane to work on using any reference plane or surface. The Live Section allows for work on an uneven surface. Look at the drive component of the wheel and how it is half in the wheel and half on the hub. In order to create a place to sketch use the Live Section command from the Home ribbon. For more information select F1 when you select the Live Section command from the Home ribbon.

After selecting the Live Section command, hover over the low spot on the wheel. It will be highlighted. Select that flat area and the plane will be created in the middle of the wheel.



Now select the Circle command from the Draw area of the ribbon. Hover over the plane created and select F3 to be able to easily draw on the surface.

Create a circle 1.4 in diameter from the center of the wheel.



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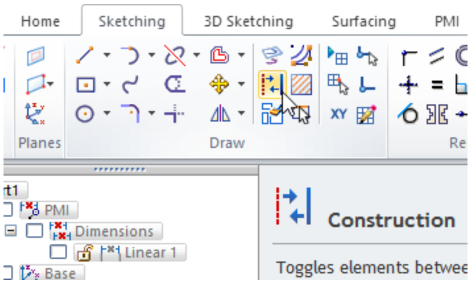
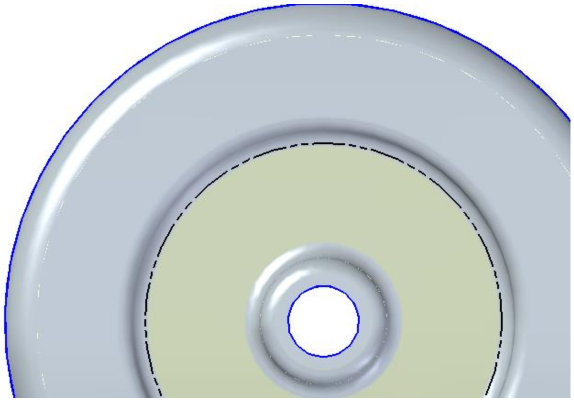
Construction Line:

A construction line is 2D geometry that allows for the placement of wanted geometry but will not be included in the creation of solid geometry. For more information select F1 when you select the command.

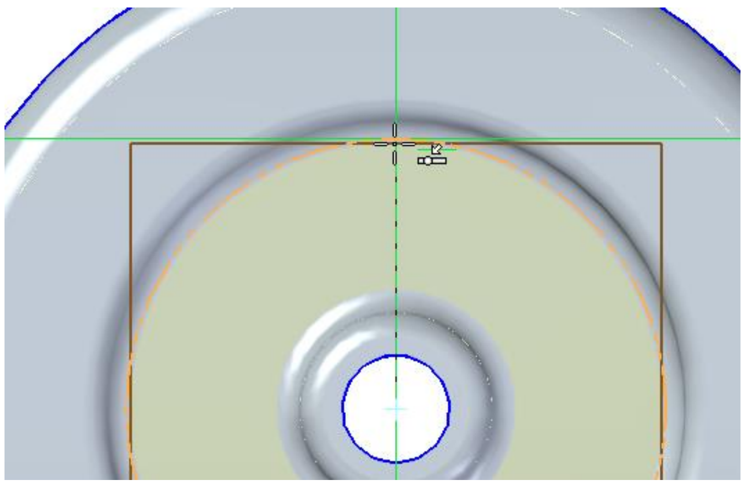
Highlight the circle you just created. Select the Toggle construction line command from the Draw area of the ribbon.



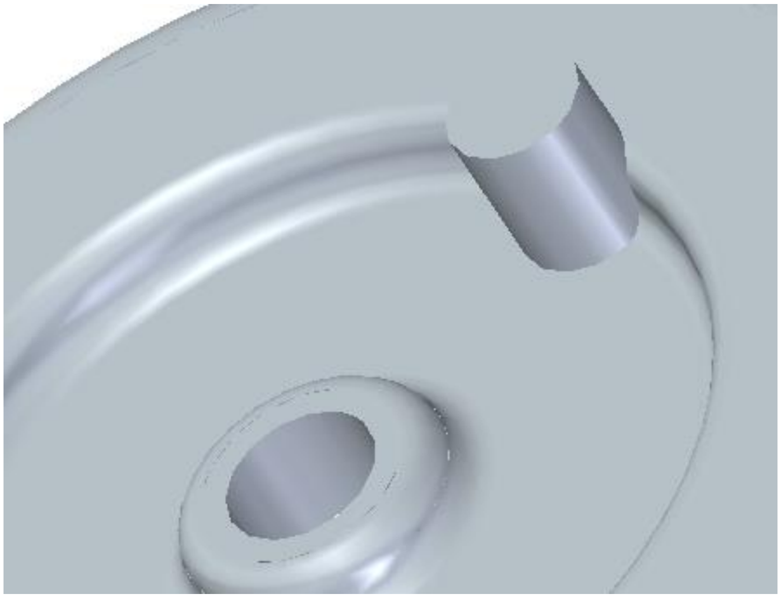
The solid 2D circle will have the appearance of a construction line - two short dashes followed by a longer dash.



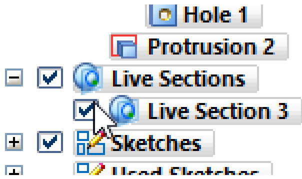
Now place a .25 diameter circle on the construction circle. Place the center so it is directly above the center of the hole in the wheel. The cursor line will show dashes and the center point will indicate the center similar to the picture below. This is placing geometric relationships on the part.



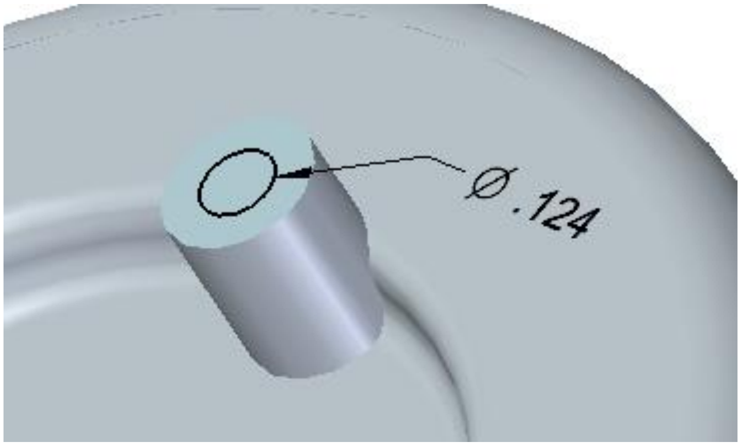
Extrude the circle. Use Chain to select the geometry and select the circle you just drew. Extrude the profile .30



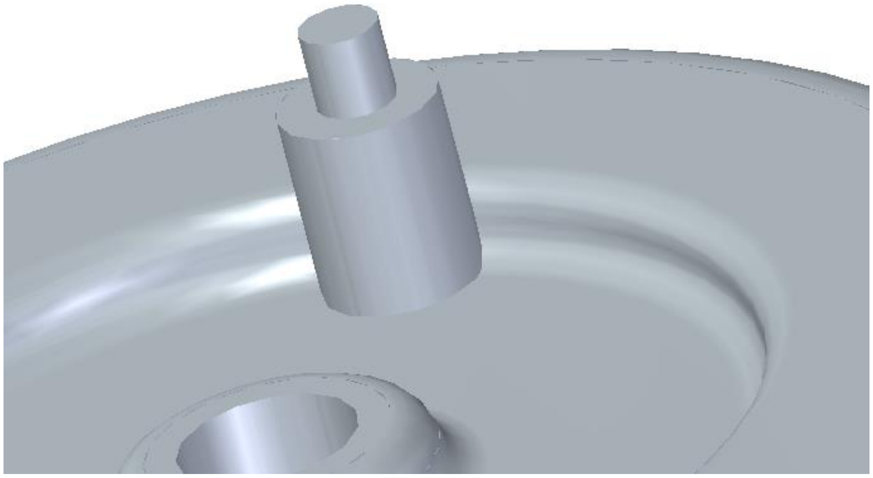
Hide the display of the Live Section by unchecking it in the synchronous tree.



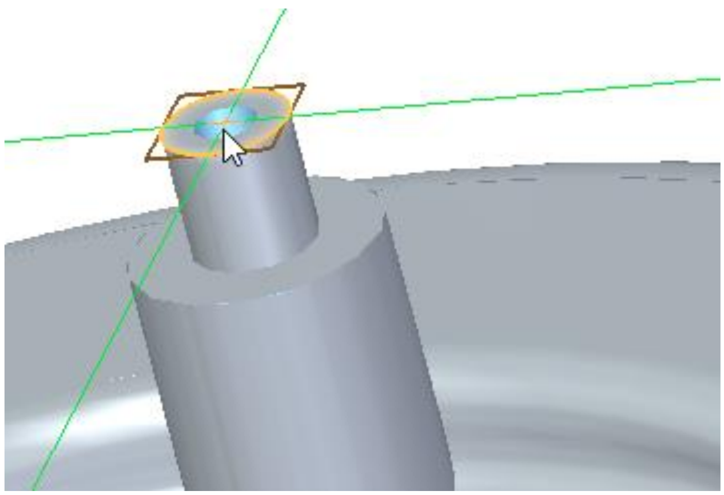
Draw a circle on top of the post you just created. Make the diameter .124



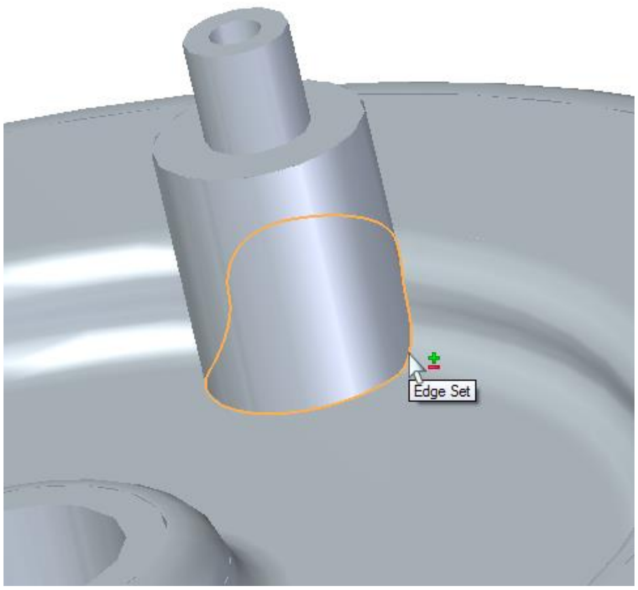
Extrude the sketch .126



Place a hole .0625 in diameter .250 deep in the center of the post.



Add fillets where the post meets the wheel. Use .0625 as the radius and chain as the selection.



This will strengthen where the post meets the wheel and remove a square corner where forces could concentrate.

Save your file.

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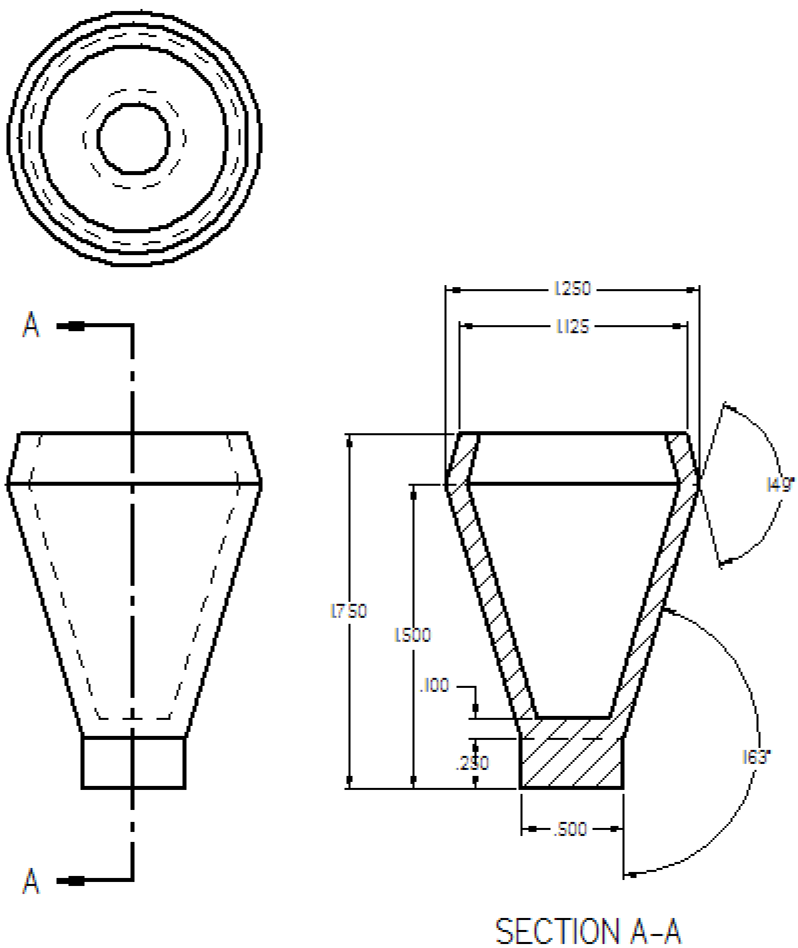
Stack

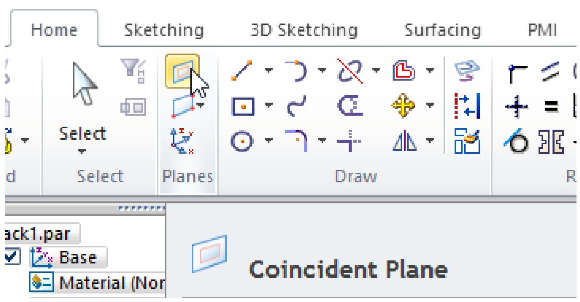
Geometric Requirements:



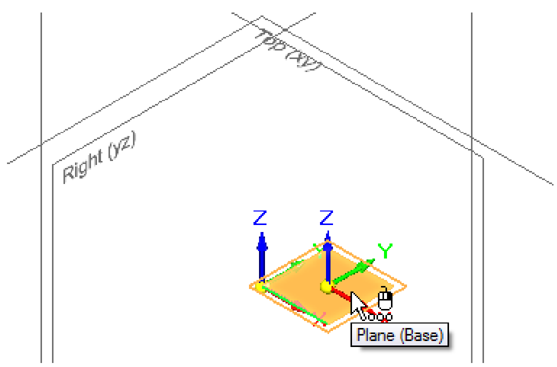
Instructions:
Lofting is the primary method for making tapered items such as wings or boat hulls. It allows for the placement of ribs, cross sections or shapes a set distance apart and connecting them with curved surfaces. In 3D modeling, planes are used to create sketches and then the computer generates the solid or surface to join them together.

Setting Coincident Planes
The first step in creating a loft is the creation of several coincident planes at different elevations. These planes are used for the sketches and setting the alignment between the sketches. Creation of these planes must reference existing surfaces or planes. For more information about coincident planes select F1 after selecting the icon.

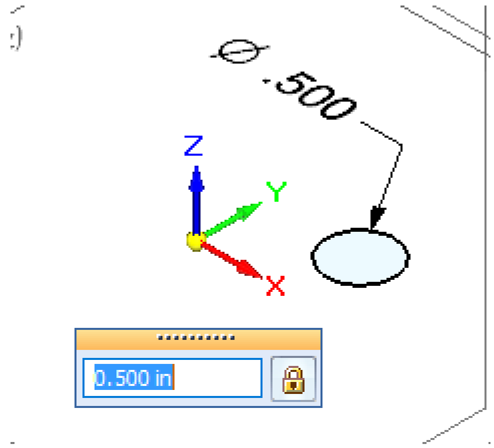
Create a new part file. Begin by selecting the Coincident Plane icon from the Planes section of the Main Ribbon.



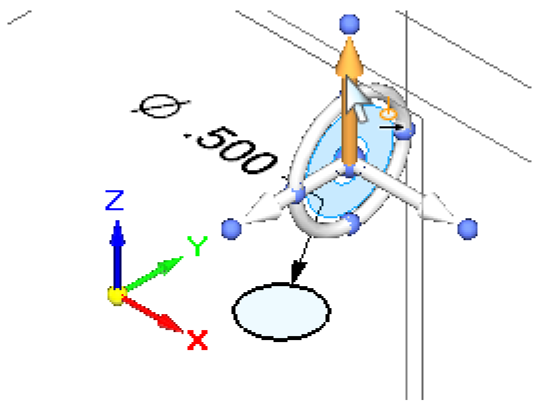
Hover over the XY or top plane until it highlights. Click on the plane.



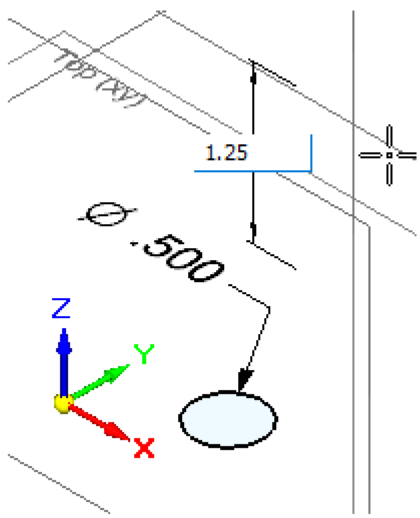
The new plane appears. Draw a circle .5 in diameter on the plane.



Select the Coincident Plane tool again. Create a second coincident plane from the first one. Select the first plane created and then select the upward arrow (Z).

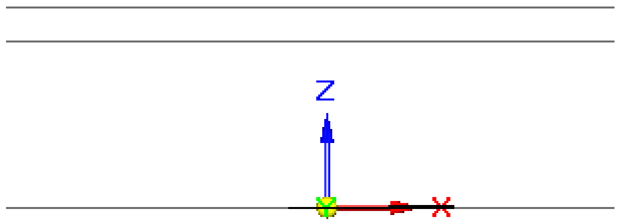


Begin to move upward and then enter 1.25 for a distance. The new plane will then appear 1.25 above the first plane.



Repeat the process so the next plane is .25 above the second plane you created.

Looking from the front you should see the three planes.



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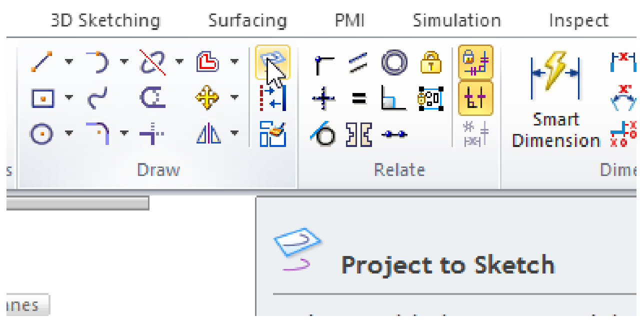
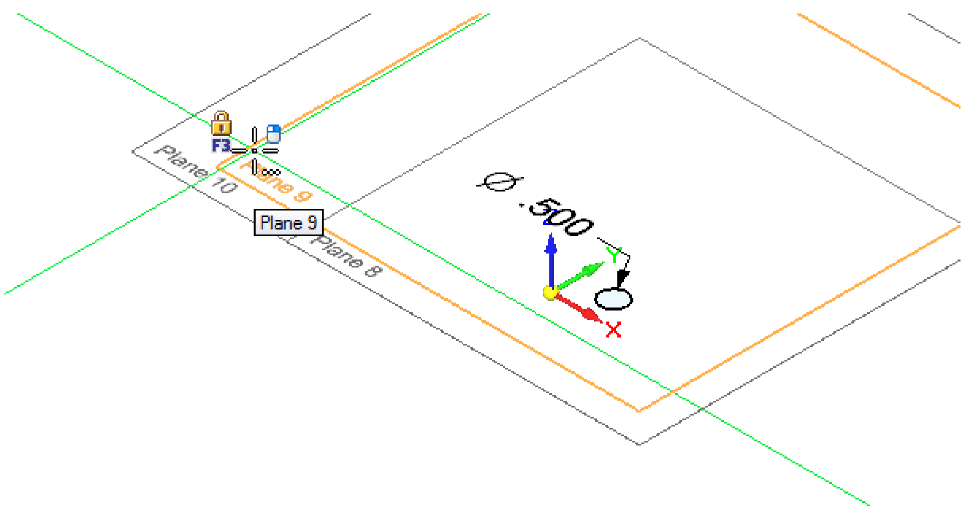
Project to Sketch

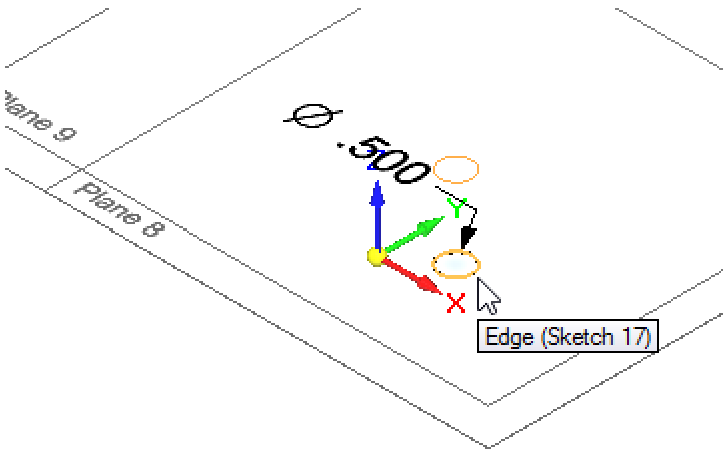
The sketches must align with the one on the plane below. Use the circle created on the first plane to position the ones on the planes above. Select the Project to Sketch icon from the draw section of the Main Ribbon. Select F1 for more information about this command.



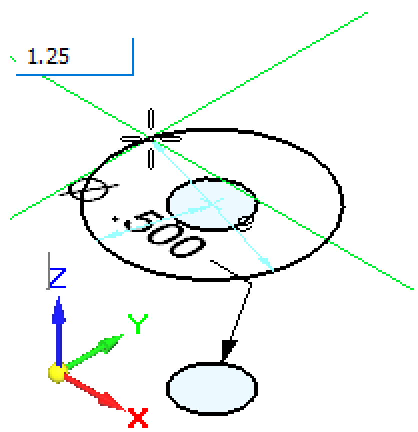
The first prompt will select the first plane. In the picture below the planes are 8, 9 and 10. Select plane 9 by clicking on the edge. This locks the sketch plane to the plane. If you see a dialog box for the options select ok.



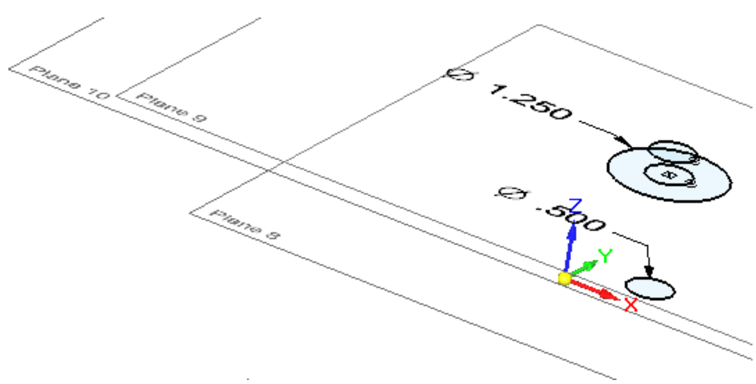
Once the Options dialog box is gone you will be prompted to select the geometry (model edge, curve or sketch element). Select the circle and it will appear on the current sketch plane.



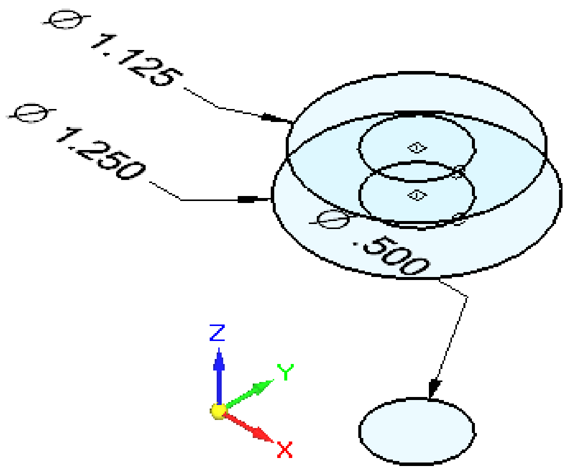
Then use the center point of that circle to create a circle 1.25 inches in diameter.



Repeat the process of Project to Plane placing a copy of the .5 circle on the top plane.



Use the top circle for the center of a sketch of a 1.125 circle.



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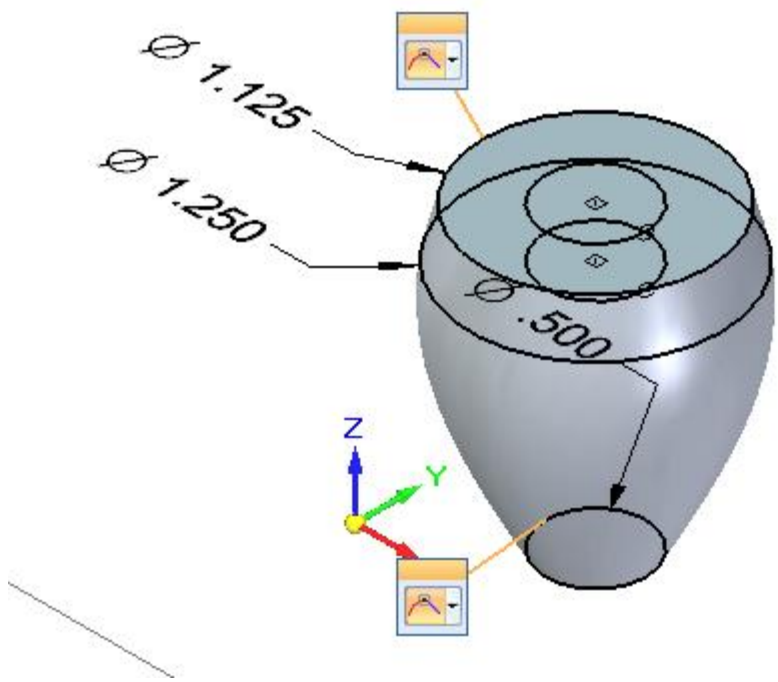
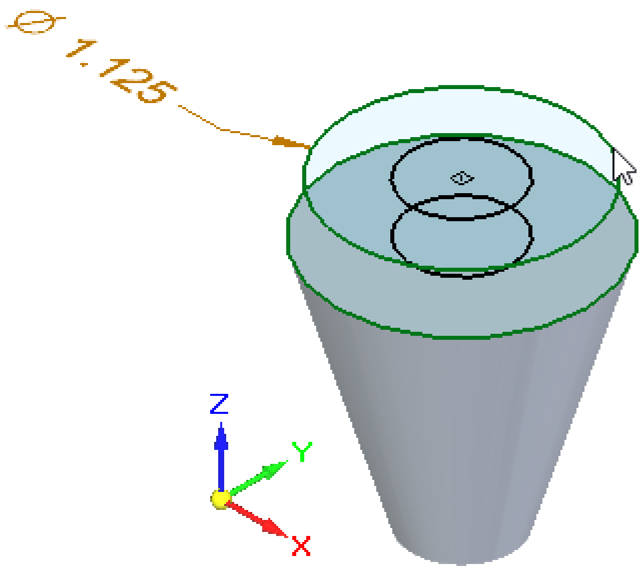
Loft:
Select Lofted Protrusion from the Solids section of the Main Ribbon. Select the original bottom circle (.5) and then the 1.25 circle and then the 1.125 circle. Right click to accept the choices. You will see a rounded shape appear. This is due to fitting the curve to pass through the center circle.



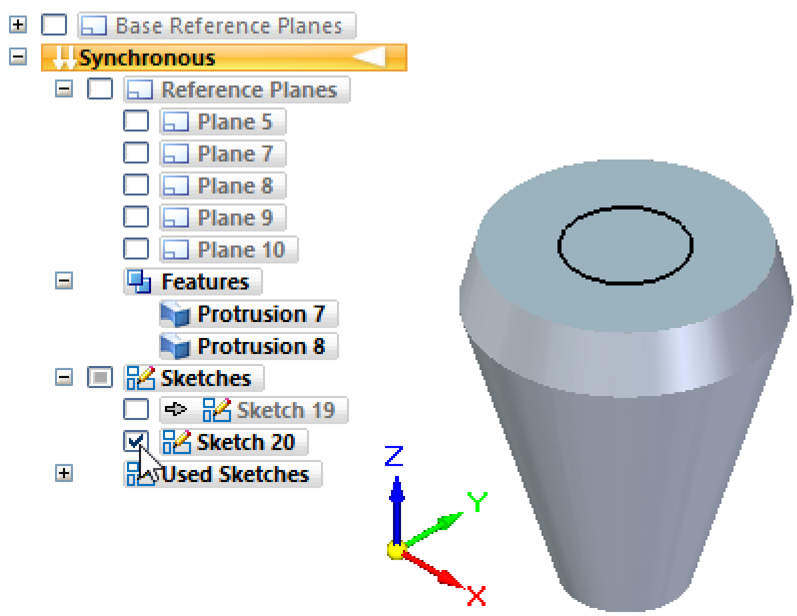
If a more angular shape is necessary utilize the (Ctrl Z) to undo this shape and then use the Loft command twice. The first loft will be from the original .5 circle to the 1.250

circle. Right click to accept and then Loft again from the top of that shape to the 1.125 circle.



Choose the desired shape.

Hide the planes and sketches left by expanding them in the tree and unchecking them.



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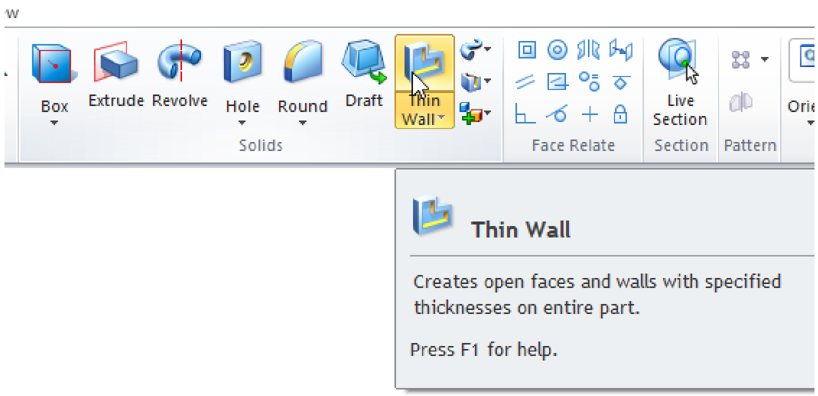
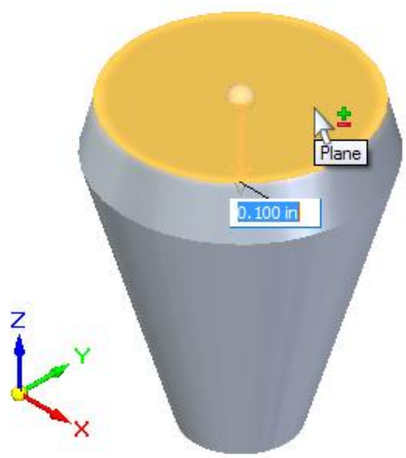
Thin Wall:

This command constructs a thin wall from a solid shape. Since the stack is to be hollow, this is an easy way to accomplish this. After you select the command you can press F1 for more information.

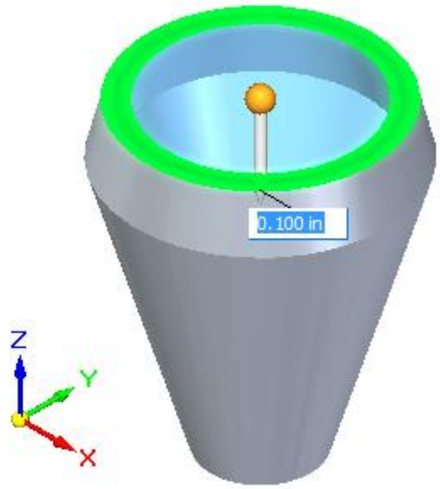
Select Thin Wall from the solid section of the toolbar.



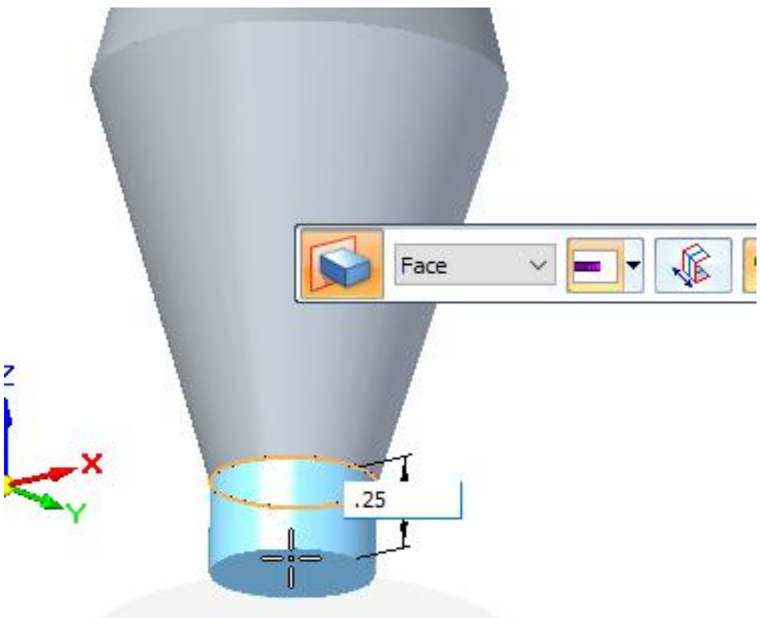
Be sure the arrow points into the stack and click on the top surface of the stack. This will be sure the top of the stack will be open. Select .100 for the thickness.



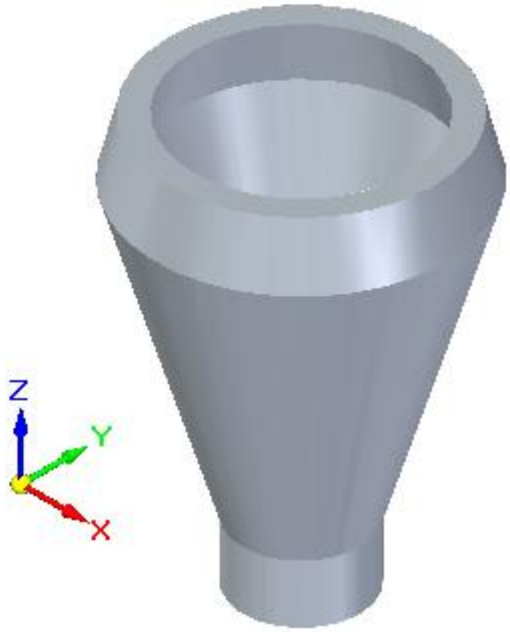
The top of the stack will disappear and the thickness of the walls will appear. Select enter to accept this.



Now rotate the stack to see the bottom of the stack. Select extrude from the solids section of the ribbon and then highlight the bottom of the stack. Extrude downward .25 so this can then be inserted into the train body later.



Save your part.



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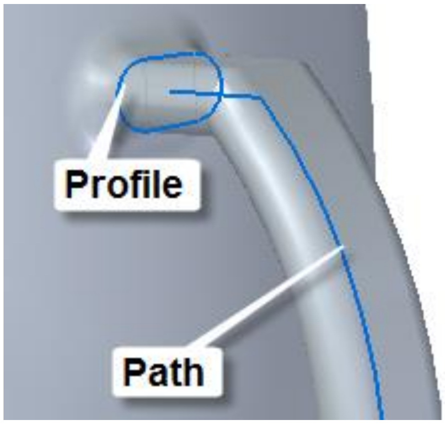
Sweep

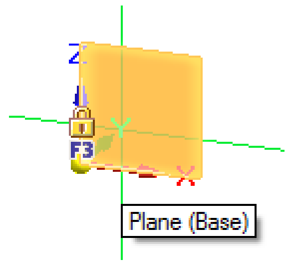
The Sweep command is a tool used to take a profile and move it along an irregular path. An extrusion moves in a straight line. The handle on the mug below was created with a sweep.

A sweep requires a profile and a path. The profile is the shape or cross section, the path is a series of lines that controls the shape.

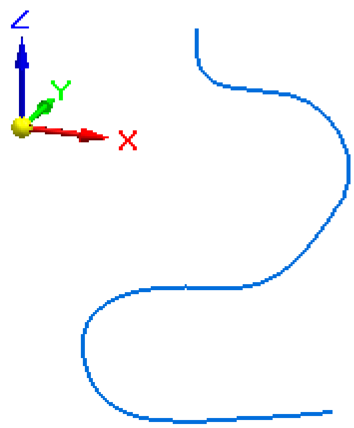


Begin a new part.

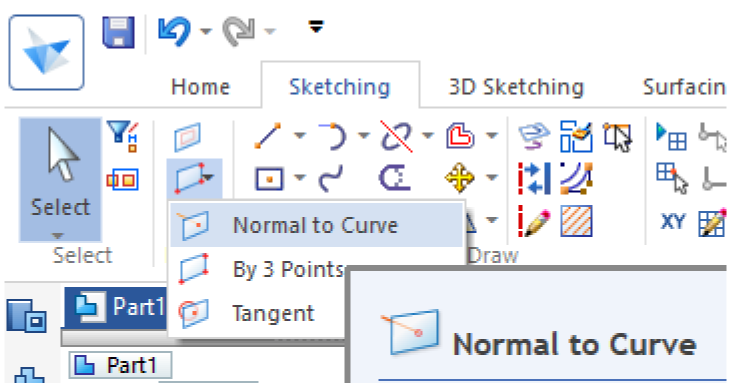
Select a Plane to draw the path upon.



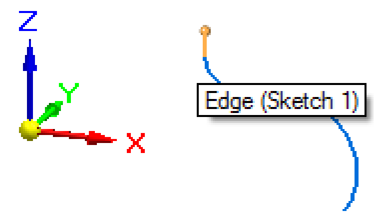
Use a combination of line types to define the path. If the turns are too tight or would cause the shape to intersect itself and an error message will appear when you go to sweep the shape.



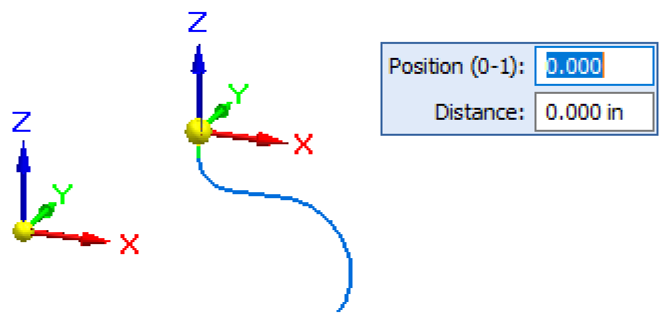
Use the ESC key to end the line command. Once the path is done you need to create a sketch that will sweep along the path. The sketch will work best if it is normal to the path. From the Planes section of the sketching tool ribbon select the option for plane Normal to a Curve.



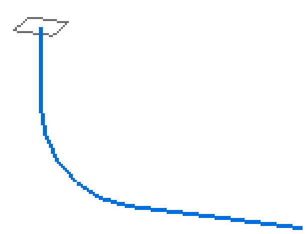
Select the very end of the path line.



Set the position to 0.0 and the distance to 0 in.

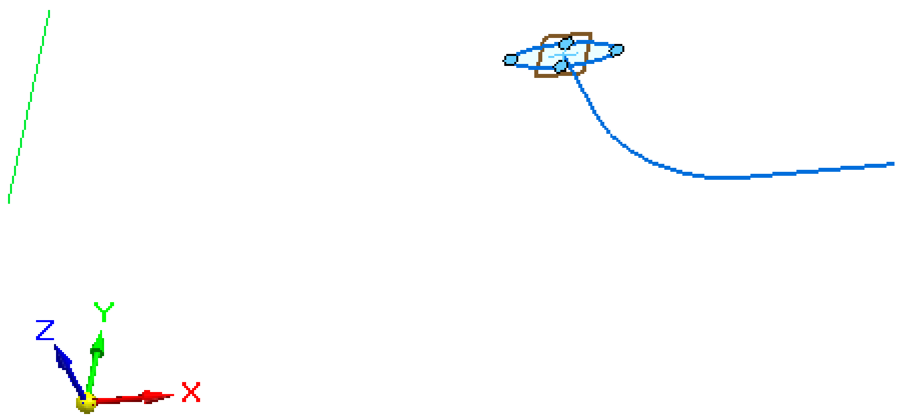


A plane will be created on the very end of the path line.

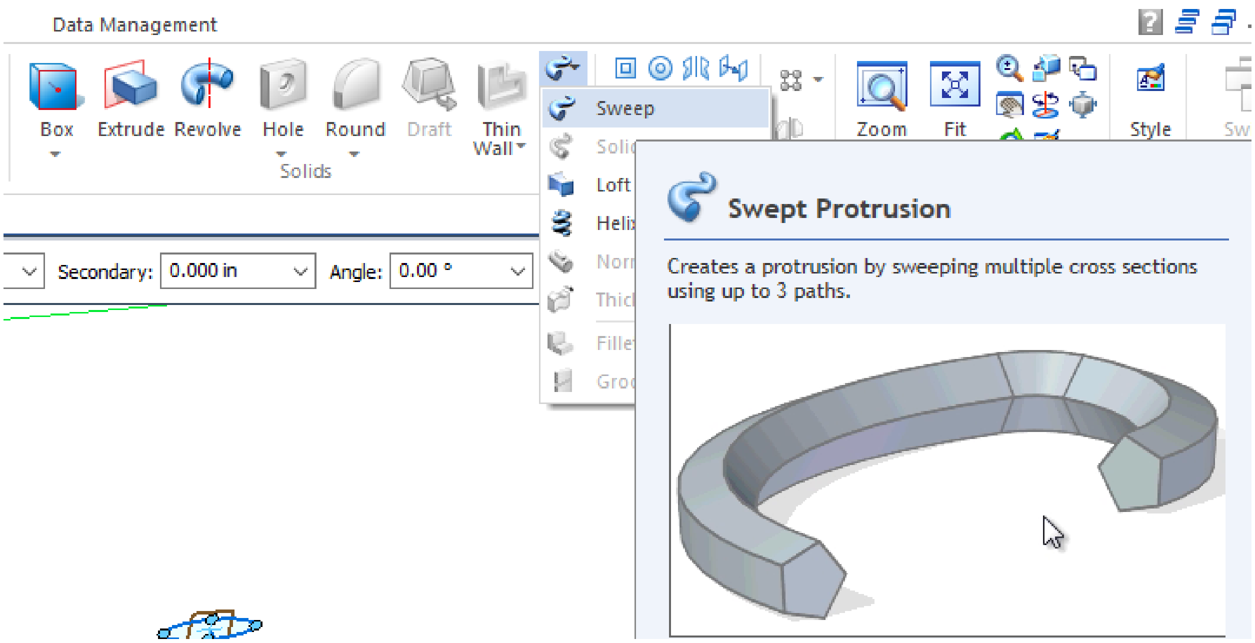


Draw the shape desired for the sweep on the plane at the end of the path.

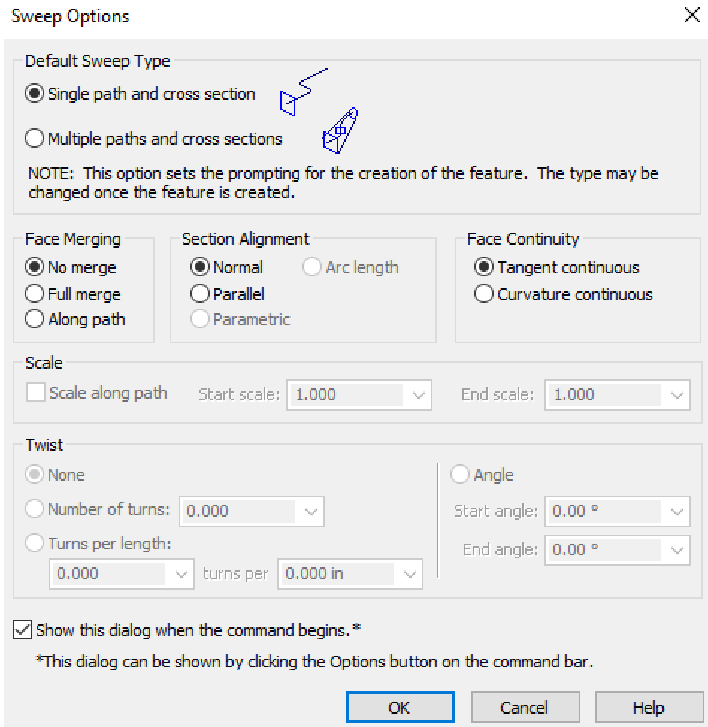
In this example, an ellipse is being created with the center directly on the end of the path. The sketch does not actually have to touch the path but it is easier for beginners if it does.



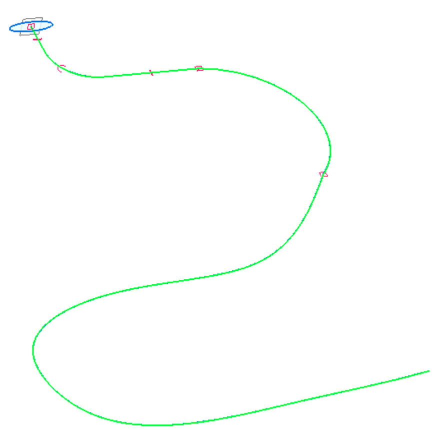
Select Sweep from the Solids Menu of the Home ribbon.



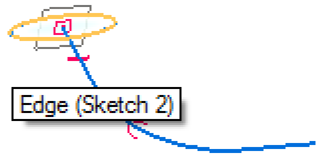
This will bring up the Sweep options dialog box. In this case select a Single path and cross section.



Select OK. In the Sweep dialog toolbar select Chain and then select the path desired.

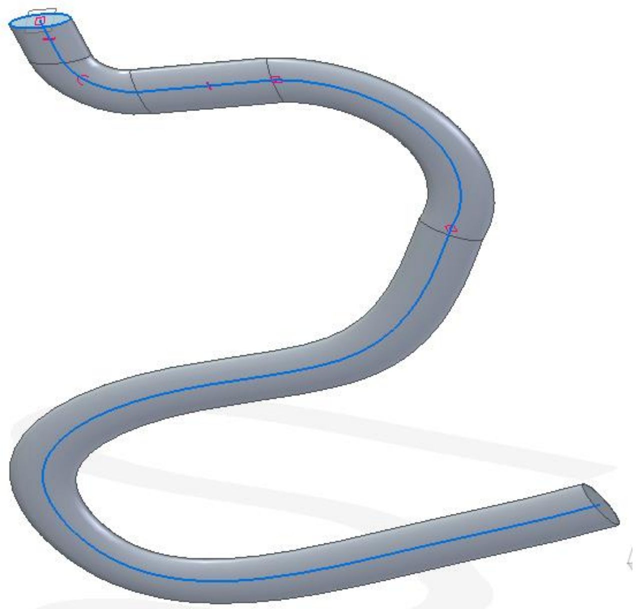


Right click to end the selection of the path. Select the face or sketch from the prompt that makes up the profile or cross-section.



Select your profile.

Assuming there were no errors in the path or profile the sweep will be created.



Save your part.

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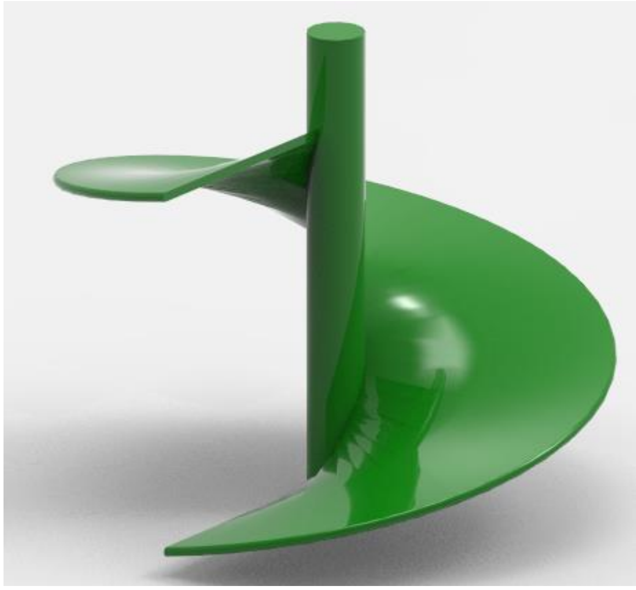
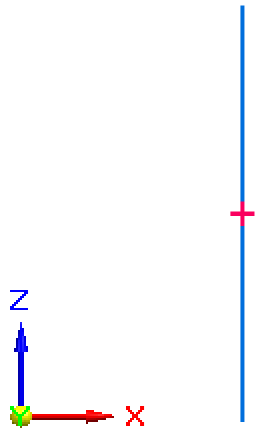
Helix

A helix is a three dimensional curve. There are lots of uses from springs to stairs to screw threads. The image below was the beginning of a slide.

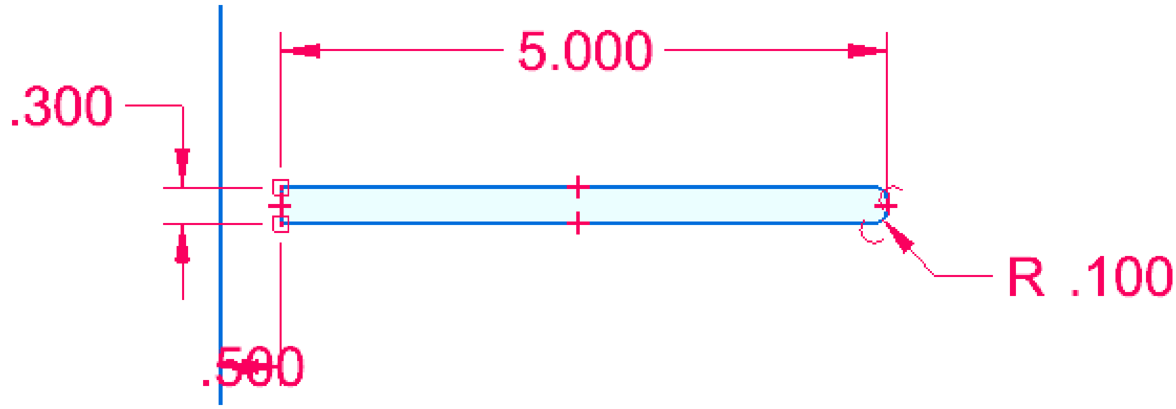


A helix needs two things. It needs a profile and an axis that the profile rotates around. The pitch is the measure of the distance between rotations.

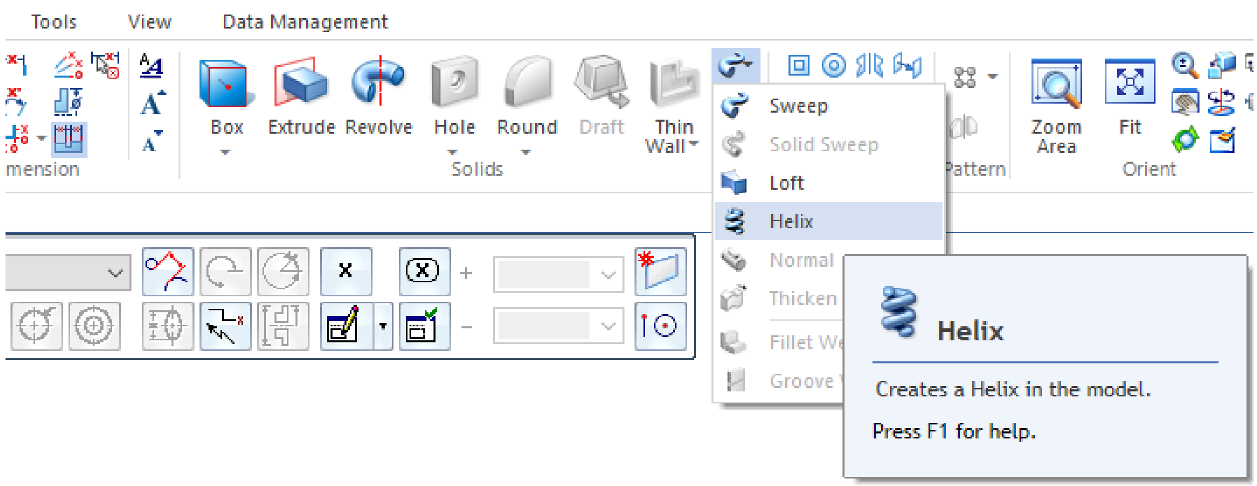
Begin by drawing a vertical line. In this example the line was 10 inches long.



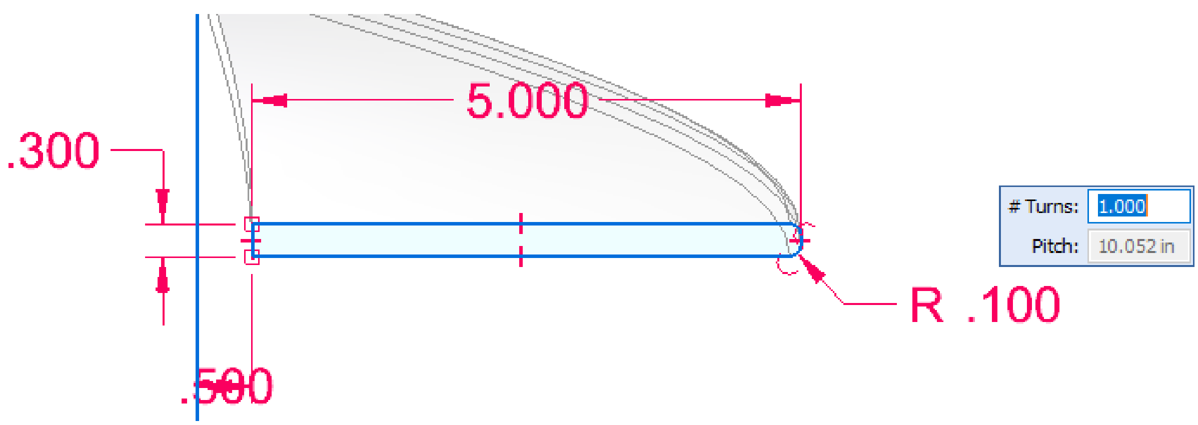
Next a shape was drawn.



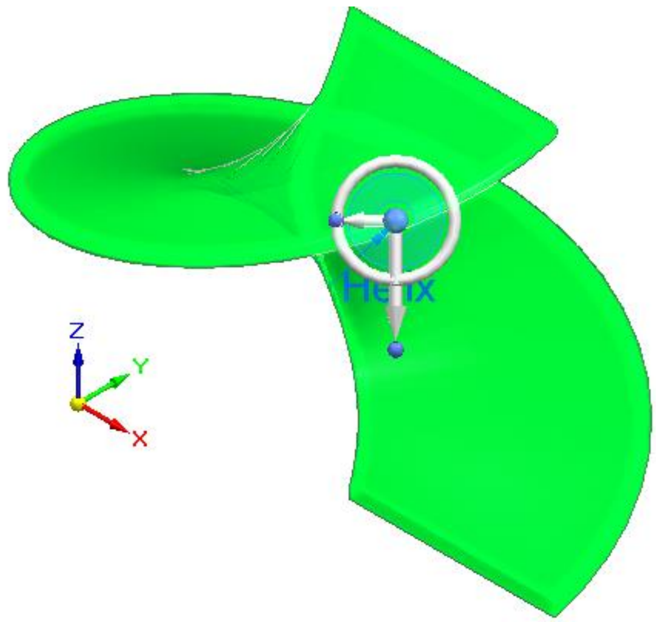
Once the shape is completed select the Helix command from the Solids section of the Home ribbon.



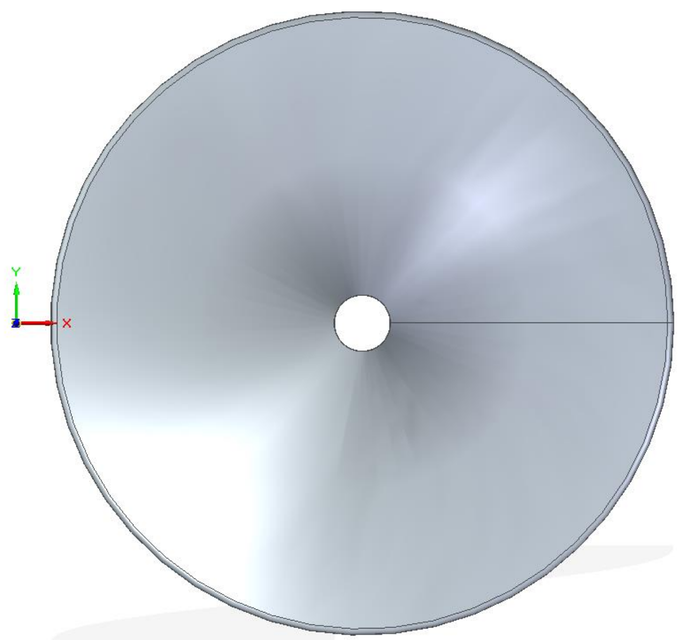
Select the profile or cross section drawn and then the vertical line. Right click to accept. A prompt for the number of turns will appear. In this example 1 was used.



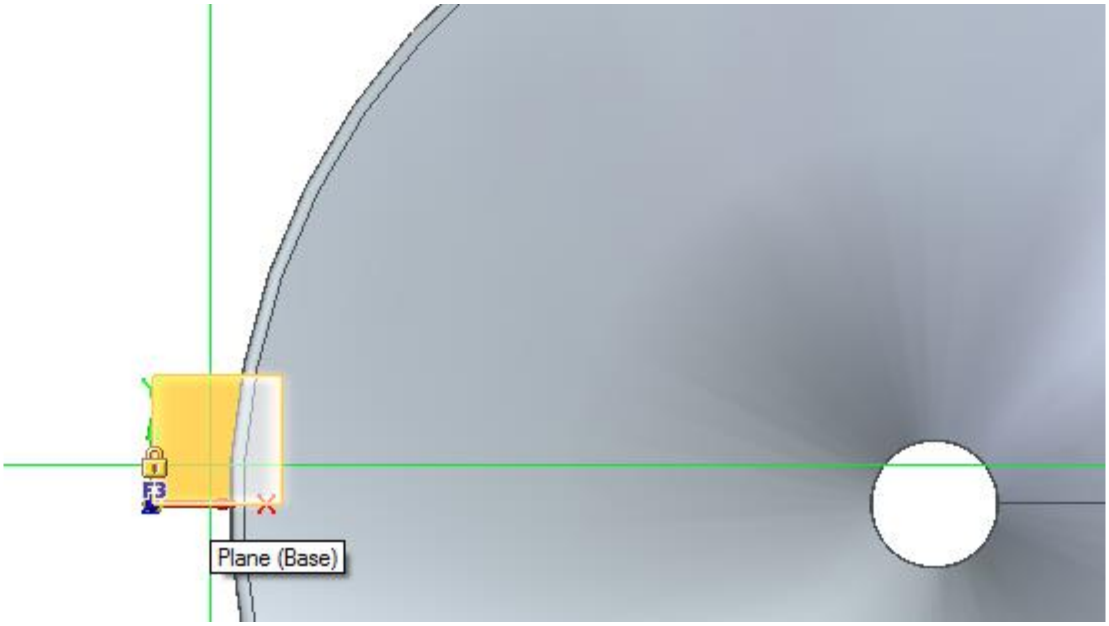
Right click again to accept. The helix appears.



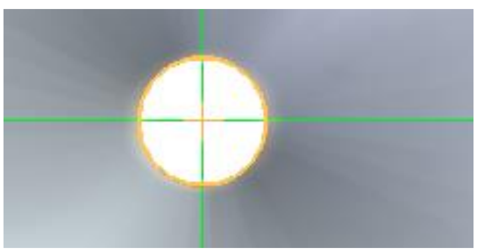
Place your part in the top view.

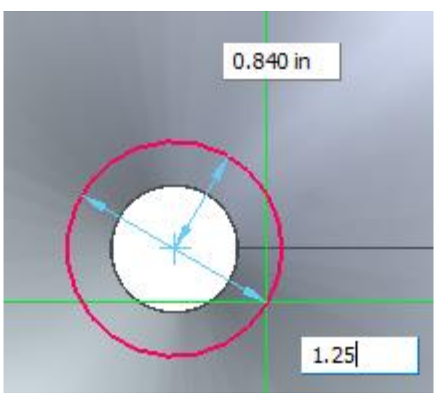


It is time to add the shaft for the center. Select the circle command. Lock the plane to the XY plane.

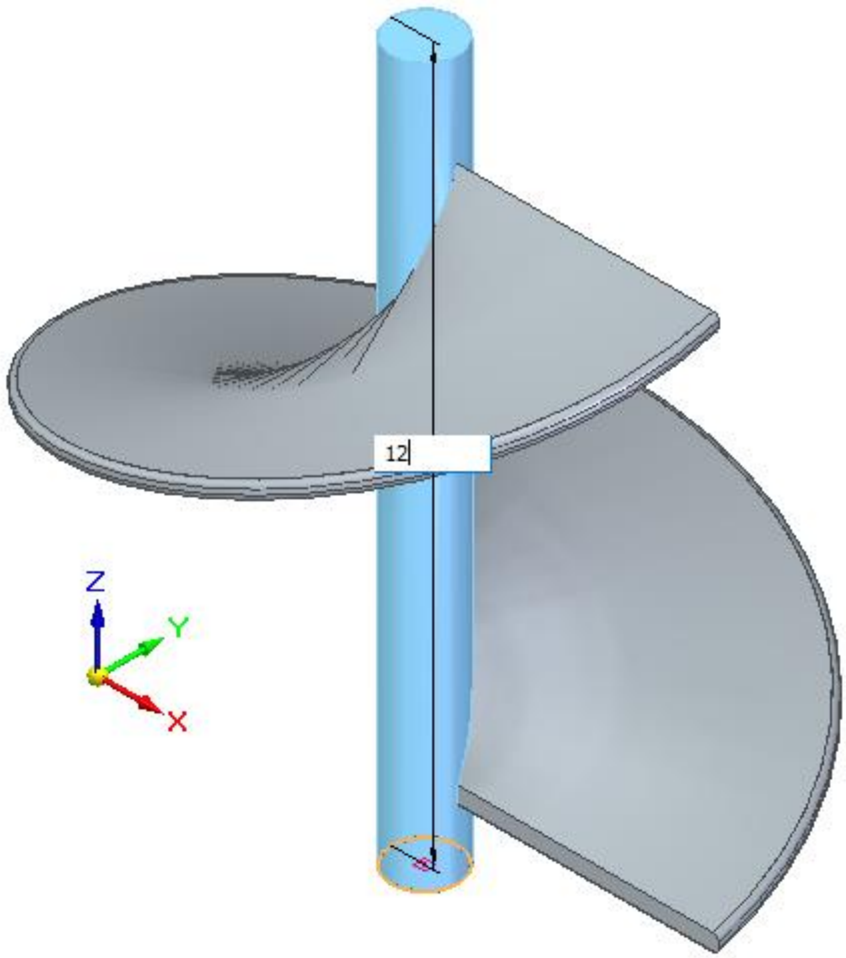


Use the center of the helix to locate the circle. Dimension the circle to slightly larger than the opening of the helix.





Return to the isometric view. Extrude the circle. In this example 12 inches was used.



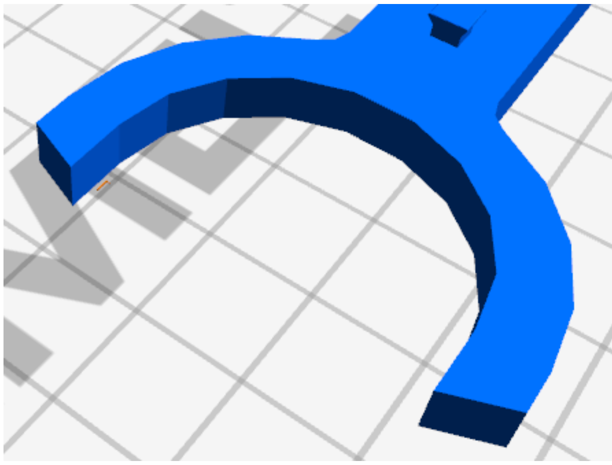
Save your part.

Back

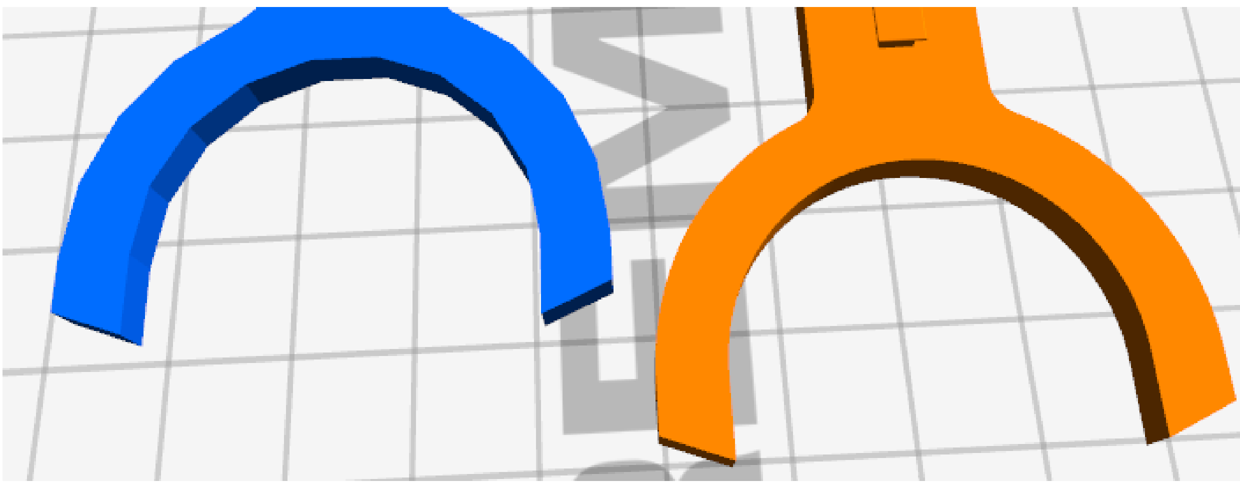
Preparing for Printing

When the design of the part is finished, it will be necessary to export the data in a format that contains the information. The most common format is the STL file. The STL file stores the information. 25 years ago 3D printers were incredibly expensive. One popular format was the Stereo Lithography printers. A LASER was used to sinter or cure the resin with head generated by the laser one layer at a time. The plastic was almost $1,000 a quart. Some think STL was short for the Stereo Lithography printers. The image below was from a file printed on a Stereo Lithography printer.

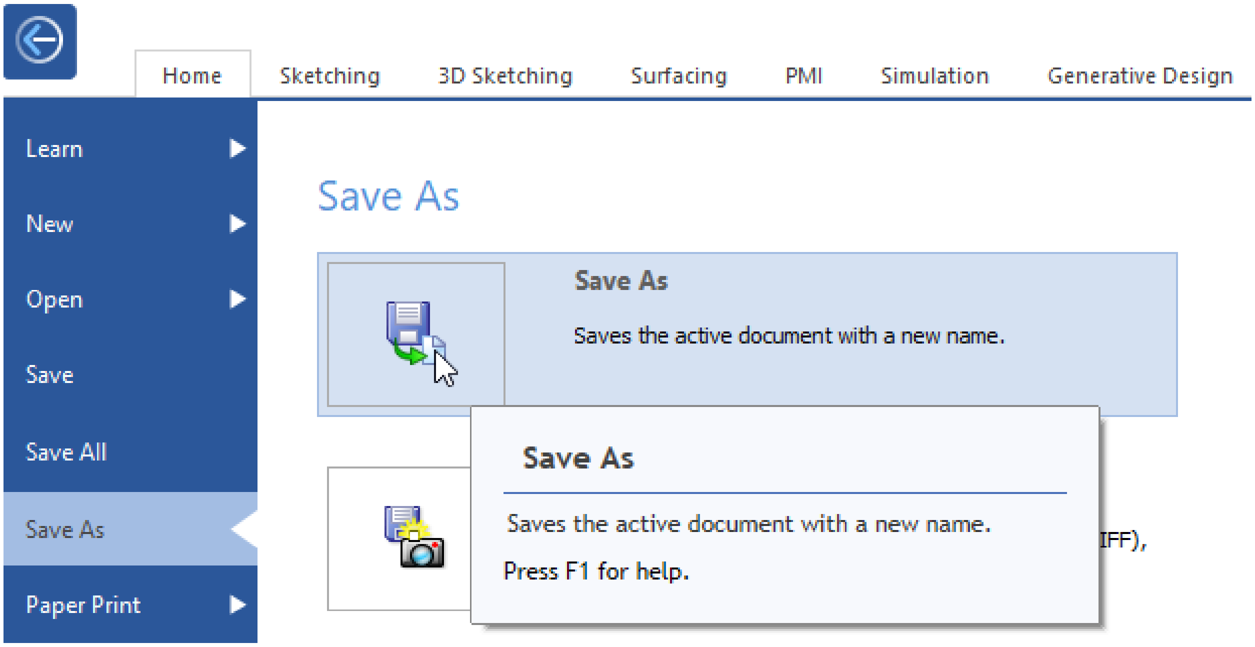
The process involved importing information from early CAD programs. These programs exported the data in terms of surfaces in a process of tessellation. The data about the surface was exported in connected triangles. Today some describe the STL file as the Standard Triangle Language. When the file is saved, the data is stored in the format requested and in the resolution requested. The resolution has a big effect on printing. If you think of a wheel being broken into triangles, you come to the conclusion that a triangular representation of the wheel will have a series of chords that form the outer surface of the wheel. The export settings can make chords smaller if higher resolution is set. The picture below was exported with low resolution. You can see the chords on the curves. Keeping the file size small means the curves are sacrificed.

 .

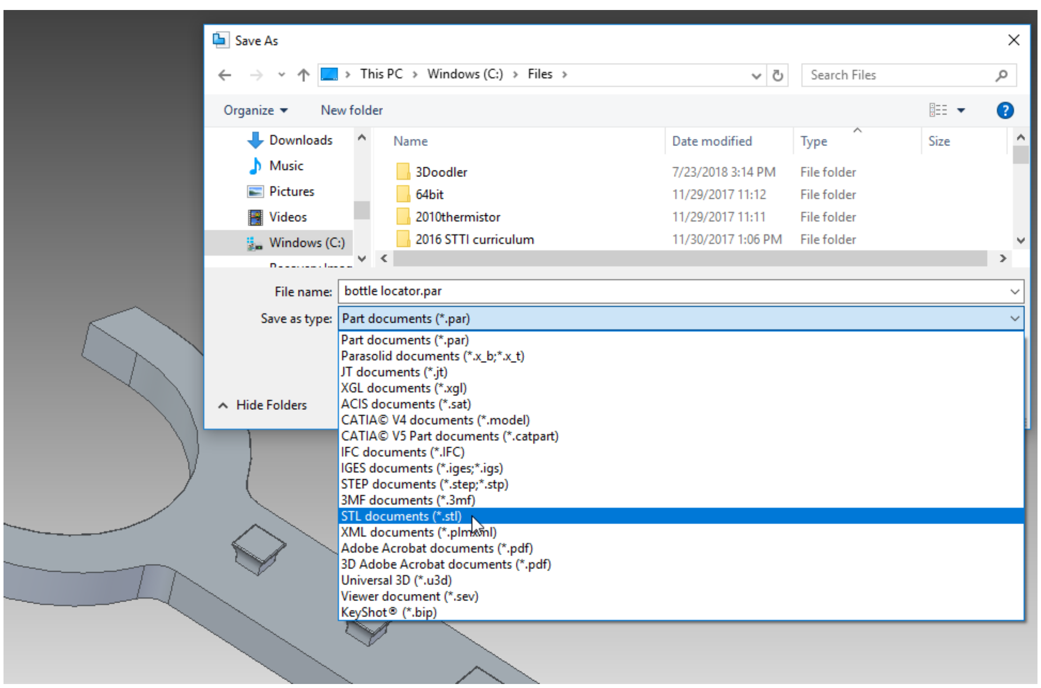
With a really fine resolution, the curves will be smooth but the file size will be quite large. In the picture below the part on the right was exported with finer detail at higher resolution. The curve is much smoother. The file size was 15 times the size of the original.



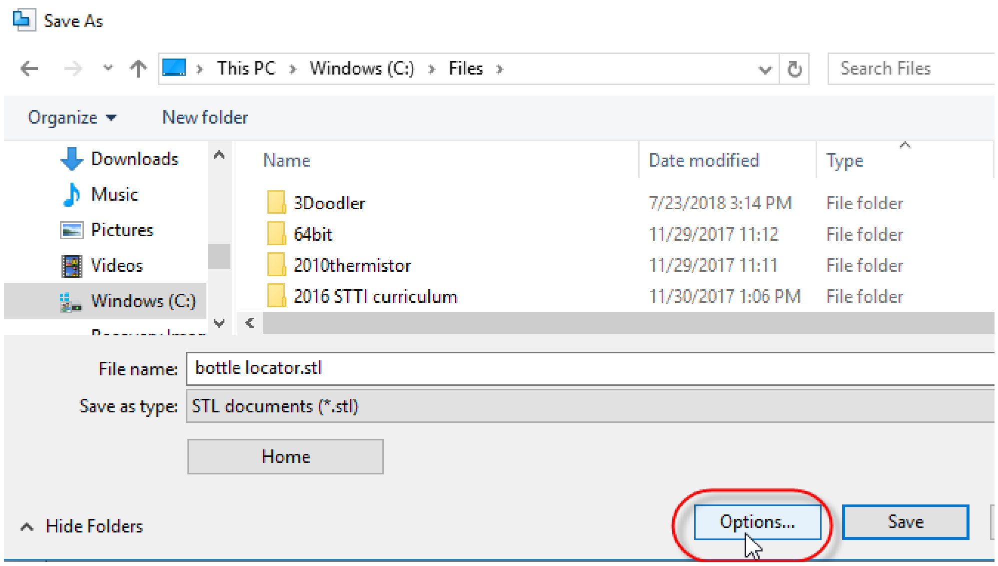
Exporting a file from a CAD program such as Solid Edge is a simple process. Once the part is finished select Save As from the application button at the top left of the user interface.



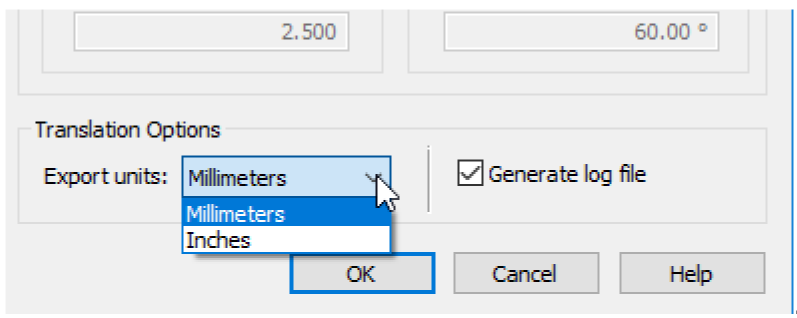
Once the Save As dialog box opens, select the option for STL from the save as type section.



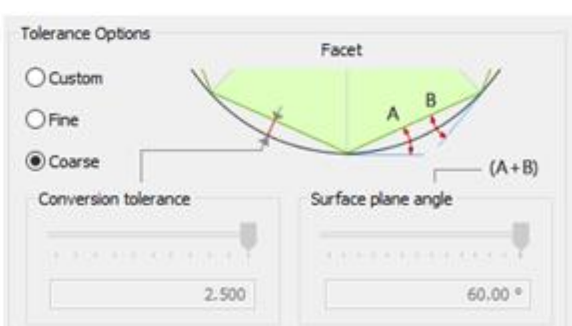
Look for the options menu. It will be located next to the Save and Cancel buttons at the bottom of the dialog box.

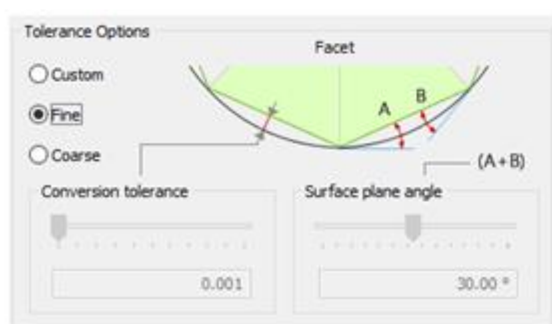


This will bring up the export options for the STL file. If the part was drawn in inches and the printer reads mm then it will be necessary to change the export units at the bottom of the dialog box.

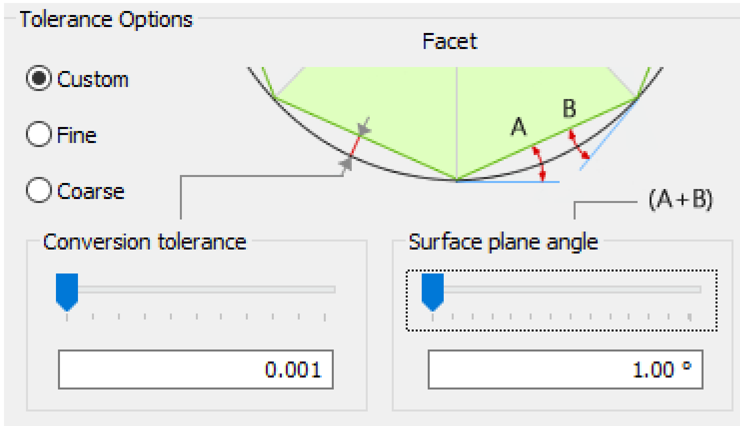


To adjust the resolution, use the Tolerance Options section of the dialog box. The two images below show the difference between course and fine settings for Conversion tolerance and Surface plane angles. These are preset but will give you an idea of the differences.





Notice the surface plane angle on Coarse is 60º while the Fine setting is 30º. By entering the Custom area you can enter in a smaller angle if needed.



When satisfied with the tolerance options and the settings match your printer, select the OK button at the bottom of the dialog box.

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Slicing Program

Transfer the data from the solid to a format read by the slicing programs available for 3D printers. Many companies have a proprietary slicing program but they all work by taking a solid object and slicing it into layers. The layers are then printed one upon the next until the entire shape is visible. Decisions are made pertaining to how thick each layer will be and whether the layers are solid or honeycombed. In addition a decision is made regarding the most efficient orientation of the part before printing. Scaling the part and assuring the part is actually located on the bed is another function handled by the slicing programs. In the example that follows, a printer from the Dremel line is used but the printers will all behave similarly.

3D printers are CNC (computer numeric control) machines. Each layer is defined. The NC file contains G&M code used by CNC machines. Each combination of letters and numbers provides control information to the brain of the printer. This file tells it where to move the printer head, the temperature needed, and how much plastic to extrude. The picture below is an example of the code slicing programs produce.

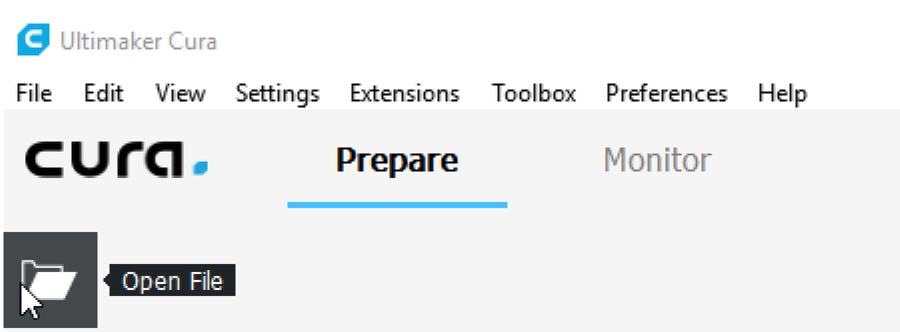
```
L M104 S220 T0G90G28M132 X Y Z AG1 Z100 F3300G1 X-110.5 Y-74 F6000M6 T0M106M907 X100 Y100 Z40 A80G1 Z0.6
F3300G4 P2000M108 T0G1 F1200.000 E-1.50000G1 Z0.300 F7200.000G1 X16.691 Y12.810 F7200.000G1 E0.00000
F1200.000G1 X15.881 Y13.810 E0.08942 F1200G1 X15.091 Y14.680 E0.17107G1 X14.171 Y15.570 E0.26001G1 X13.461
Y16.190 E0.32550G1 X12.441 Y16.980 E0.41514G1 X11.221 Y17.810 E0.51767G1 X10.411 Y18.300 E0.58345G1 X9.041
Y19.010 E0.69066G1 X7.871 Y19.530 E0.77962G1 X6.991 Y19.860 E0.84493G1 X5.811 Y20.230 E0.93085G1 X5.131
Y20.410 E0.97973G1 X3.781 Y20.710 E1.07581G1 X3.111 Y20.820 E1.12299G1 X2.181 Y20.940 E1.18814G1 X0.901
Y21.030 E1.27730G1 X0.081 Y21.050 E1.33429G1 X-0.949 Y21.030 E1.40587G1 X-2.409 Y20.920 E1.50760G1 X-2.879
Y20.860 E1.54053G1 X-4.349 Y20.600 E1.64425G1 X-5.269 Y20.380 E1.70998G1 X-6.389 Y20.060 E1.79091G1 X-7.259
Y19.760 E1.85485G1 X-8.449 Y19.290 E1.94375G1 X-9.309 Y18.890 E2.00965G1 X-9.979 Y18.540 E2.06217G1 X-11.089
Y17.900 E2.15120G1 X-11.749 Y17.480 E2.20556G1 X-12.519 Y16.930 E2.27131G1 X-13.439 Y16.210 E2.35248G1 X-
14.169 Y15.580 E2.41948G1 X-15.039 Y14.740 E2.50350G1 X-15.689 Y14.050 E2.56937G1 X-16.519 Y13.060 E2.65913G1
X-16.879 Y12.600 E2.69972G1 X-17.759 Y11.320 E2.80765G1 X-18.249 Y10.510 E2.87342G1 X-18.699 Y9.700 E2.93781
```

What follows is an example of the process done with a slicing program called Cura. Other programs are available and work with great similarity to this one.

Setting up the Slicing Program

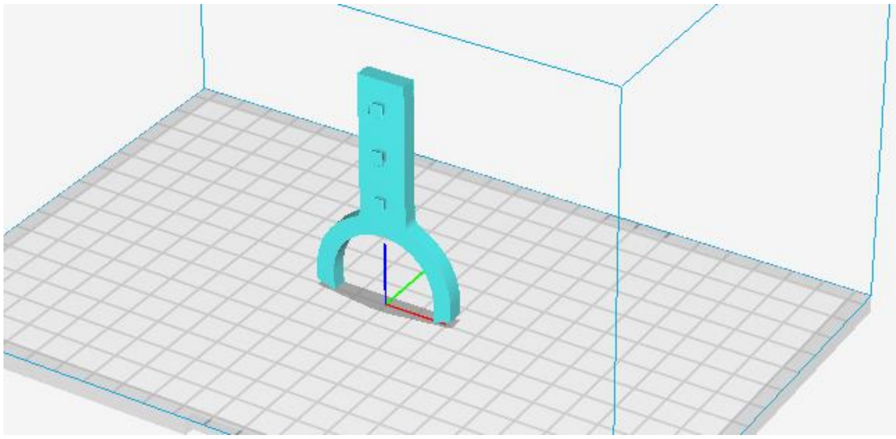
The procedure is similar with most slicing programs. The file is imported and then sized, scaled, and rotated to print the part the designer envisioned. When creating the part the actual size of the object was not a consideration. Therefore, it will be necessary to adjust the size in the slicing program.

Open Cura, the Slicing program.



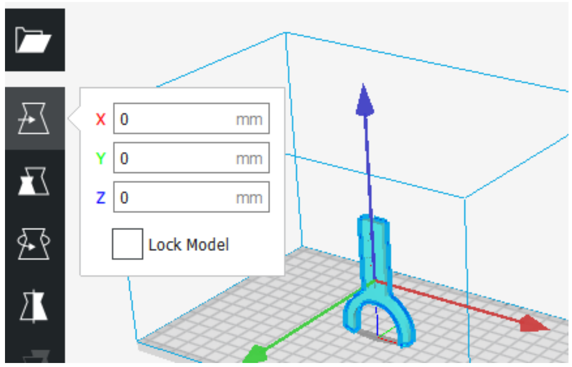
On the left side of the screen is the icon for Open File. Open the STL file you saved from Solid Edge.

This will import the file you created. It will display the build area and the file. You can see the file below on the build plate.

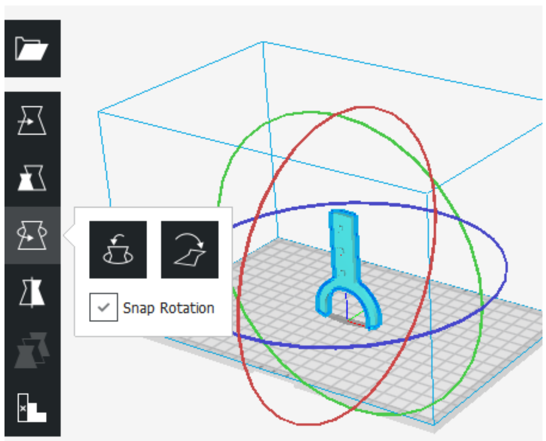


This might not be in the best orientation to print. There are the pins on one surface. The back is basically flat. The more contact with the base, the more stable the print is. If the level of the plate is not quite correct, the part might come loose from the build area. When that happens it might create quite a mess if not caught right away.

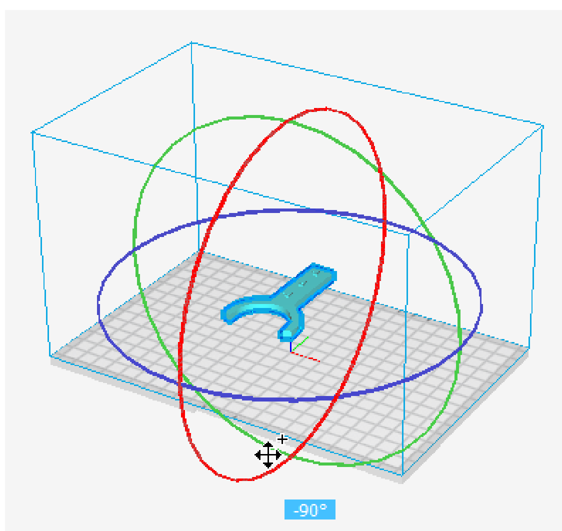
We can manipulate the model by using the tools on the left of the screen. The three major tools used to orient the part are the top 3. From the top they are Move, Scale, and Rotate.



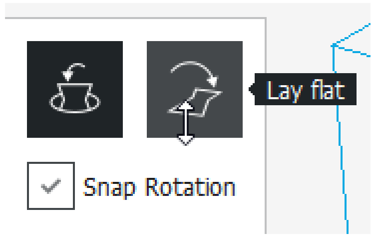
Since the model was exported in the correct size, it will not be necessary to scale the part to fit. It is important to have the part in the correct orientation for printing. Select the Rotation tool.



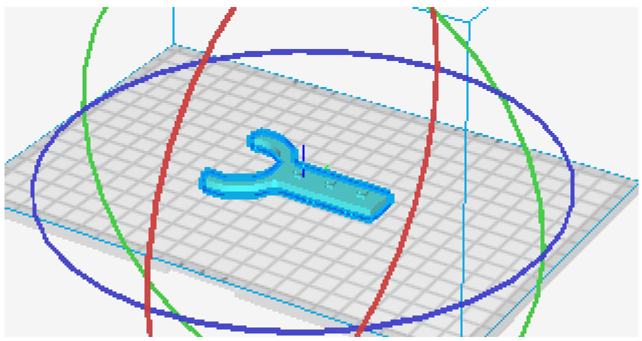
In this example we will rotate with the red rotational wheel. As you rotate with the snap rotation on you will see a report of degrees. In this example -90º is what we wanted.



Once you let go of the wheel the part will settle on the base. If this is close but not quite enough use the Lay flat tool.



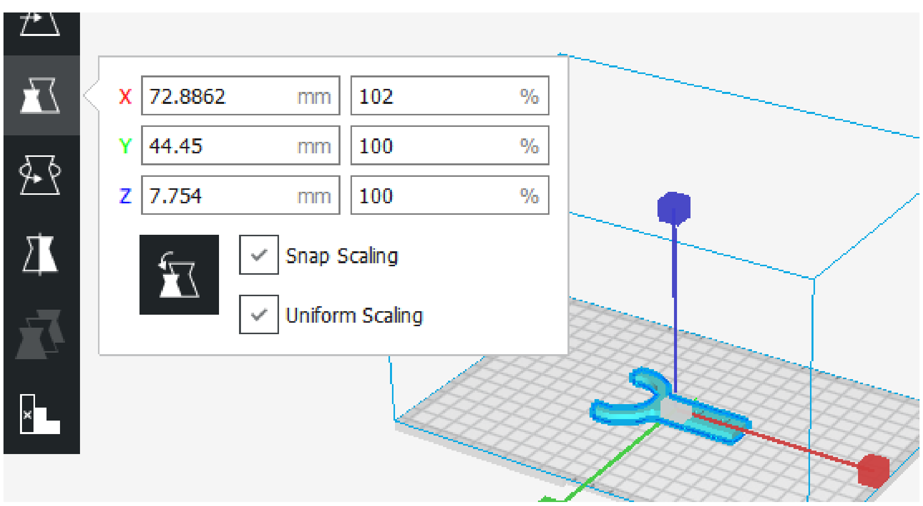
Continue rotating the part until it is in the orientation you want.



The scale and move tools are very intuitive. You can utilize them if you want.

For example, the pins on this one might not fit quite right. You could decide that if it was 2% larger, then the pins will lock into the slot the way your original design called for. Rather than returning to Solid Edge to redesign we can reprint using the Scale tool.

In this case you would utilize the scale tool. You could enter in the desired amount. With the uniform scaling checked it will scale all axis the same.



Rotate the view to be sure the part is on the plate. Holding the mouse wheel down and moving the mouse will pan the view. Holding the right mouse button down will allow you to rotate the view.

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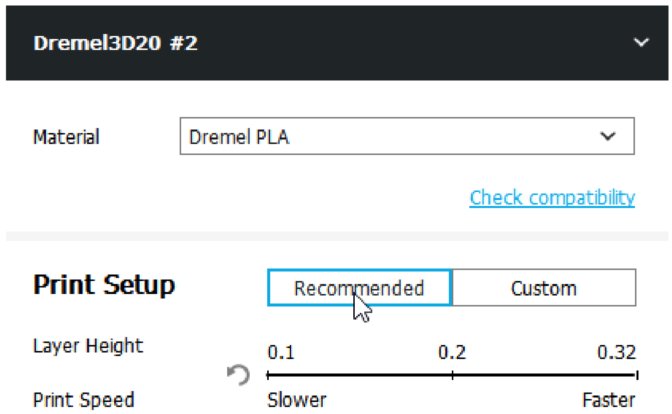
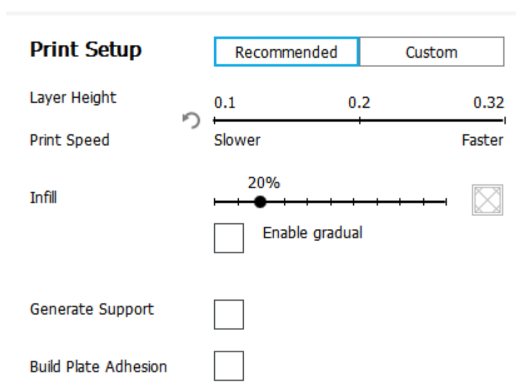
Print Setup

The next step requires the setup of the parameters for the printer. The fastest way to print is to select the Recommended settings in the print setup area.

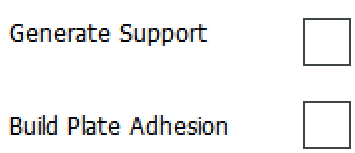


Slicing

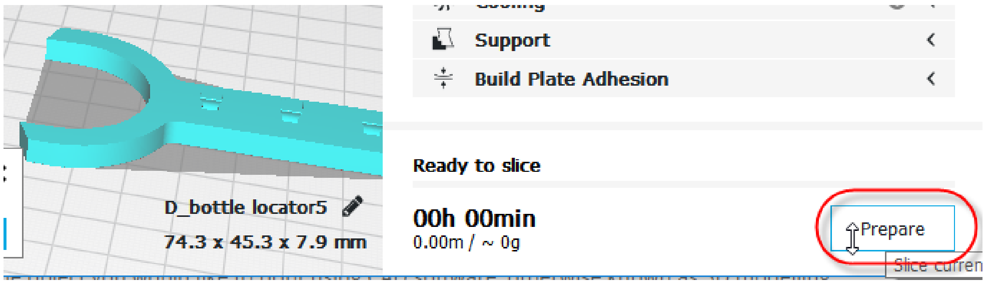
For this example, the recommended settings are used.



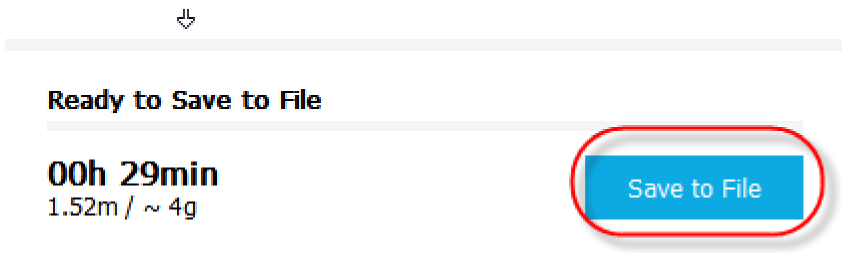
This plate fits well to the bed. If the part you are printing is smaller, you can check the icon for build plate adhesion. This prints a wide layer under the part. If your parts have overhangs or open area underneath you can check the box for generate support. This is a thin layer of material that is laid down to support structures above them. These are removed after printing, sometimes with needle nose or diagonal pliers.



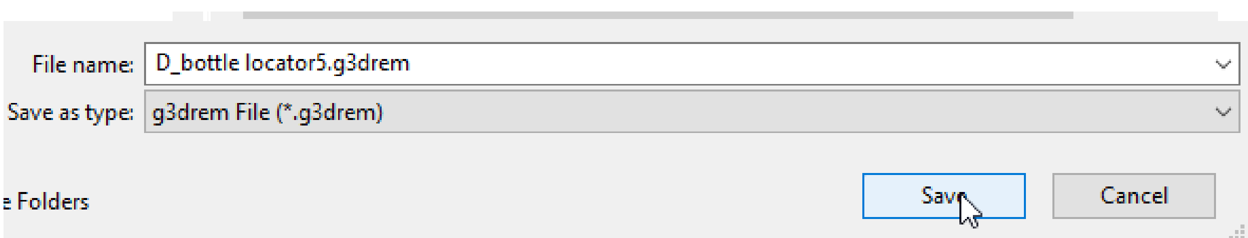
Select the Prepare button at the bottom of the screen.



Once prepare is selected the computer slices the object according to the parameters in the profile. It then presents a summary of the process. In this instance the program is reporting that it will take almost ½ hour to print and use about a meter and a half of filament. It will weight in the neighborhood of 4 grams. Select the option to Save to File.



Save the file to a location you can find again later. In this case the printer is a Dremel 3D20 so it needs the .g3drem extension.



You can now take this file to your printer.

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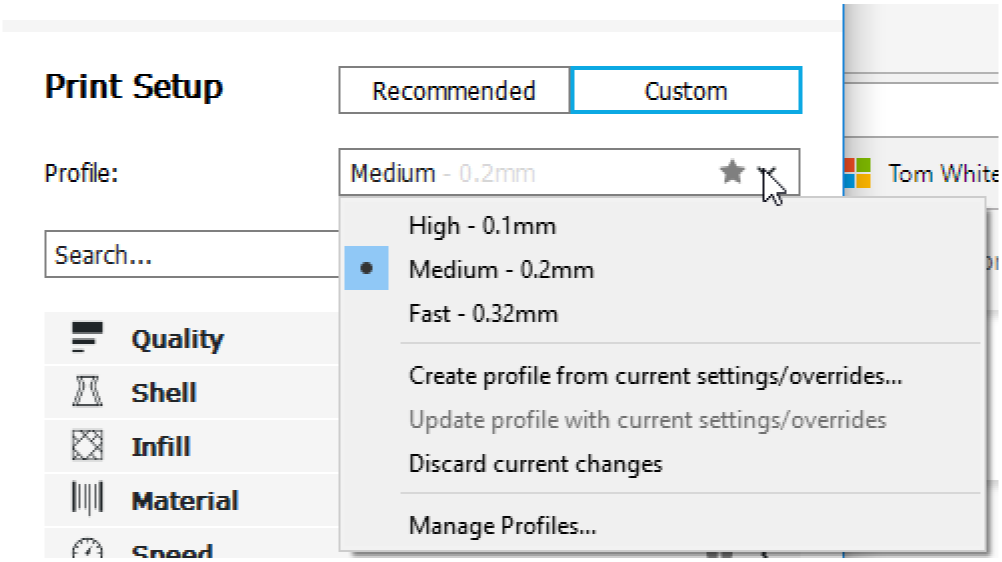
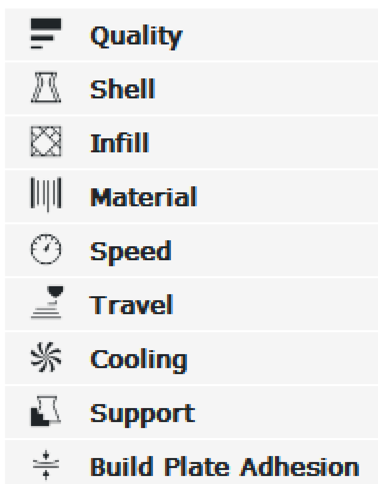
Advanced Settings

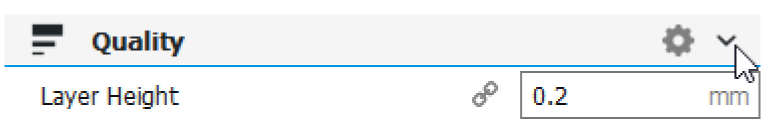
If you select the custom option you can begin to change the parameters. The medium option for resolution is the one that is shown under the Recommended tab.



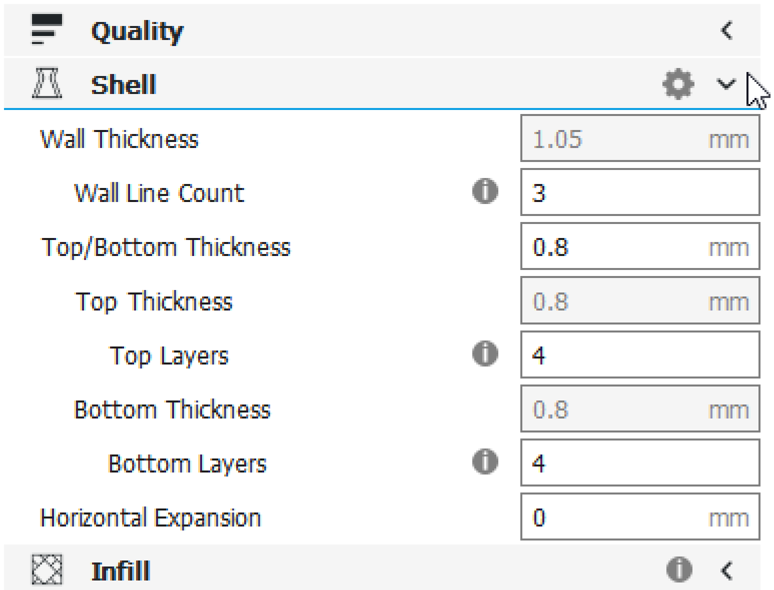
The high setting will give smoother results but it will take twice as long. The fast option will not be a great prototype but sometimes you only want a concept. Individual settings can be changed to your liking and saved as a profile. The various options are shown below. Each can be expanded to select what is desired.



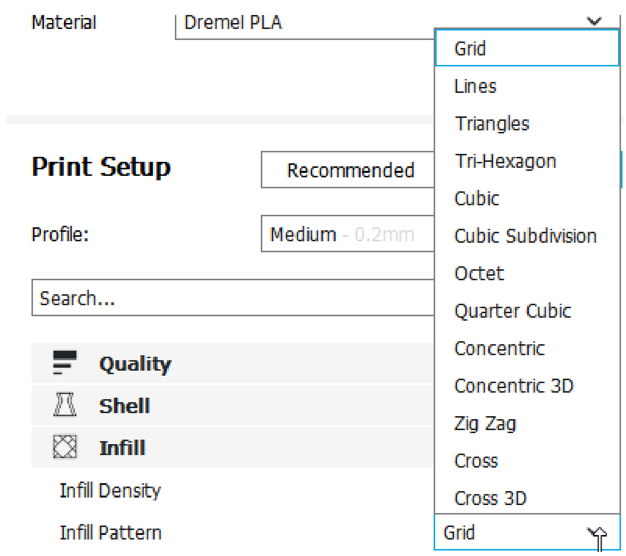
Quality will allow you to set the height of the layer. If you wanted a .22mm layer you can enter that in the window.



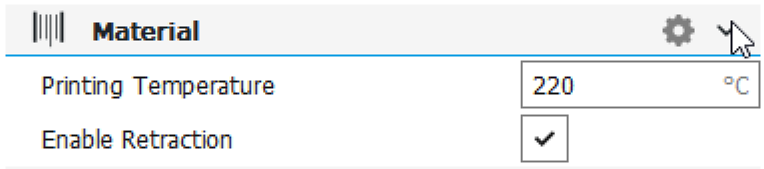
Shell is the area where you describe how many solid layers the model will have. The walls in this example will have three solid layers on the outside while the top and bottom will have 4. This is important as you might want to be sure the top layers look good and are strong but an entire model printed as a solid would take forever and use a lot of material.



Infill is a pattern that allows support of the layers on top but reduces the amount of material used. This setting allows the selection of the amount of infill and the pattern used. The orientation of the pattern changes on each layer.



The material setting allows for the adjustment of the printing temperature. 220ºC is the recommended setting for the Dremel PLA filament. Other filaments might have a different recommendation.



There are more settings you can adjust. The more you read the help manuals and print, the better control you will have over the print quality.

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Creating Drawing Views

Drawing views are a two dimensional representation of a 3D part. Designers use these views to communicate the shape, size, and finish of a part and how the parts are assembled. The drawings apply international standards that determine how to display information in the proper format. Like an engineering notebook the engineering drawings are legal instruments containing all the available information about a design. It is important to know how to create detailed drawings. Drawings, along with 3D solid models, communicate exactly the designer's intent for the part. Dimension and tolerance describe the exact shape and size of a part to fit with the other components in a product.

There are a wide variety of drawings. Each allows the viewer to see information undistorted in two dimensions. "Working drawings" is the name of the collection of drawings for a product. Working drawings typically contain a collection of different drawings. Drawing creation can be researched in various help menus and reference texts. For more information about drawings you can research:

- Multiview drawings
    - Orthographic
    - Auxiliary
    - Section views
- Annotation
    - Dimensions
    - Tolerance
    - Class of fits
    - Notes
    - Material
    - Finish marks
    - Weldment symbols
- Assembly drawings
    - Part identification balloons
    - Bill of materials
    - Exploded assembly drawings

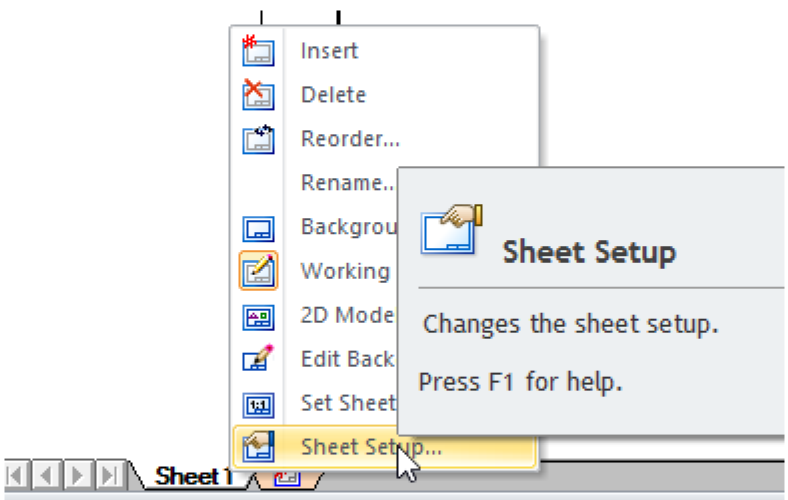
CAD systems have evolved to create lines automatically and allow for the solid model to communicate with the drawing views. In the tutorial that follows we will explore many features of drawing views. There will be faster methods of doing this work and good designers educate themselves on the standards to make communication the central goal. Before beginning this tutorial, create the 3D models of the individual parts.

Setting up the Sheet

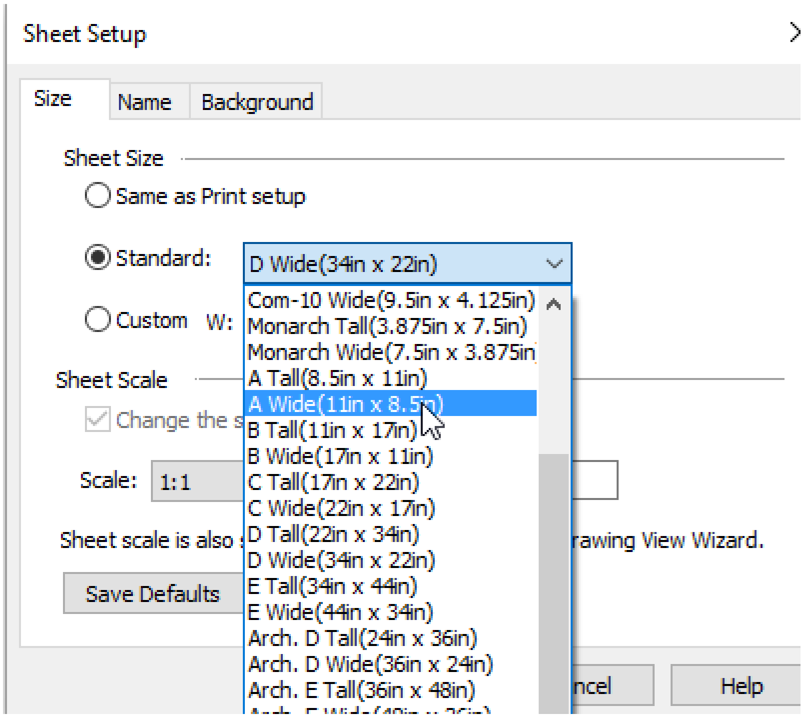
“Drawing sheets” contain information about a part or assembly. Standards define the size and shape of the sheets to allow the viewer of the working drawings to find information quickly. Companies customize sheets and create templates to include information specific to their industry. There is a border on the sheet which limits the formal drawing area. Sometimes there is a location grid included in the border. This is important on large sheets so information can be located quickly. There is also a title block. This block contains information such as the author of the drawing, date, company name, revisions, people that have checked the drawings and other standardized information. Individual companies customize this so it always contains the similar information in the same location on every drawing.

Begin a new Draft document.

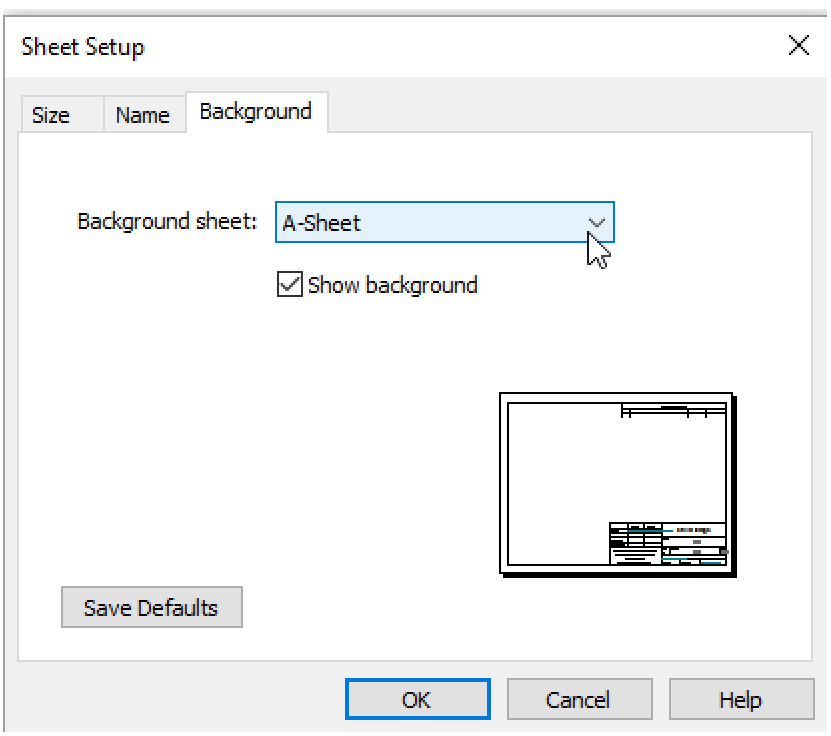
You will see the title block and border. The default setting is for a D sized sheet. This size is too big to print unless a large plotter is available. Most small printers will handle A sized paper. To adjust the paper size, edit the properties of the sheet. Right click on Sheet 1 at the bottom of the screen. Select Sheet Setup from the options.



Begin with the Size tab. Look through the options selecting “A Wide”.



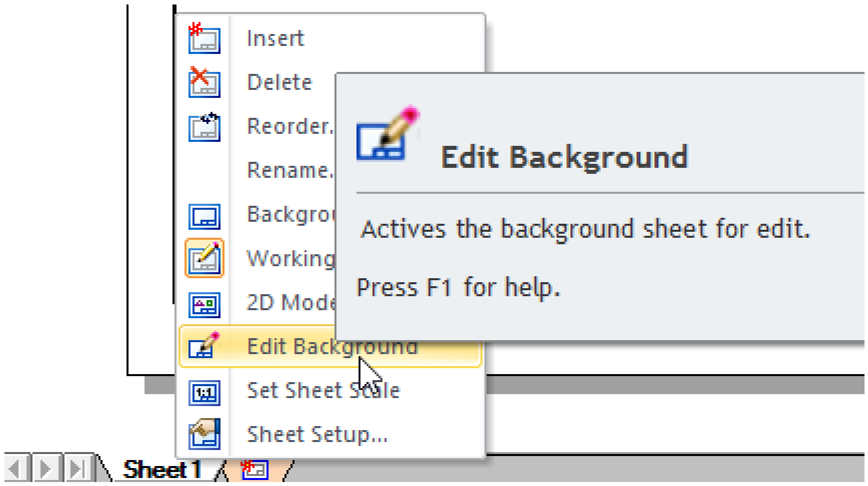
Go to the background tab. Change the background sheet to A-Sheet.



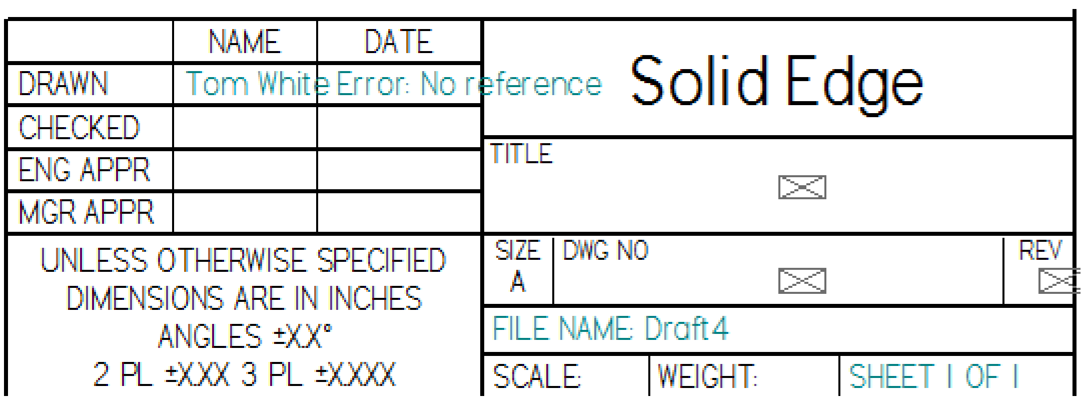
Click on the Save Defaults. Then click OK. This will apply the settings to all the sheets in the working drawing set.

The sheet and background should now appear for an A sized paper. The title block isn't designed for a school. We can edit the background to personalize the sheet.

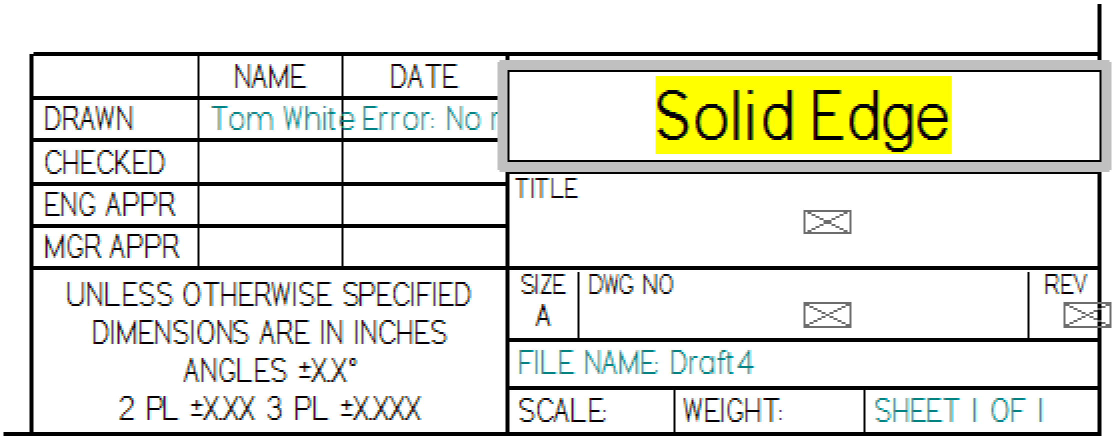
Right click on the sheet 1 again and select Edit Background from the options.



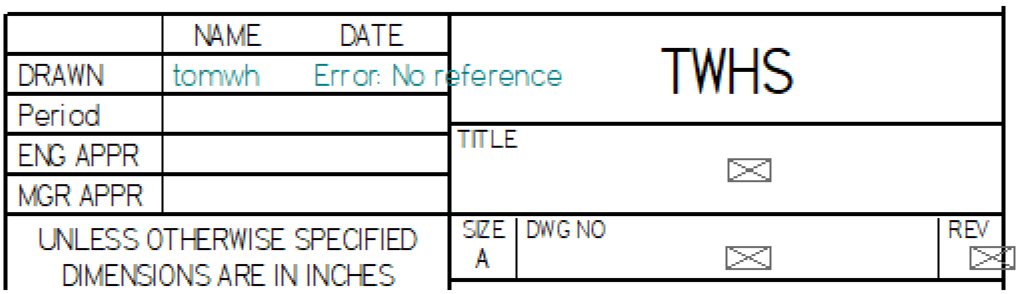
This brings up the background for the A-sized sheet. If you look at the title block you see the name is crowded. It is really set up for initials not a name. We will edit the block to personalize the sheet for use.



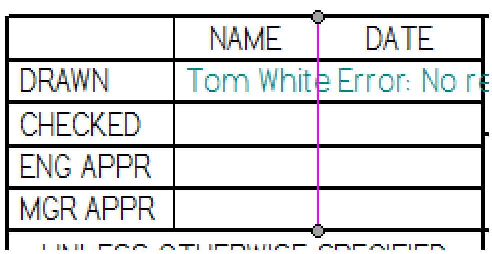
Where it says "Solid Edge", highlight by swiping across the text.



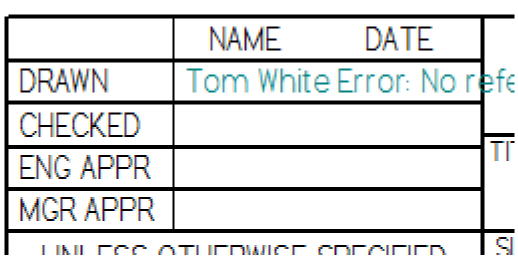
Change the text so your school name is listed.



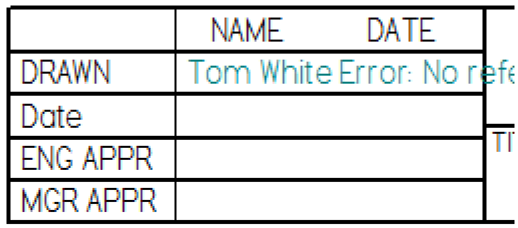
To provide more room for your information delete the line between name and date. Click on the line to highlight the line.



Select your delete key to remove the line.

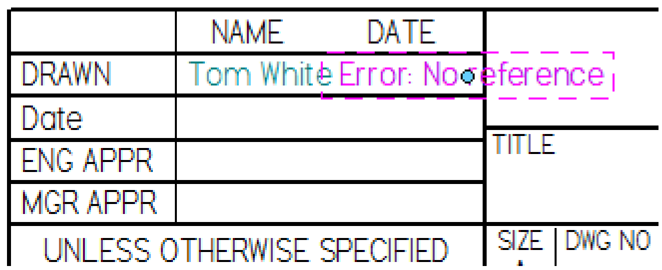


Now change the "Checked" label to the word "Date" by highlighting and replacing it.

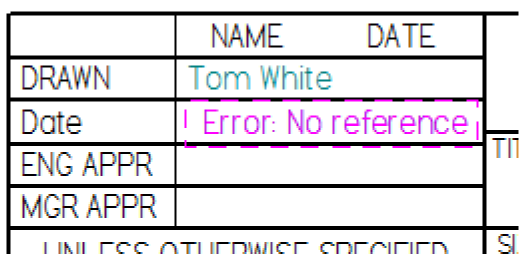


Now we have a place to put the automatic date. Left click where it says Error: No Reference.

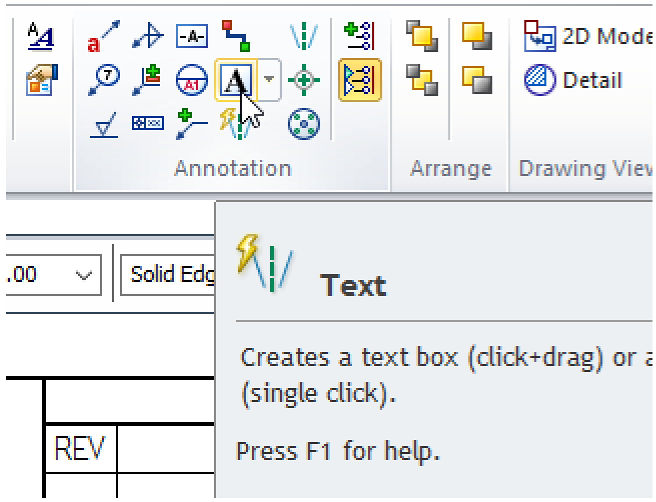
It will highlight and a blue dot will appear in the middle.



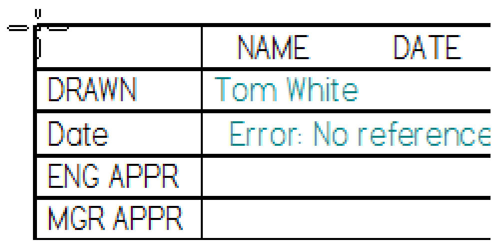
Left click, someplace in the box and drag the text so the blue dot is in the center of the block next to the word Date. Remember Ctrl Z will undo the last action if necessary.



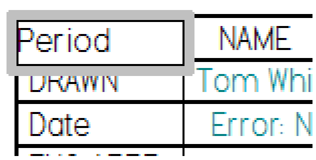
From the Sketching ribbon select the icon for text



Click the top left hand box of the title block and drag to the opposite corner to place a label.

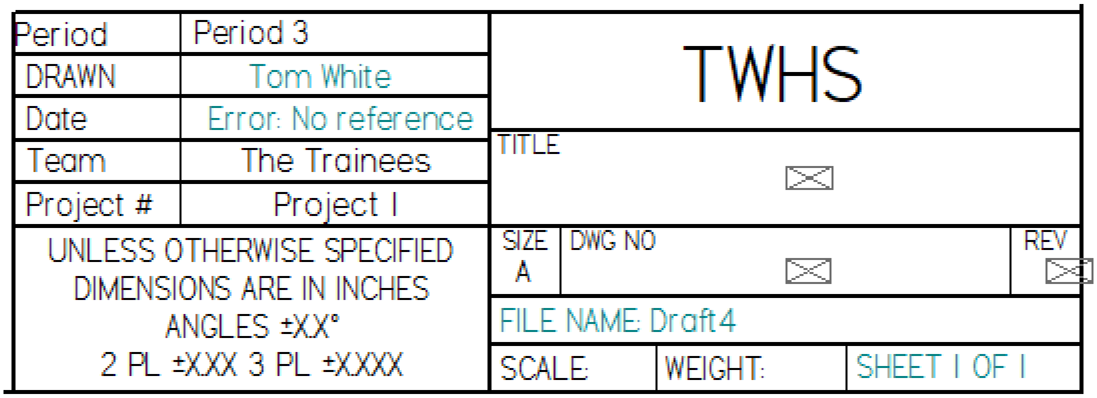


Type the label “Period” in the box.



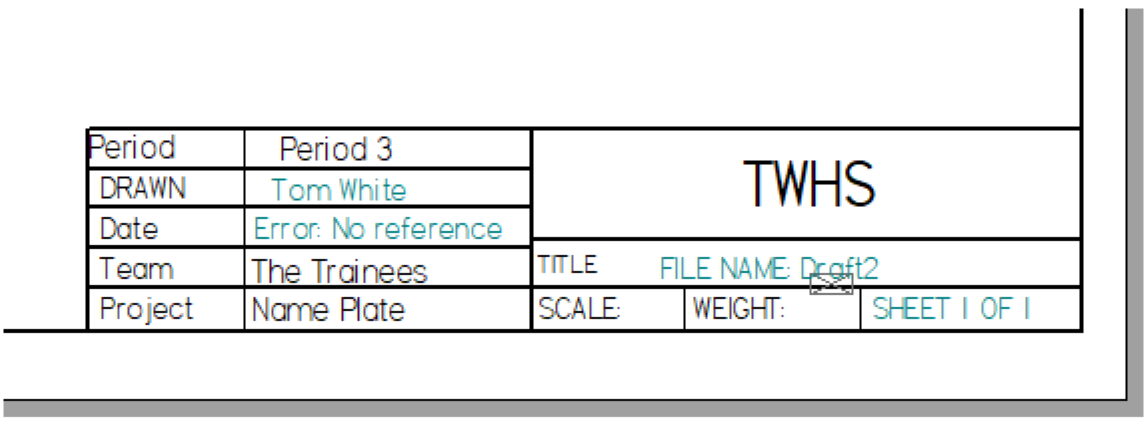
Now delete the text next to period and place your period number in the space.

Add your team name and other information to personalize the sheet.

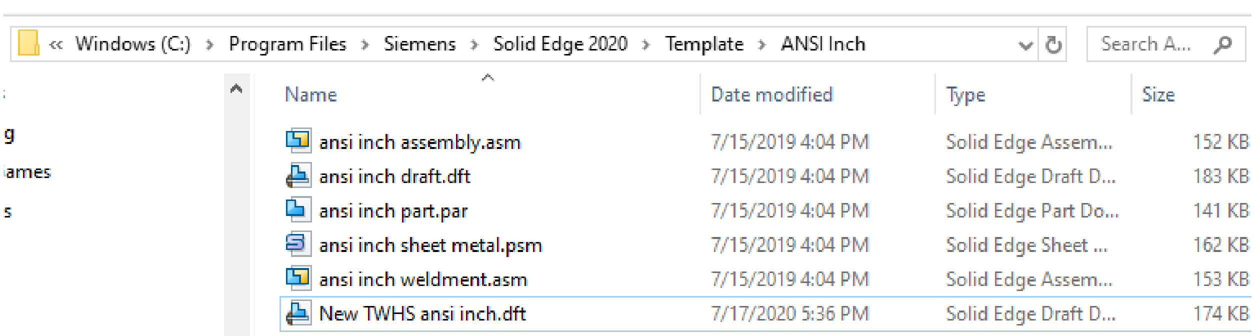


Delete lines and unused spaces to provide more space to place drawing views.

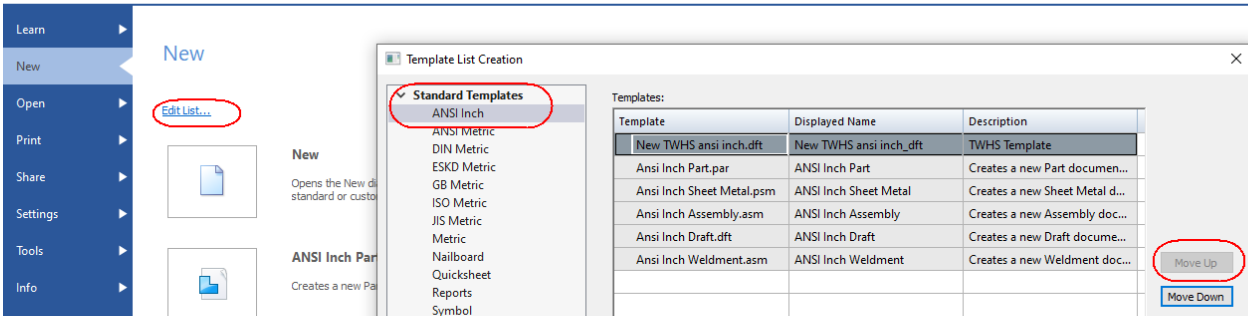
When satisfied with your title block, right click on Sheet 1 and select Background. This will turn off the background sheets and your title block will show. As you add sheets to the set of working drawings you can select the sheet setup and select the A background and all the data appears as edited. When you save your Draft with a name you will see the date and name appear on the sheet. New sheets will update with a new sheet number.



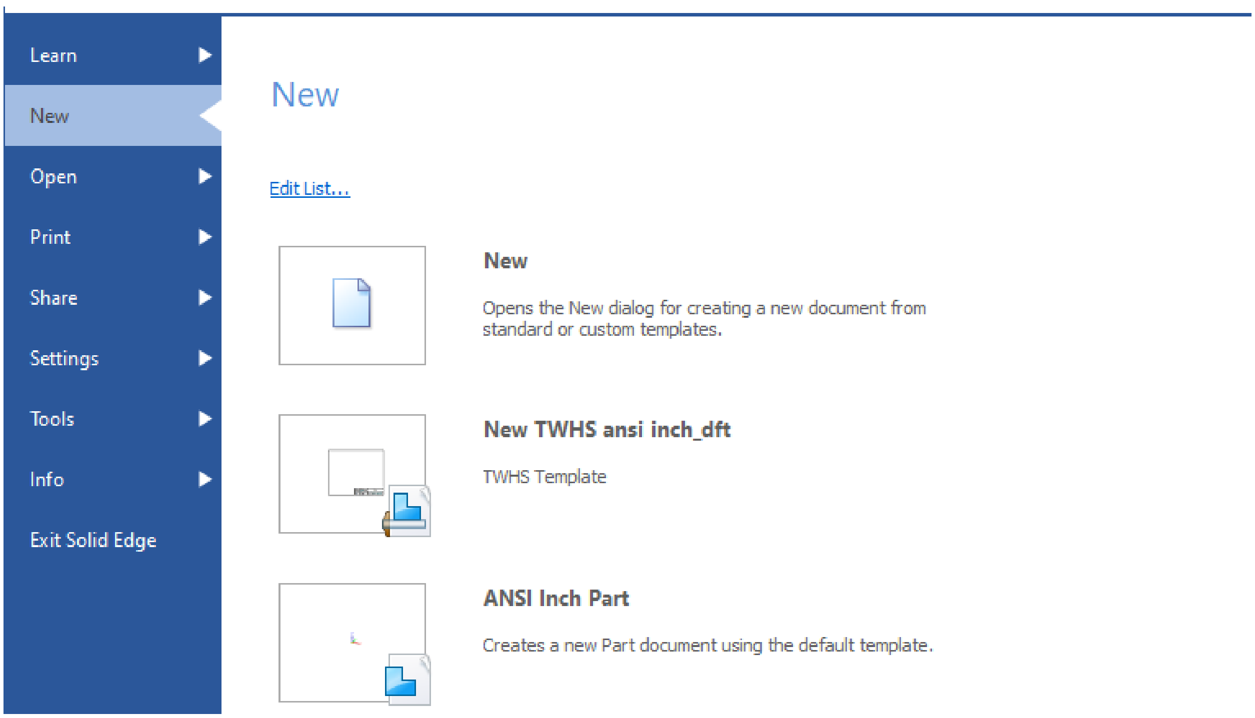
To use this as a template for your students save the blank draft file with a unique name to the template folder for the standard you are using. In this case the location is C:\Program Files\Siemens\Solid Edge 2020\Template\ANSI Inch.



Select New from the Application button menu. Click on the Edit list button. Select the template folder you saved the template to. Use the move up button to move it to the top of the list or where in the list you want it. Click OK



Then when you select New you will see the file you created and named.



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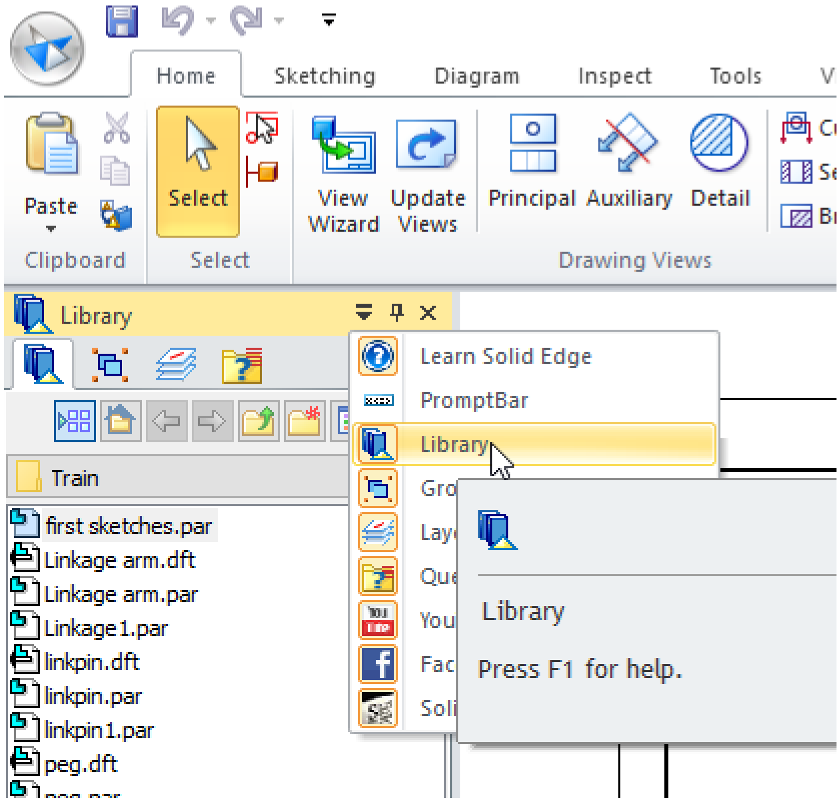
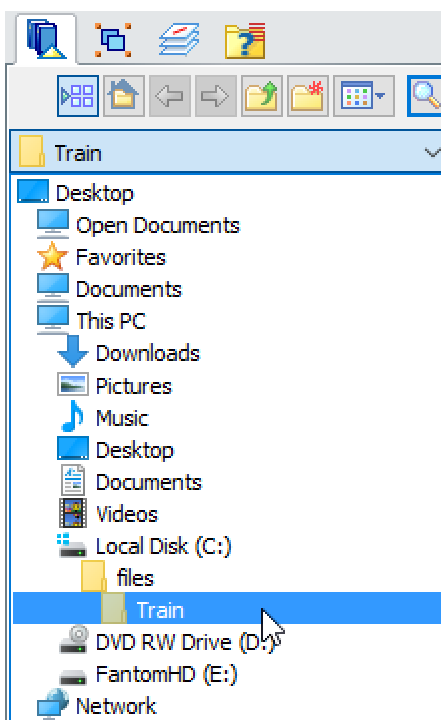
Basic Views

Once you have the correct title block and information, the process of creating drawing views can begin.

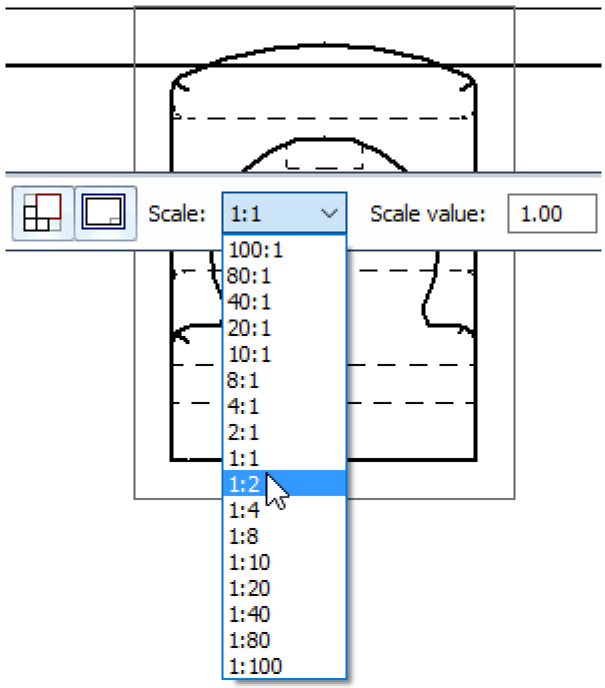
To begin creating views access the Library.



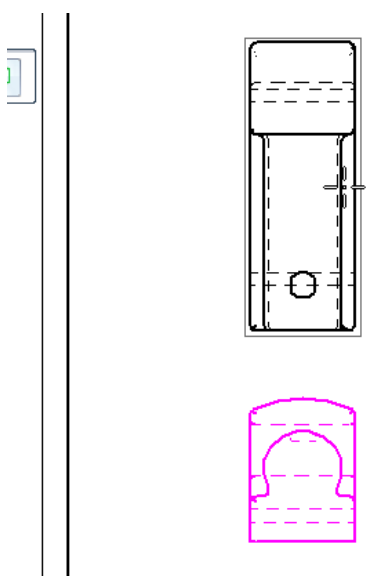
Navigate to where your parts are stored.



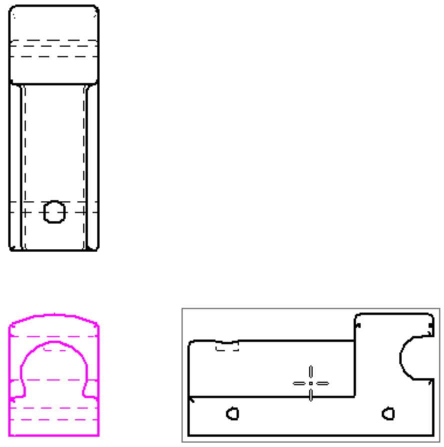
Once in your directory you will see the saved parts. Left click on the train body and drag it out to your sheet. Depending on the size of the parts you have drawn you might have problems fitting them on the paper. Use the scale setting to adjust the size of the view.



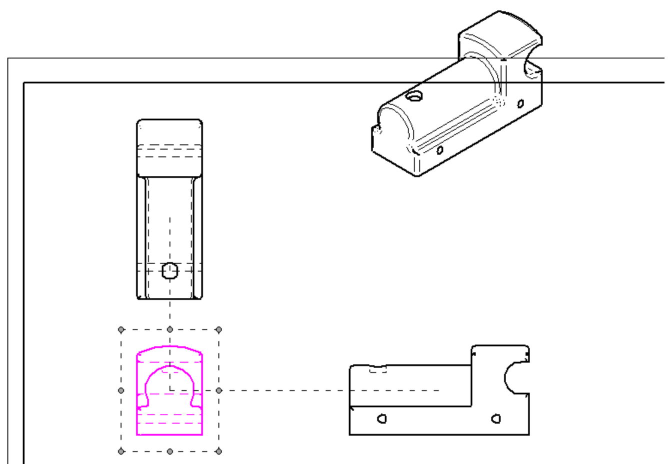
For this one use a scale of 1:2. Once the ratio is selected the drawing will shrink. Move it to the lower left hand section of your drawing sheet and left click to place it. Slide the mouse above the view you just placed and left click again to place the top view.



Now move to the right of the original view and click to place the side view.

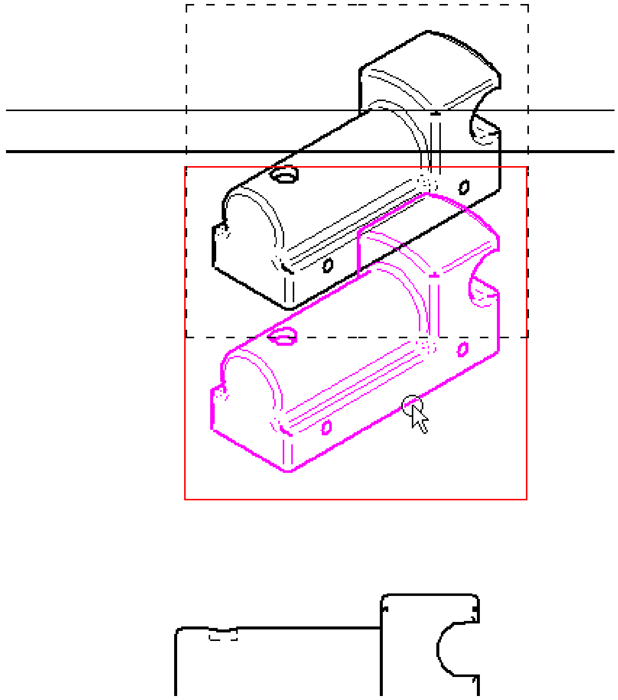


Move the mouse to a diagonal from the original view and this will create the isometric view of the train body.

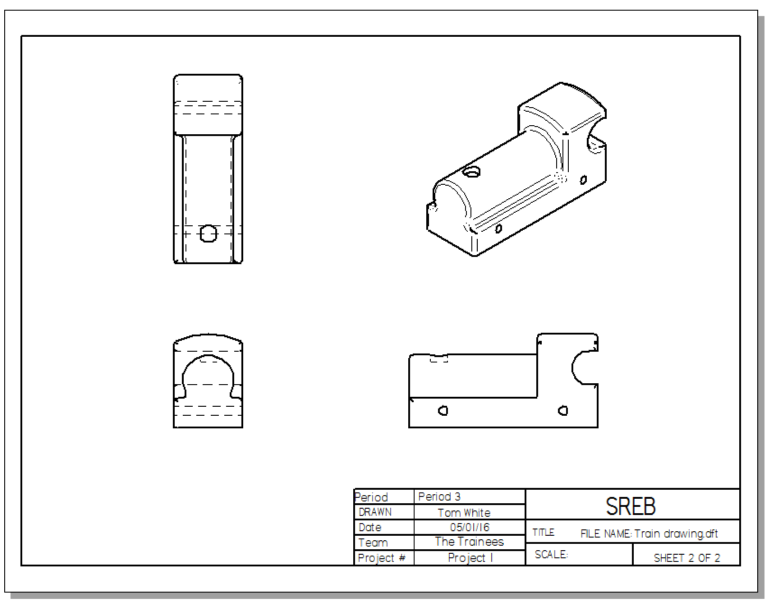


Hit the Esc key to exit the command.

Don’t worry about the actual positioning at this point. Once the views are placed you can then move the views as desired to make room for dimensions or fitting them inside the borders. To move a view, click on a line of the view. It will highlight and you will be able to drag it to the position you wish.



Let go of the mouse button and the view will be in a new position. Practice moving views.



Save your file.

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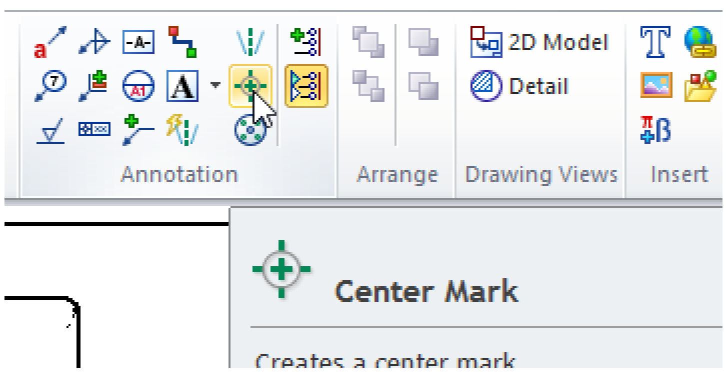
Adding Dimensions and Annotations

Dimensioning a view shows size, location, and the orientation of the various elements in the drawings. Annotations are text and graphics that give information about the design. More information about dimensioning and annotation standards can be found in reference texts and help menus. Search for dimensioning overview. It is the combination of the dimensions and annotations that provides the reader the completed design intent.

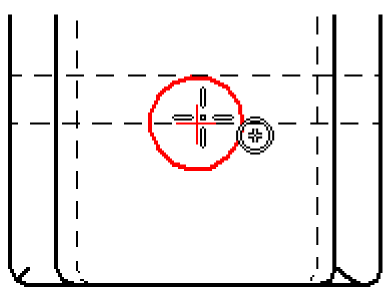
Dimensions and annotations should appear in the views that best show the intent of the designer. In the train body there are several circular features. To dimension circular features, use centerlines so the reader knows the distance to the centers.

This example has magnified the dimensions to be easier to read.

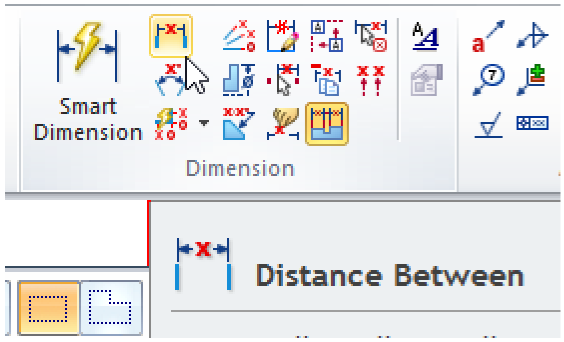
The top view contains a hole where the stack will fit. Begin the dimensioning by adding a center mark. Select the center mark from the annotation section of the ribbon.



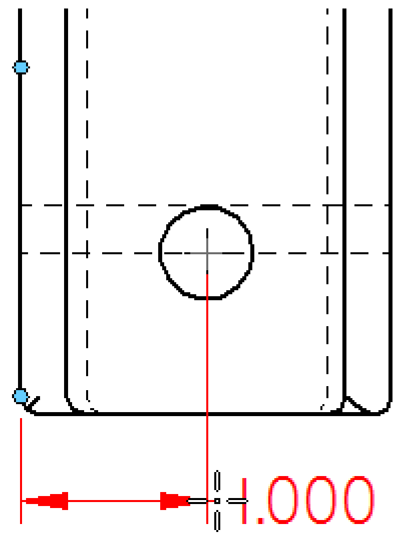
Slide the mouse over the hole and select the center of the hole.



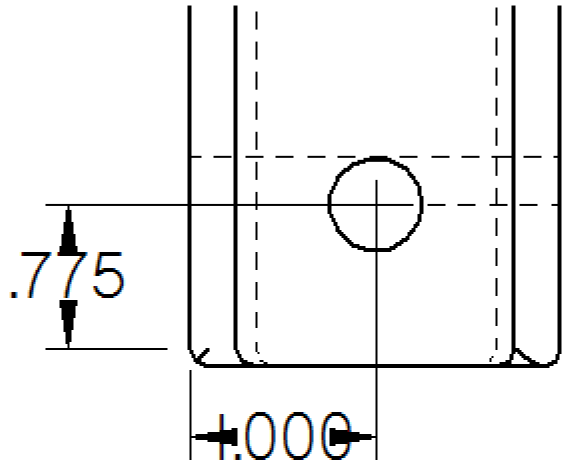
The center is now defined. Measure from the edge to find the exact placement. Use the Distance Between option to place the dimension.



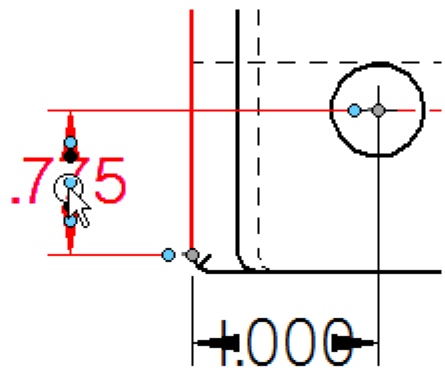
Select the edge of the train and the center mark of the hole. Slide below the top view to position the dimension. Hit the esc key to exit the command.



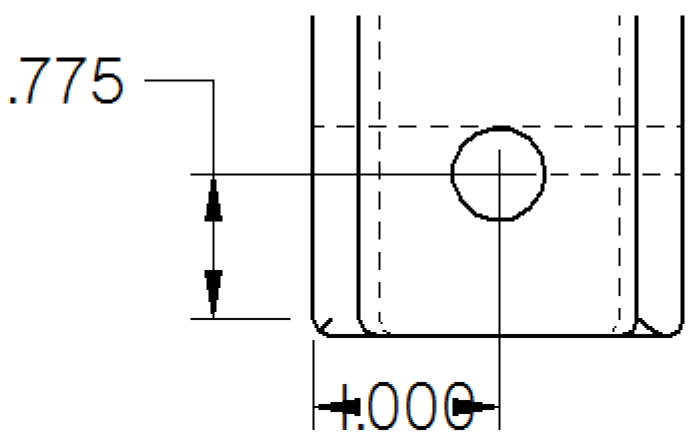
Select the same two places only slide to the side and the distance to the center from the front of the train will appear.



While the dimensions are correct they are difficult to read. Hit the esc key to exit the dimension command. Click on one of the dimensions to see the grips. Grab the blue grip in the middle of the dimension.

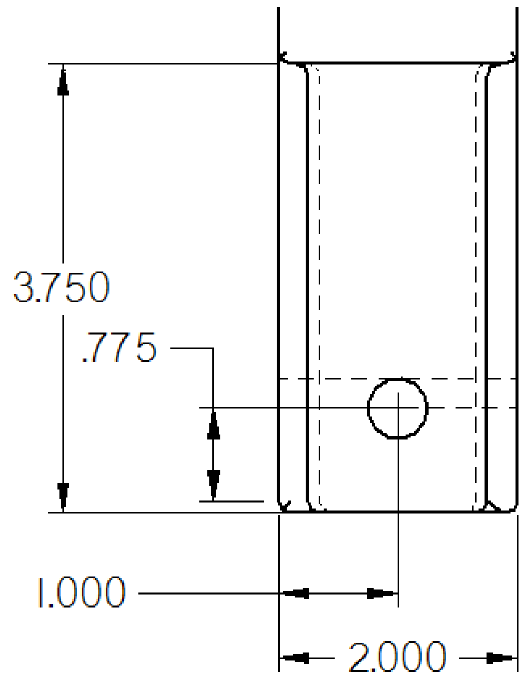


Move your mouse up above the extension lines to move the dimension outside of the lines.

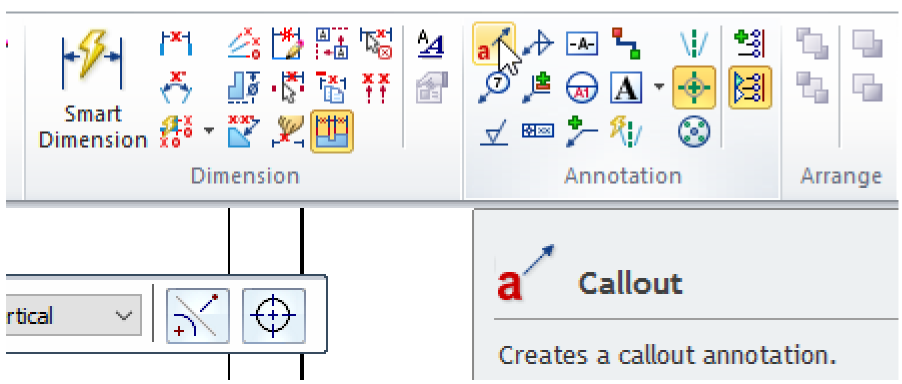


Repeat the process so the other dimension is readable.

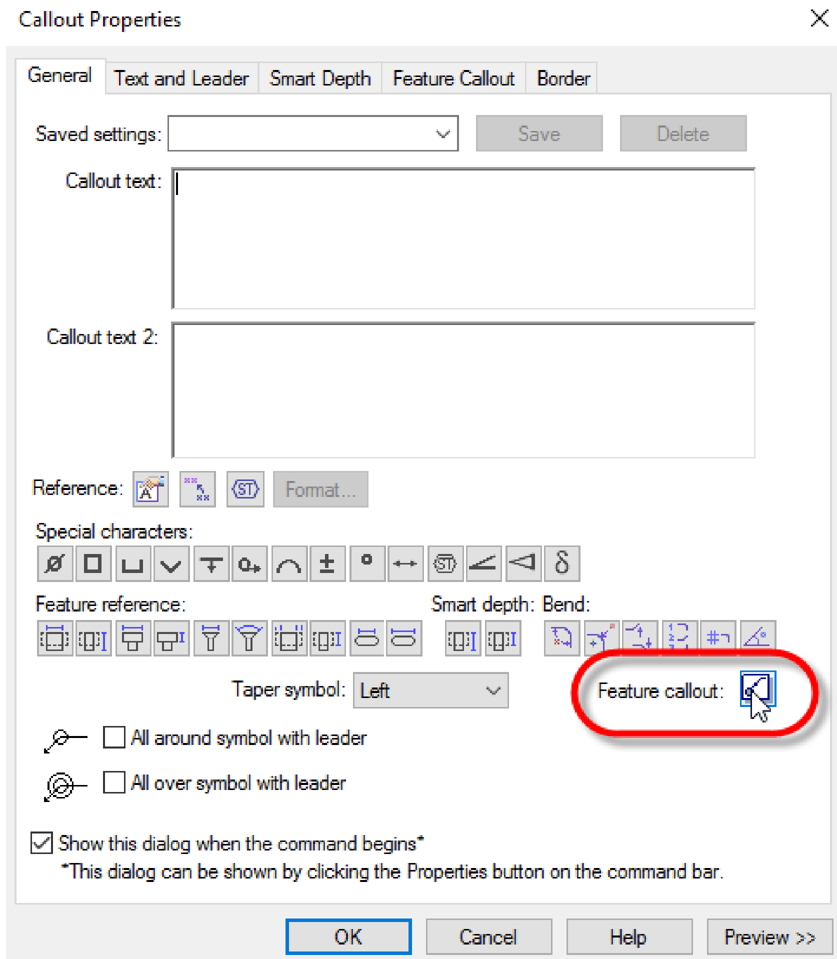
Add dimensions to match the picture below.



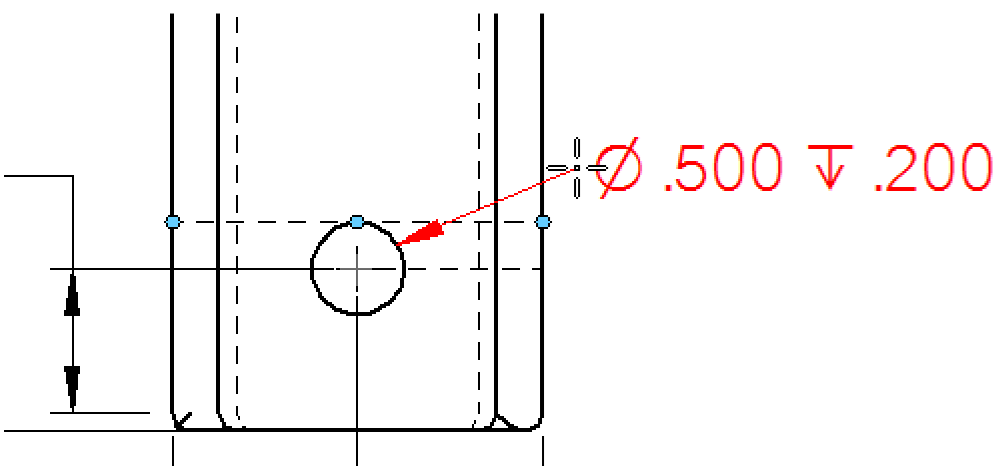
Add a note to let the viewer know the size of the hole. Use a callout to add clarity about a feature, calling the reader's attention to a specific location. Select callout from the annotation section of the ribbon. For more information hit the F1 key.



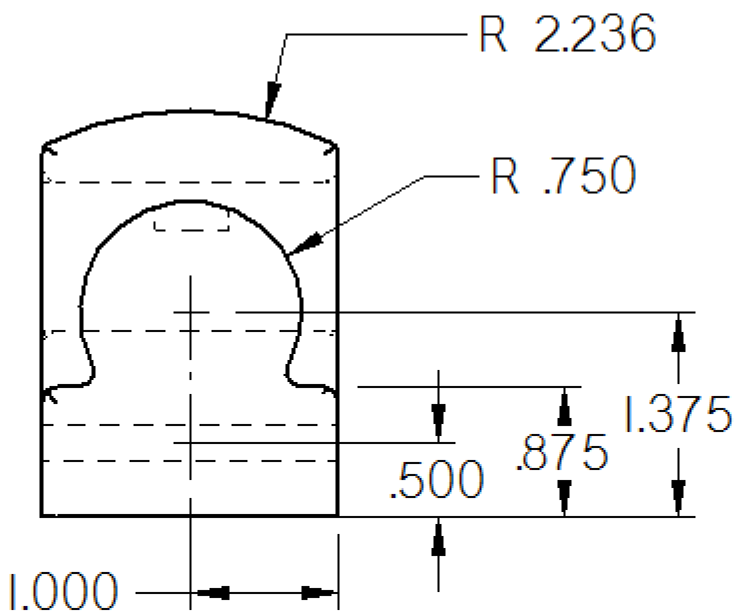
In the Callout properties dialog box, erase the current callout text. Then click on the feature Callout button.



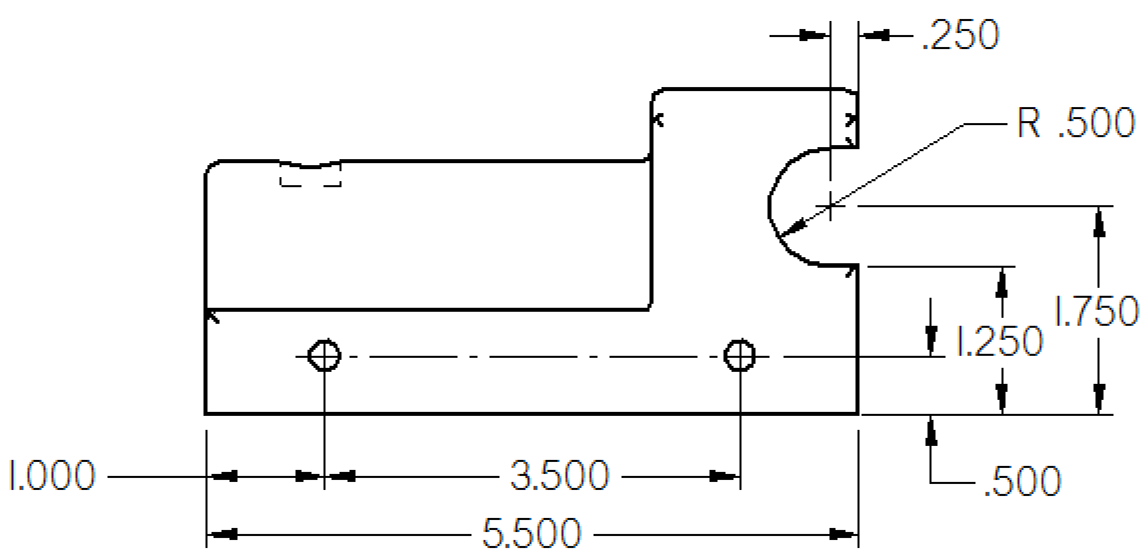
Select OK and then click on the circle representing the stack hole. Move off the hole and click to place the hole note. This lets the reader know the hole is .500 in diameter and .200 deep.



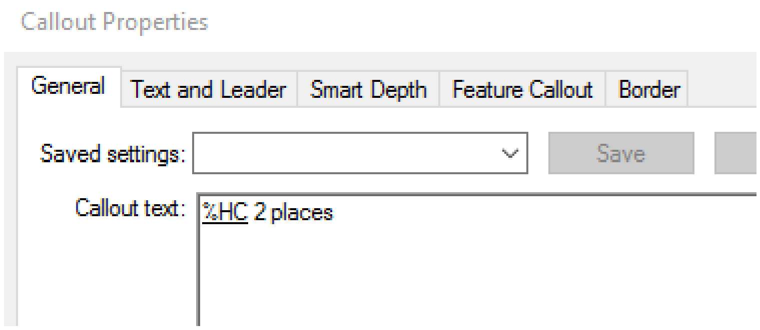
Add center lines and marks to the front view to communicate the centers of the important arcs. Dimension the front view to resemble the picture below. Notice how the dimensions are organized so the reader can quickly find the desired dimension.



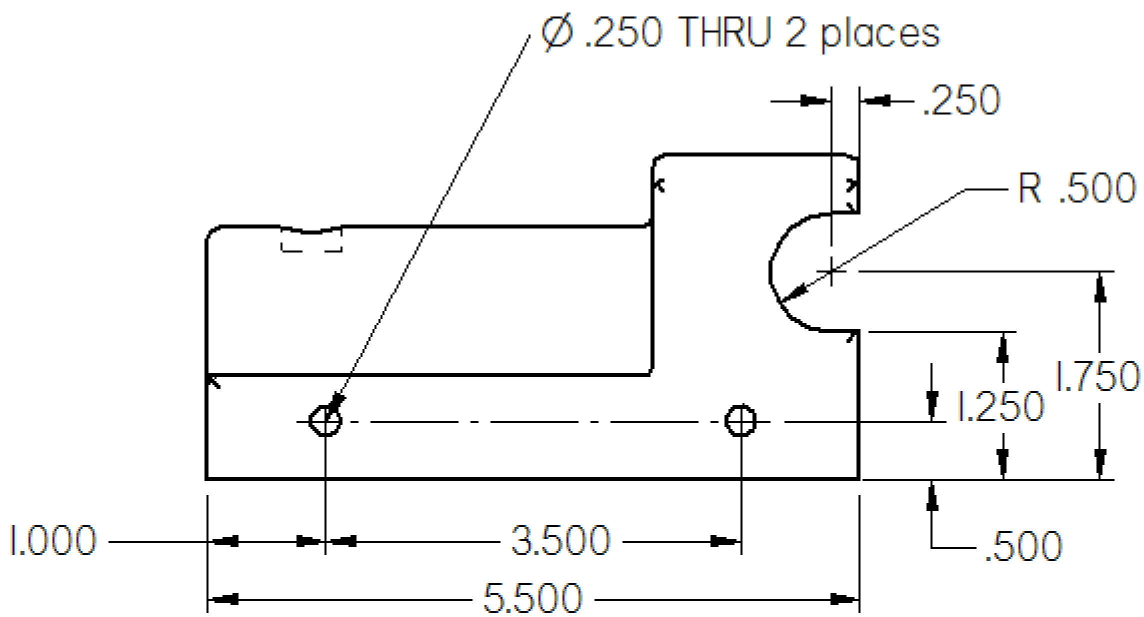
Add center marks to the side view and add dimensions.



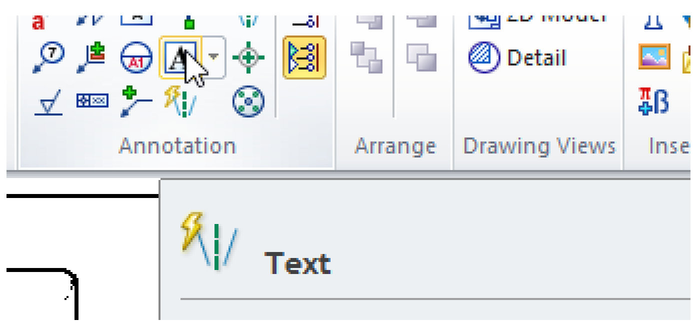
Add a callout to dimension the holes. Since the holes are the same we can use one callout for them. Select the Callout command. This time click on the Feature Callout button and then type in “2 places” after the command in the callout text.



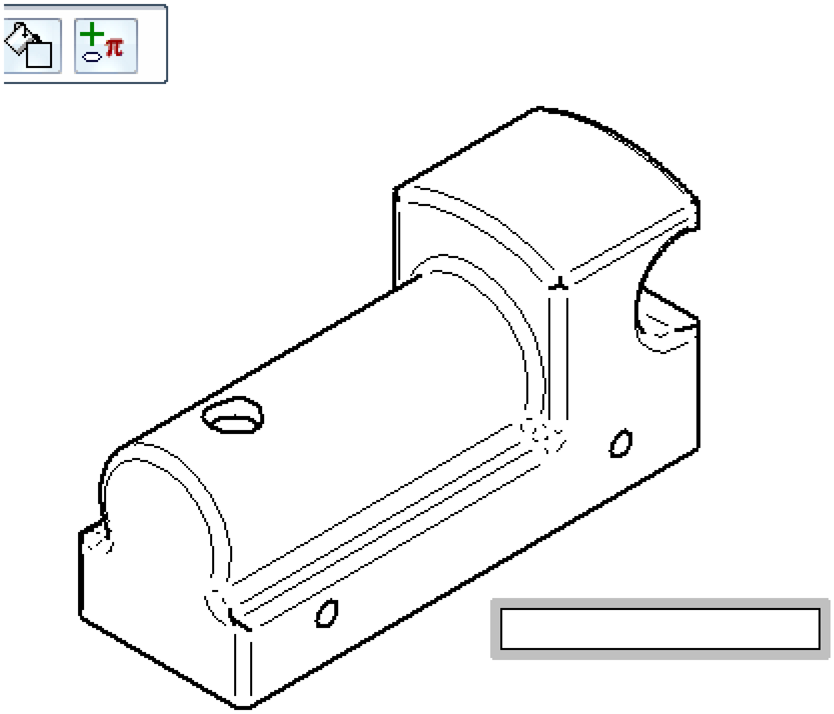
Select OK and highlight one of the holes to place the note.



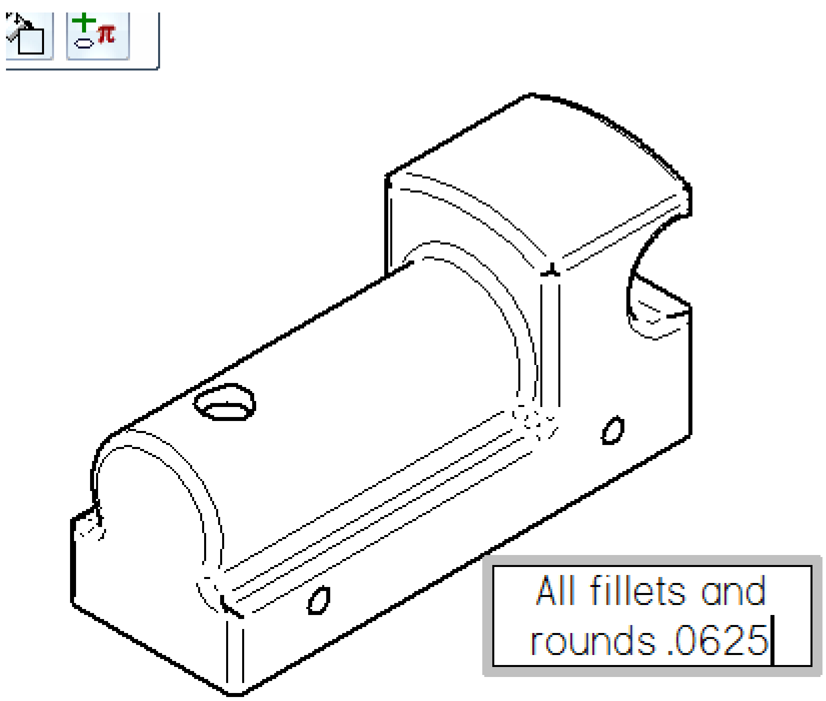
To complete the annotations add a note about the fillets and rounds on the train body. A note that is general about views can be placed where it will be seen. Select the Note icon from the Annotation section of the ribbon.



Drag a rectangle on the screen where the note will be located.



When the dialog box opens, type the following into the box.



Save your file

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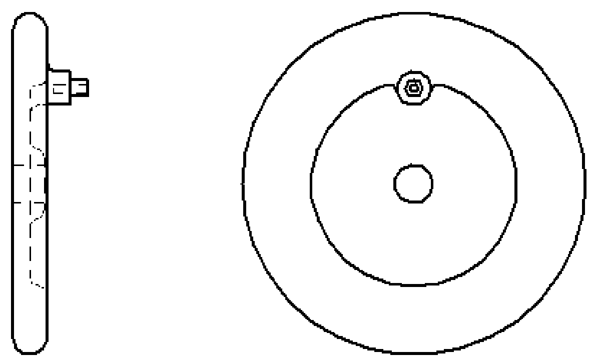
Section Views

Occasionally, normal views of a part do not show hidden detail. Additional views are needed when detail is obscured by the part itself. A “section” view is what would be seen if the part was sawed horizontally through a part and looked at the cut edge. Designers use a line called a cutting plane defining where the cut is and the arrows at the end indicate the orientation.

Begin a new drawing sheet in the working drawings.

Drag the wheel from the Library onto the work area. Use a scale of 1:1 placing a front view and right side view.



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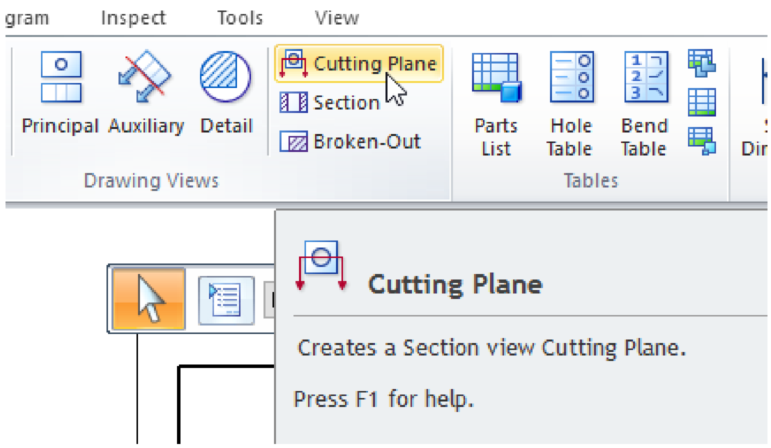
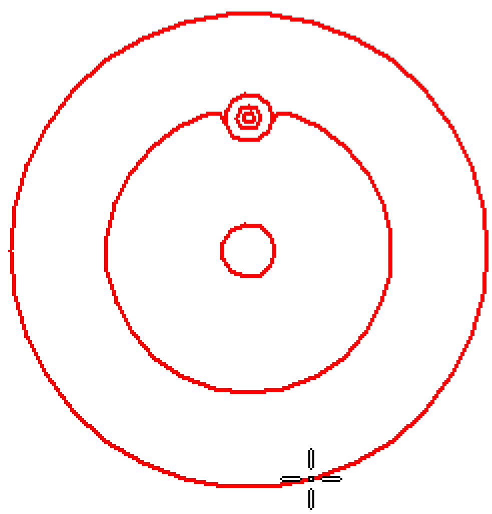
Cutting Plane

To create a section view, create a cutting plane. A cutting plane is an imaginary plane used to show where a part will be split for a section view. The simplest is a single line through an object. If there are multiple things to show that are not in a line the section plane can be created to pass through several points as long as the lines touch each other and don’t form a closed region or loop. Check a reference text for section views and cutting planes. Use the F1 key for help during the command.

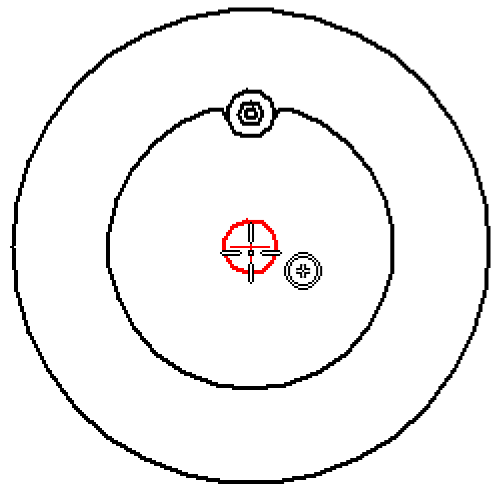
Select the Cutting Plane tool from the Drawing Views section of the Main ribbon.



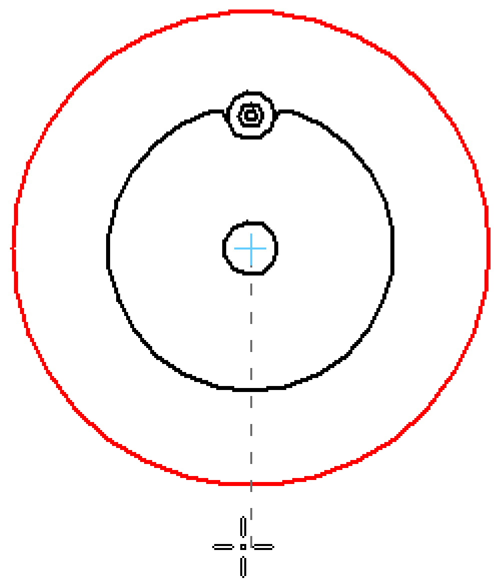
Click on the view that shows the circular nature of the wheel.



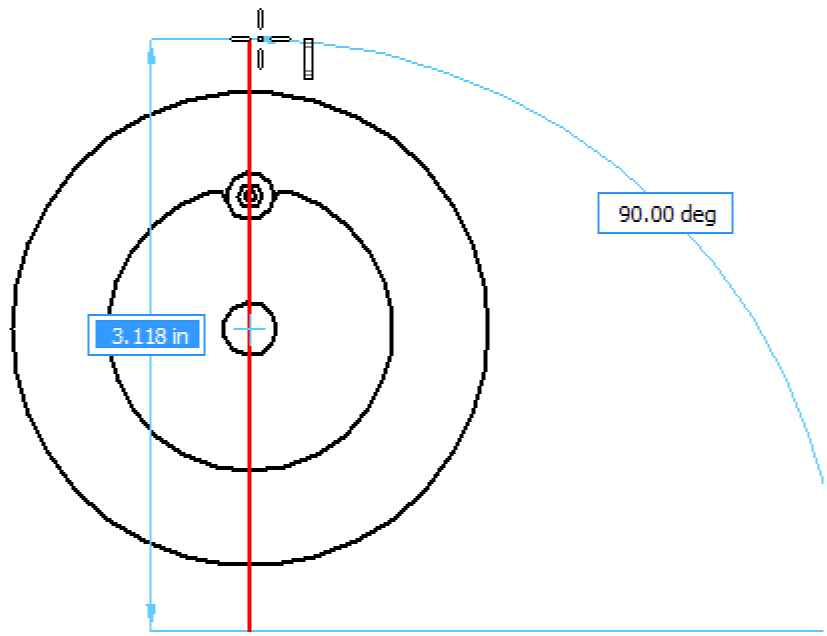
The screen will change and prompt for the first point. We want a line right through the center of the wheel through the cylinder for the linkage rod. Hover over the center of the wheel until you see the center mark appear.



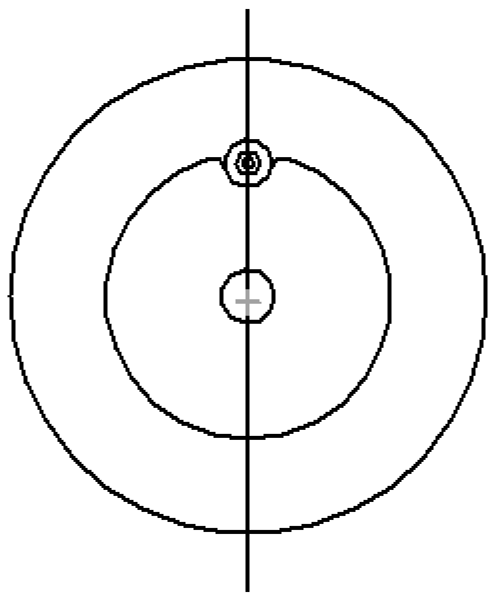
Do not click here but move the mouse straight down. You will see the intelligence of the program figuring out you want a line through the center.



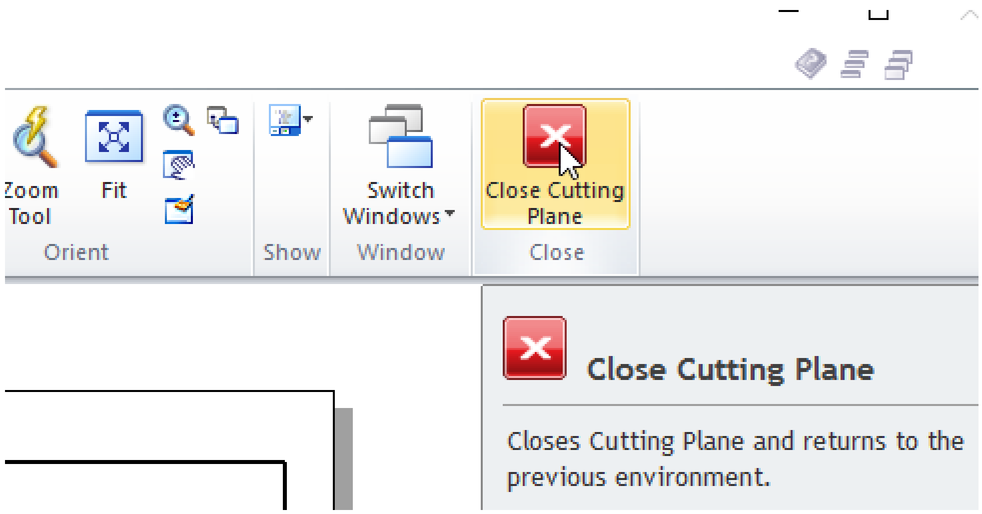
Click below the wheel. Then move your mouse straight up past the top of the wheel to click again. This will create a line through the center of the wheel.



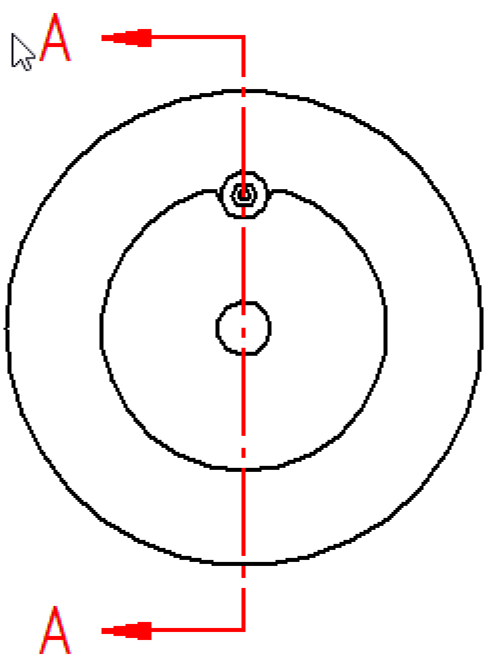
Hit the esc key to indicate you are finished. The line drawn will appear.



From the ribbon select the Close Cutting Plane icon.



A prompt will appear to select the side view desired. Move your mouse toward the left side of the screen and click. You will see two arrowheads appear with a letter next to each. The first section is labeled A-A. The second is B-B etc.



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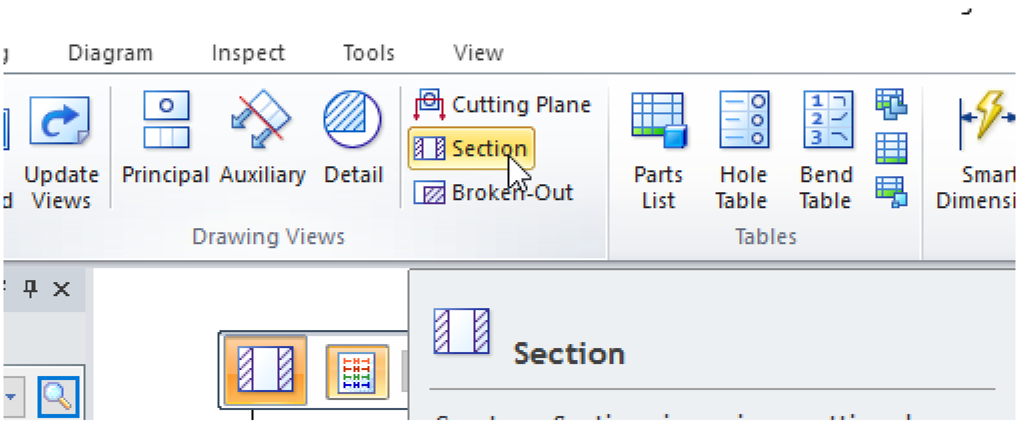
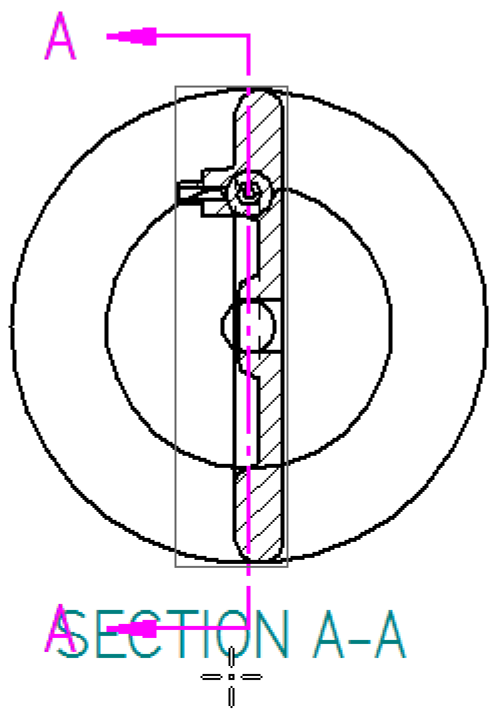
Full Section

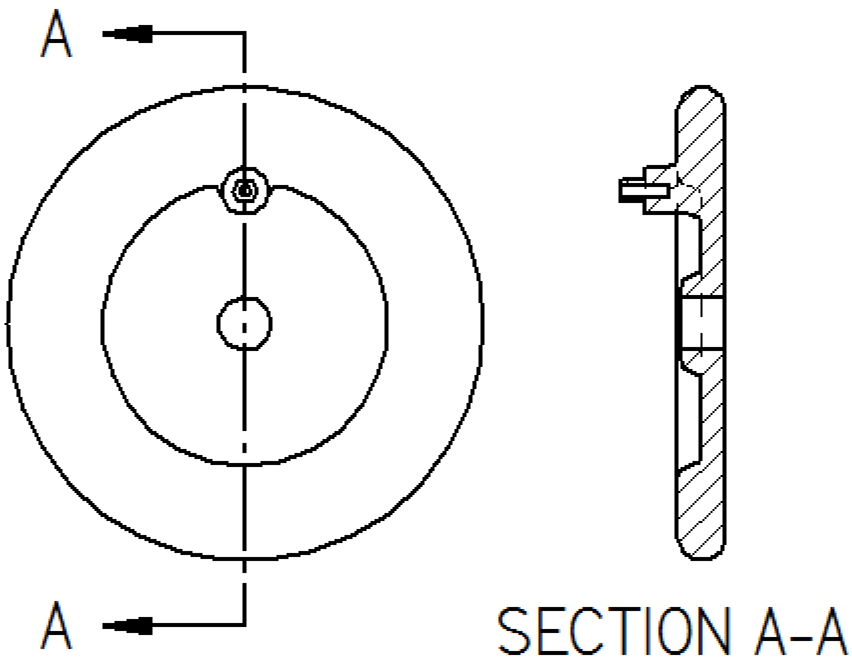
Splitting an object in half to see the internal structure is called a
Full section. Now that the cutting plane is in place, create the section view. Select Section from the Drawing Views section of the ribbon.



Select a cutting plane line at the prompt. Click on the one just created.

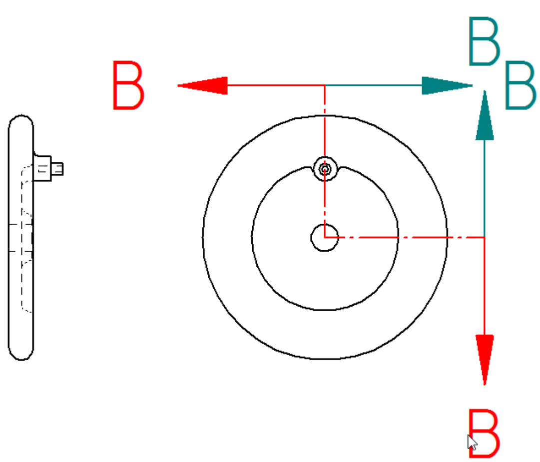


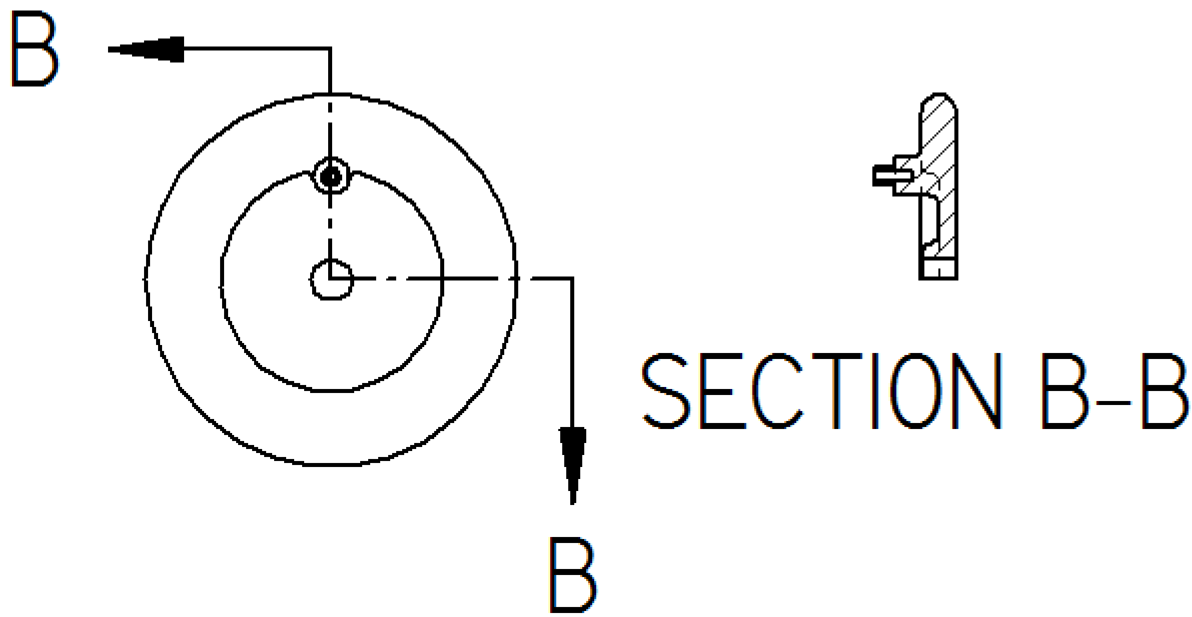
You will see the section view created and labeled Section A-A. Slide to the right and place the section to the right of the wheel.



If you didn't want to section the entire wheel you could create a half section by using a different cutting plane line.

In this case the cutting plane is set to look down and to the left.





Notice how this section is different from the Full section.

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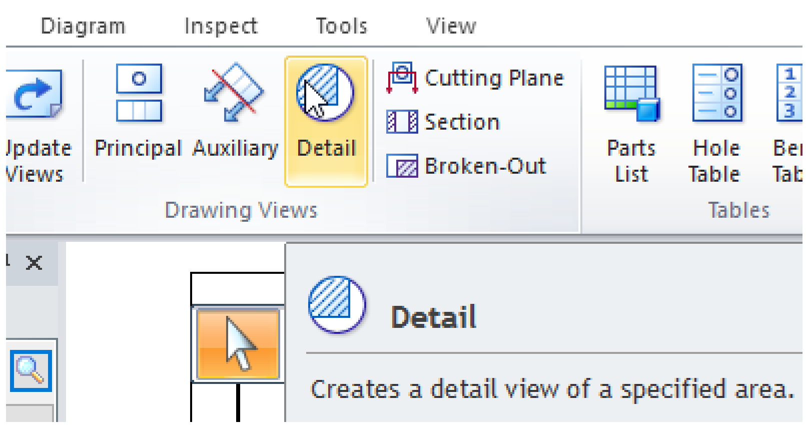
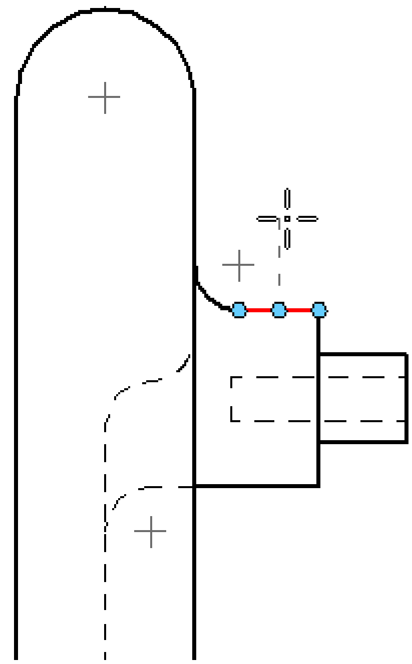
Detail Views

Detail views are utilized to show detail and dimensions on small areas. We change the scale making them larger so dimensions and annotations can be added without crowding the view.

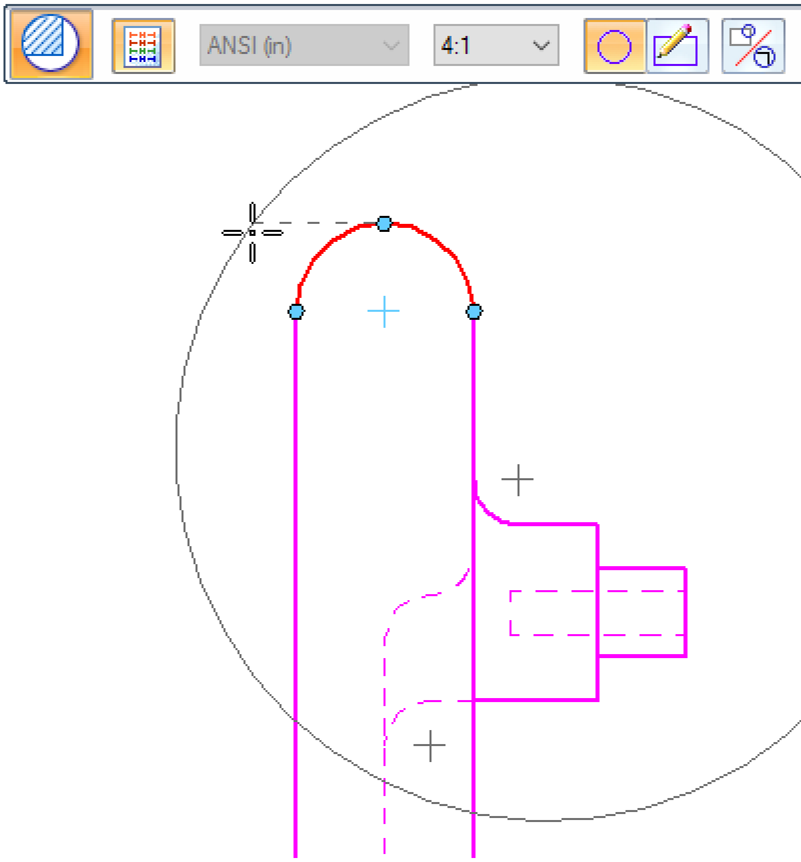
Select the Detail icon from the drawing views section of the ribbon.



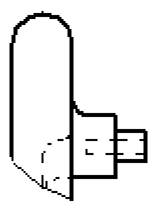
The prompt will ask for the center of the circle that will define the area of detail.



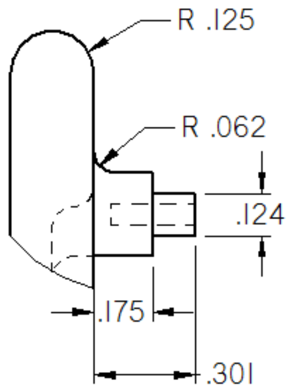
In this example, a point is selected that will allow the drawing of a circle around the top of the wheel and also the raised cylinder for the linkage rod.



From the dialog box, set the amount of magnification wanted on the detail view. 2:1 or 4:1 will provide a detail that can be dimensioned without crowding.



DETAIL C

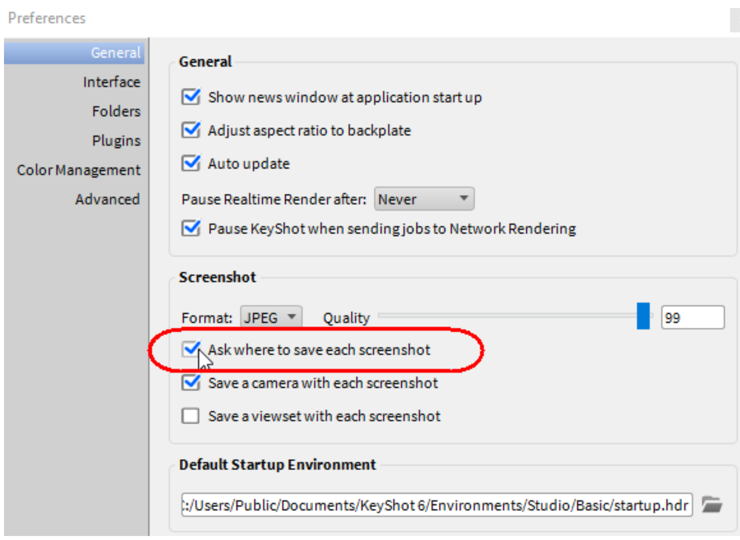


DETAIL C

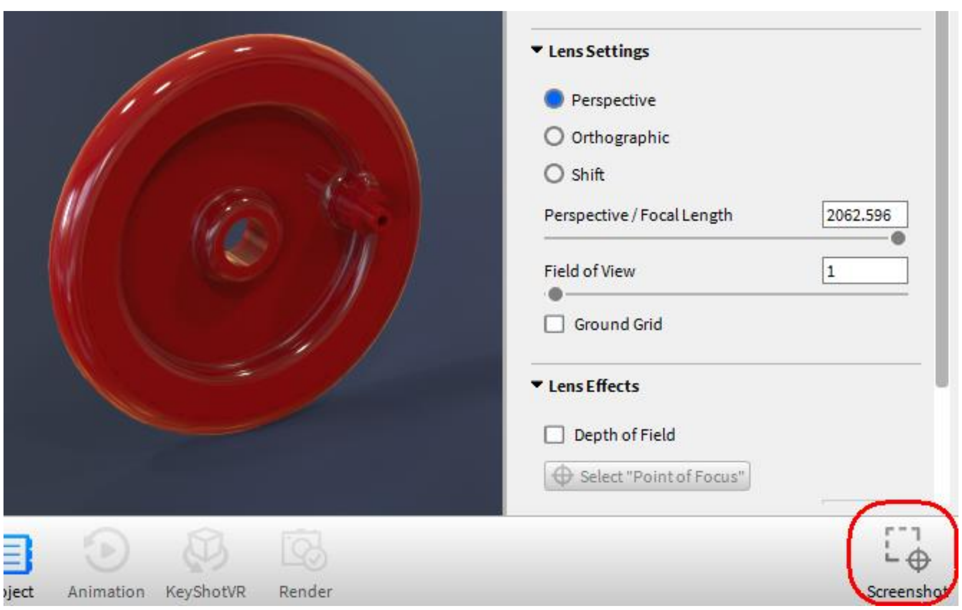
[Back](#)

Try textures, lighting, and materials until you have a feel for how to best present your part. When you are satisfied with the results you can save a screenshot of the image. By default, the software will save the screenshots to a folder C:\Users\Public\Documents\KeyShot 6\Renderings. This might not be the best location to find your images quickly. Change this setting at the Edit Pull Down menu and selecting Preferences from the options.

On the General tab, place a check in the box for “Ask where to save each screenshot”



Select the box for Save changes by selecting the icon at the lower right of the screen.



You will be prompted for a location. Select a folder you can access. Name the file to be retrievable at a future time. It will be saved with a .jpg extension to enable insertion into a PowerPoint presentation or an engineering report.

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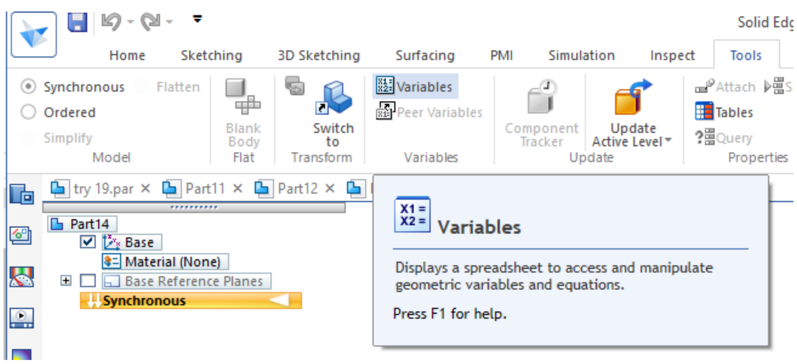
Dimensioning with Equations and Variables

Variable table

All dimensions used in a Solid Edge 3D model appear in the Variables table. As the dimensions are created they are given a designation following the protocol built into the software.

Create a new part.

From the Tools tab on the ribbon select Variables from the variables section. This will display the variable.



The Variable table should have two entries at this point. As materials are assigned these entries change. The part name will display the name assigned to the part. In this example is it part14.

Part14:Variable Table

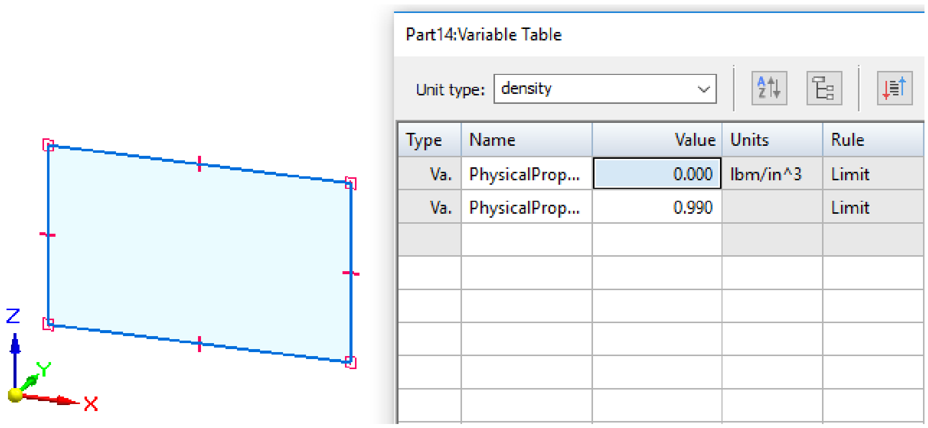
Unit type: density

Help

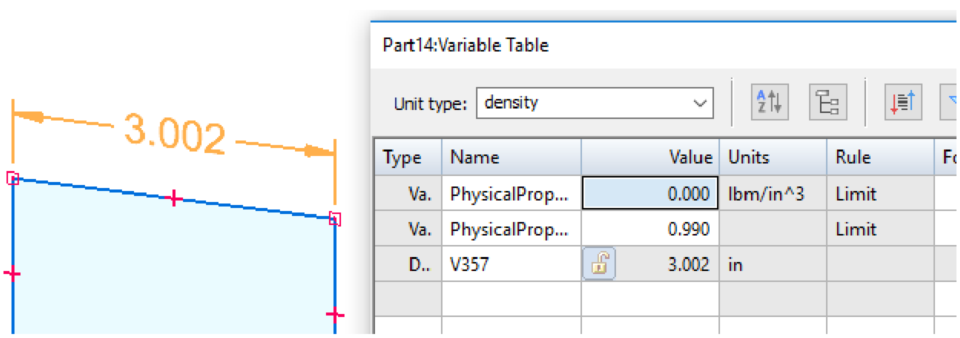
Type	Name	Value	Units	Rule	Formula	Range	Expose	Exposed Na...	Comment
Va.	PhysicalProp...	0.000	lbm/in^3	Limit		[0.000 l...	☑	Density	
Va.	PhysicalProp...	0.990		Limit		(0.000;1...	☑	Accuracy	

Move the table off your drawing area and leave the table open so you can see and edit dimensions as they are created.

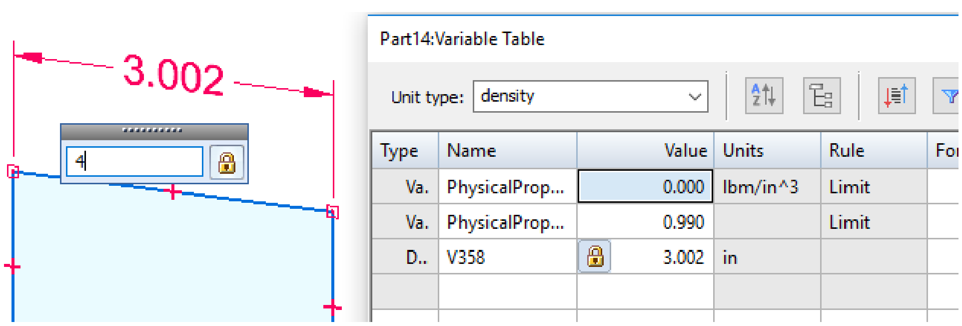
Enter the Sketch environment and create a rectangle.



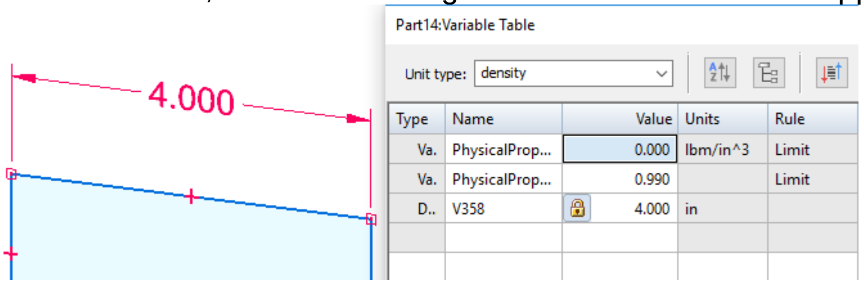
Since no dimensions are assigned they do not show up yet. Add a dimension on the top line of 4”. As soon as you click on the top line you will see the dimension has been assigned a name and it will show the current dimension. In this example the name is V357 and it displays 3.002 in which is the current value.



As you key the number “4”, the dimension will not change until you hit the enter key as the model has yet to change.

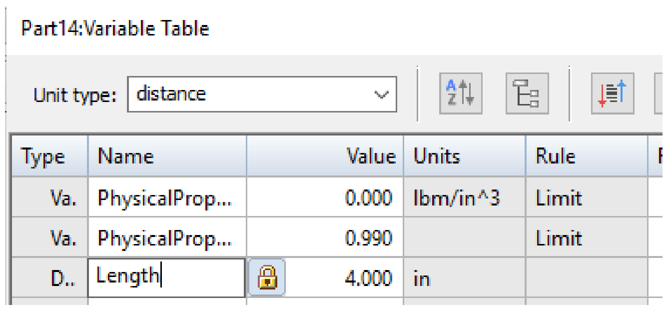


After accepting the dimension, the model changes and the value entered appears.



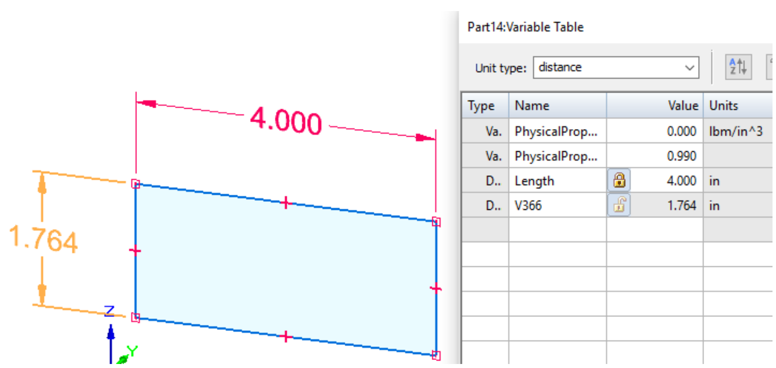
Type	Name		Value	Units	Rule
Va.	PhysicalProp...		0.000	lbm/in^3	Limit
Va.	PhysicalProp...		0.990		Limit
D..	V358		4.000	in	

Since the name V357 or V358 are not indicative of what the dimension is, it is possible to rename the dimension. Click on the dimension in the table and enter in the name "Length" to retrieve at a future time. Selecting the Enter key saves the name.



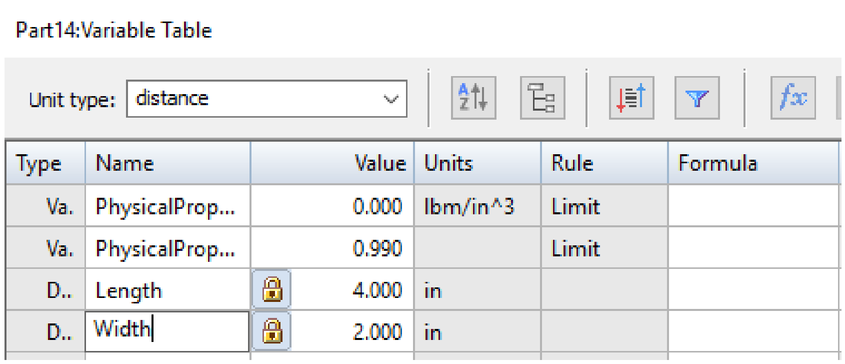
Type	Name		Value	Units	Rule
Va.	PhysicalProp...		0.000	lbm/in^3	Limit
Va.	PhysicalProp...		0.990		Limit
D..	Length		4.000	in	

Now dimension the width of the rectangle to 2 inches.



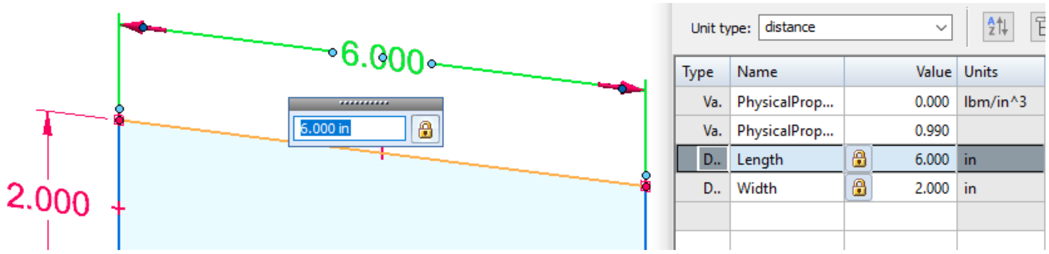
Type	Name		Value	Units
Va.	PhysicalProp...		0.000	lbm/in^3
Va.	PhysicalProp...		0.990	
D..	Length		4.000	in
D..	V366		1.764	in

As soon as the line is selected the table automatically creates the entry. Assign the dimension to 2". Rename the dimension to "Width".



Type	Name		Value	Units	Rule	Formula
Va.	PhysicalProp...		0.000	lbm/in^3	Limit	
Va.	PhysicalProp...		0.990		Limit	
D..	Length		4.000	in		
D..	Width		2.000	in		

Now change the length of the rectangle to 6 inches and see how the table is affected.

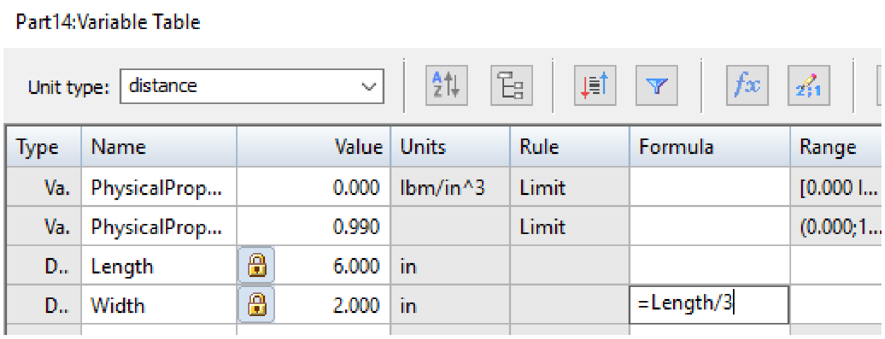


Type	Name		Value	Units
Va.	PhysicalProp...		0.000	lbm/in^3
Va.	PhysicalProp...		0.990	
D..	Length		6.000	in
D..	Width		2.000	in

The table automatically updates to keep up with any changes.

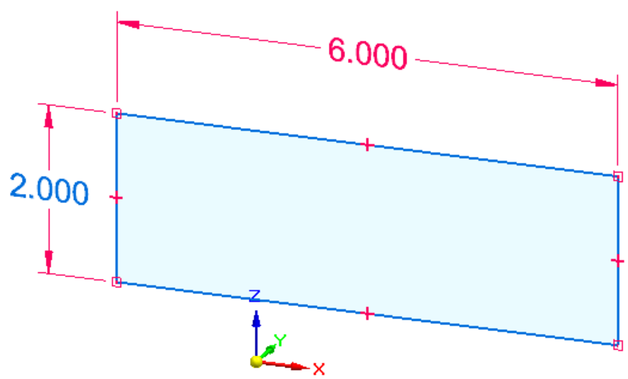
The width did not change when the length was changed. If you want your drawing to always have this proportion we can tie the two dimensions together with a formula.

On the table enter the phrase =Length/3 into the formula section on the width line.

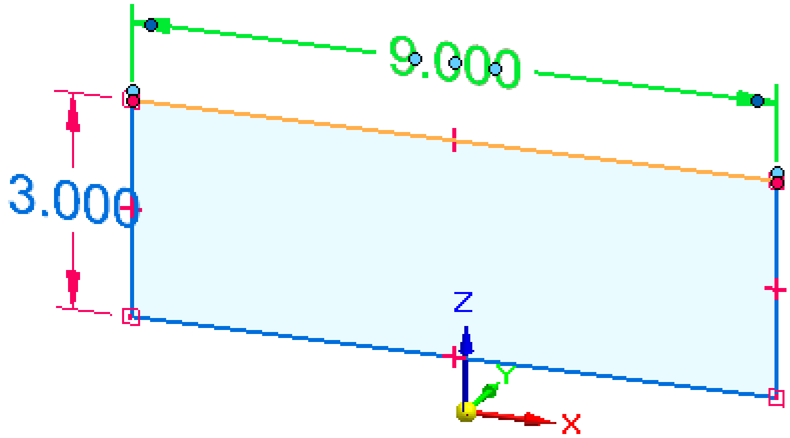


Type	Name		Value	Units	Rule	Formula	Range
Va.	PhysicalProp...		0.000	lbm/in^3	Limit		[0.000 l...
Va.	PhysicalProp...		0.990		Limit		(0.000;1...
D..	Length		6.000	in			
D..	Width		2.000	in		=Length/3	

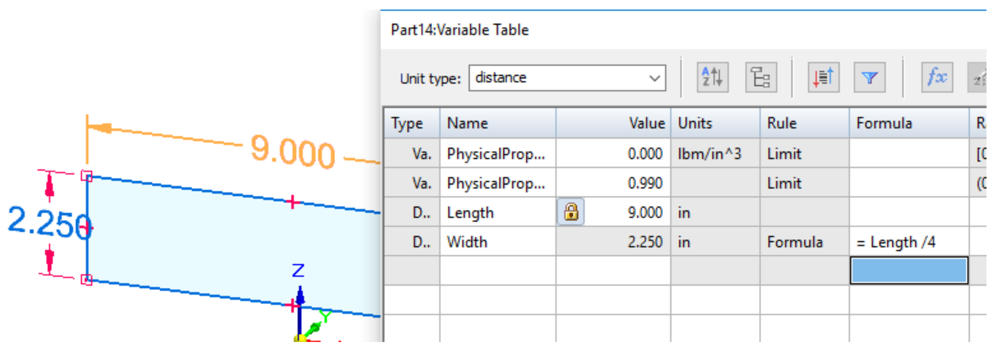
Notice that once you complete the entry the color of the dimension changes. This is an indication that the dimension is determined by formula.



Now the width of the rectangle is always going to be 1/3 of the length. Change the 6" dimension to 9". What should happen to the width?



We might want to change the proportion so the width is only ¼ of the height. On the table change the formula for the width to the phrase =Length/4.

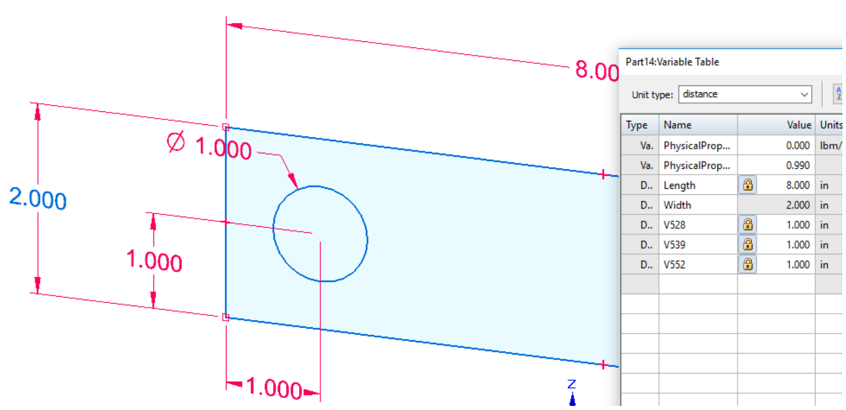


The part automatically updates.

Change the length to 8.

Draw a circle in from one end of the rectangle.

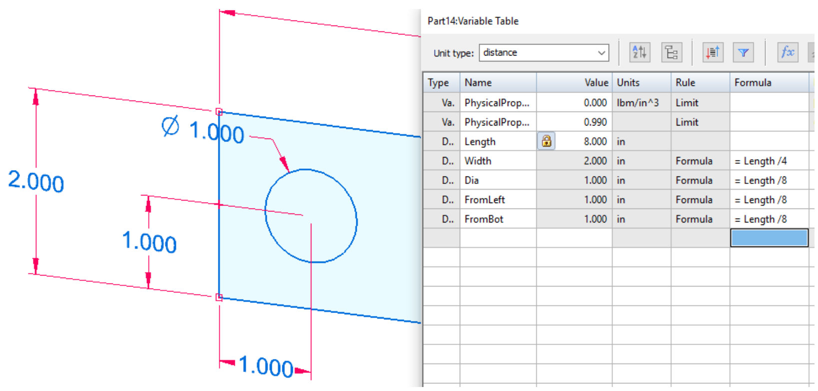
Add a dimension of 1 inch to the diameter of the circle. Then add dimensions of 1 inch to the center in both vertical and horizontal directions.



Rename the dimension so it represents something you can recognize. The circle is renamed Dia.

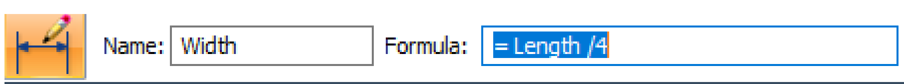
Type	Name		Value	Units
Va.	PhysicalProp...		0.000	lbm/in^3
Va.	PhysicalProp...		0.990	
D..	Length		8.000	in
D..	Width		2.000	in
D..	Dia		1.000	in
D..	FromLeft		1.000	in
D..	FromBot		1.000	in

We can assign a formula to each. Enter the phrase =Length/8.

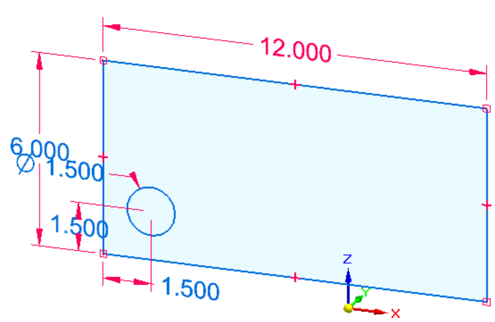


The dimensions turn blue as you enter the formula. Now change the length of the rectangle to 12. What happens to all the other dimensions?

Now double click on the blue dimension for width. This opens a dialog box on the work area. We can change the formula here.



Change the formula to =Length/2. Notice the change in the drawing.



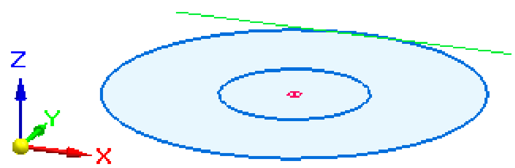
Change your other formulas to place the hole in the center of the rectangle.

Controlling a part with Excel

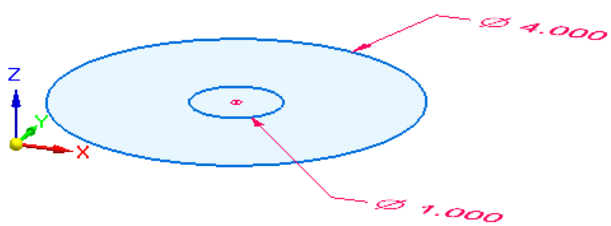
We can similarly build a 3D part with formulas so the part retains an identifiable shape. Many brands are identified by shape alone. If you design everything with only a few dimensions to change you can very quickly change the size without sacrificing the identifiable shape. The same is true of things such as socket wrenches or other products of variable sizes. Frequently the changes in a family of parts are not enough to require their own drawings. Dimensions are given in their own table. With a 3D solid model it is possible to link a table in Excel to the variable table and then use Excel to drive the changes in the part.

This exercise will help you create families of table driven parts.

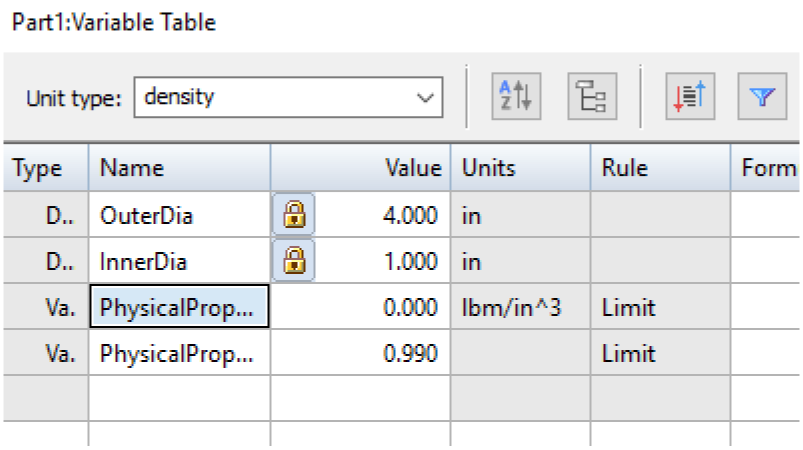
Begin a new part. Lock onto the XY plane. Create a sketch with a circle.



Add dimensions similar to the picture below.



Open the variable table and change the names to match the ones below.

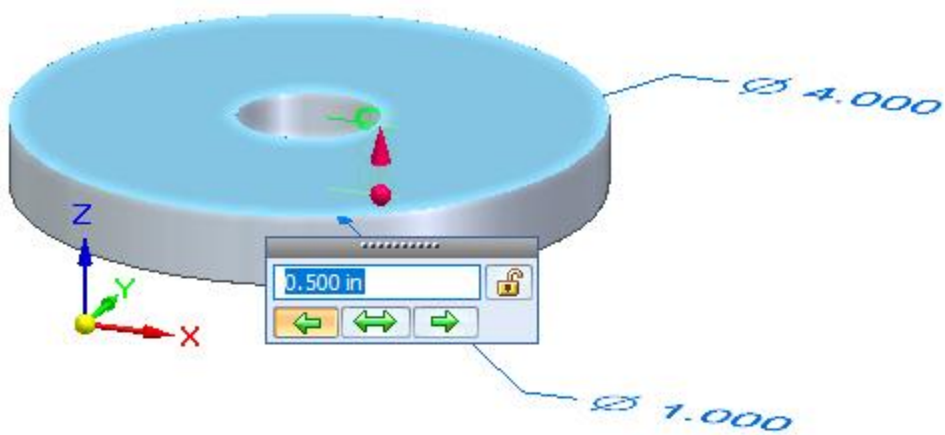


Part1:Variable Table

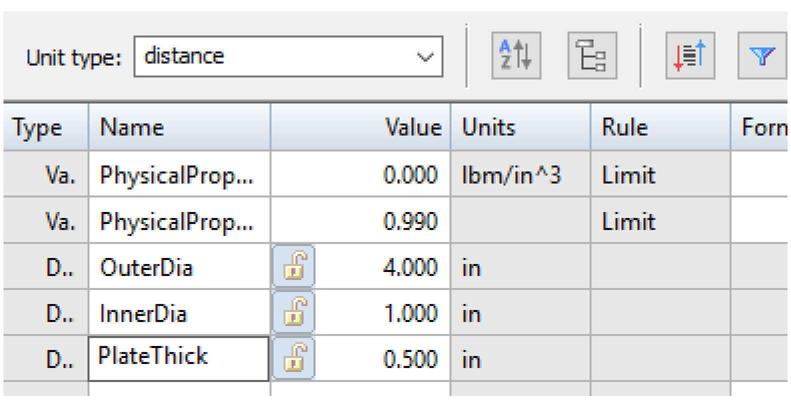
Unit type: density

Type	Name		Value	Units	Rule	Form
D..	OuterDia		4.000	in		
D..	InnerDia		1.000	in		
Va.	PhysicalProp...		0.000	lbm/in^3	Limit	
Va.	PhysicalProp...		0.990		Limit	

Extrude the circle sketch to a distance of .5



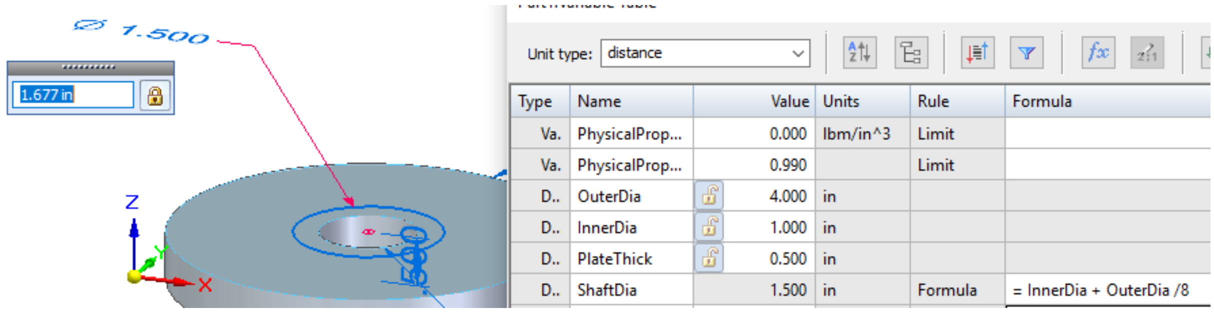
In the variable table change the name to PlateThick.



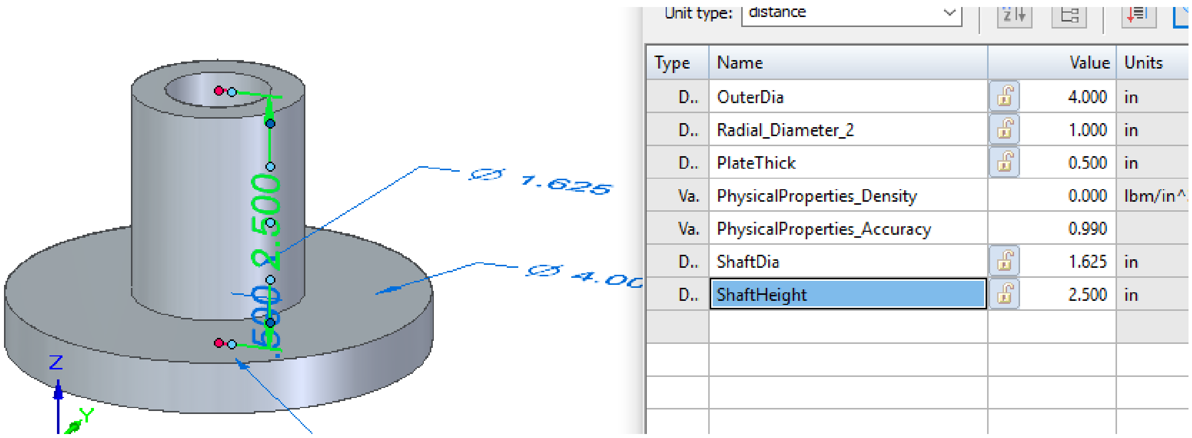
Unit type: distance

Type	Name		Value	Units	Rule	Form
Va.	PhysicalProp...		0.000	lbm/in^3	Limit	
Va.	PhysicalProp...		0.990		Limit	
D..	OuterDia		4.000	in		
D..	InnerDia		1.000	in		
D..	PlateThick		0.500	in		

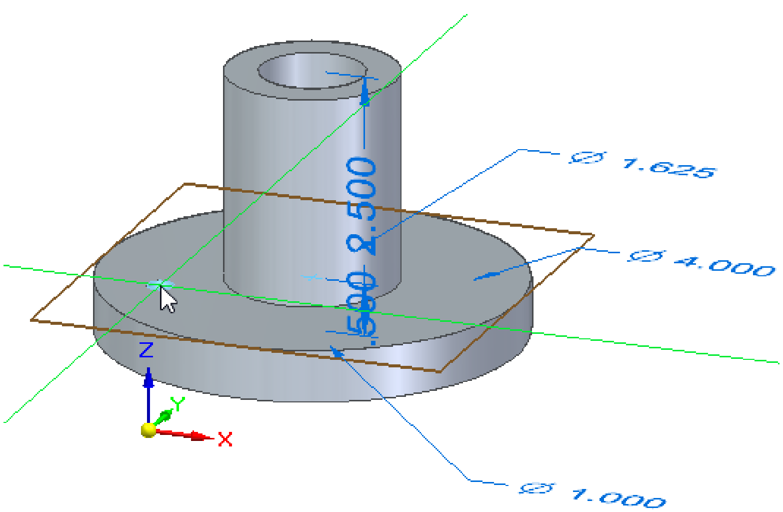
Place a circle on the top. For the dimension use 1.5”



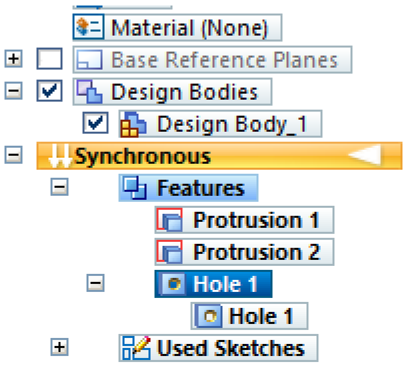
Extrude the shaft upwards a distance of 2.5”



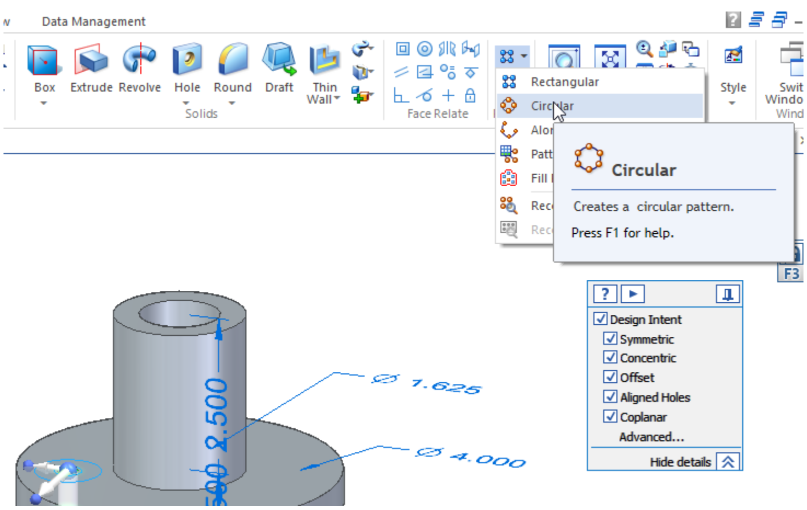
Place a hole on the plate. Don’t worry about dimensions.



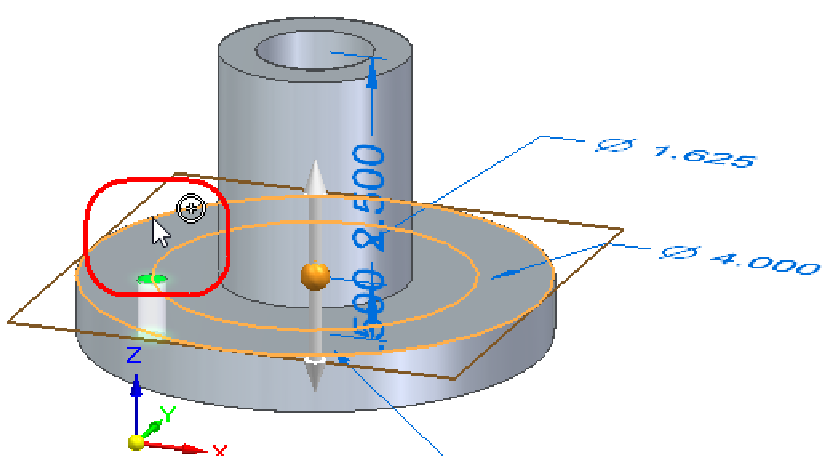
Highlight the hole in the Synchronous section of the tree.



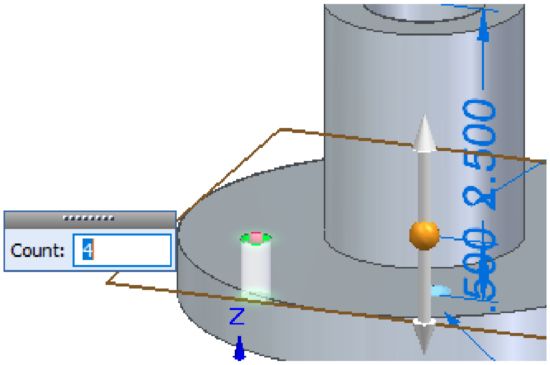
Use the Circular Pattern command found in the Pattern section of the Home ribbon.



Slide your mouse over the curved edge until you see the center mark and then select to capture the center of the part.



Use a count of 4.



Your table should resemble this one.

Unit type: distance

Type	Name	Value	Units	Rule
D..	OuterDia	4.000	in	
D..	Radial_Diameter_2	1.000	in	
D..	PlateThick	0.500	in	
D..	ShaftDia	1.625	in	
D..	ShaftHeight	2.500	in	
D..	Pattern_1_Diameter	2.734	in	
Va.	PhysicalProperties_Density	0.000	lbm/in^3	Limit
Va.	PhysicalProperties_Accuracy	0.990		Limit
Va.	Hole_1_Diameter	0.250	in	Limit
Va.	Pattern_1_XCount	4.000		

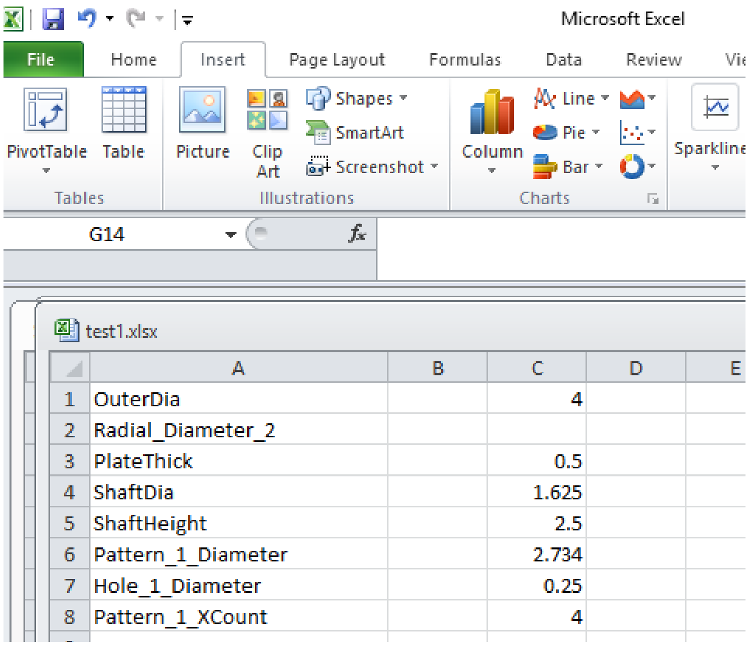
Lock the dimensions by clicking on the open padlocks to allow for the insertion of formulas. Leave the inner diameter unlocked.

Type	Name	Value	Ur
D..	OuterDia	4.000	in
D..	Radial_Diameter_2	1.000	in
D..	PlateThick	0.500	in
D..	ShaftDia	1.625	in
D..	ShaftHeight	2.500	in
D..	Pattern_1_Diameter	2.734	in

Save your part.

Excel

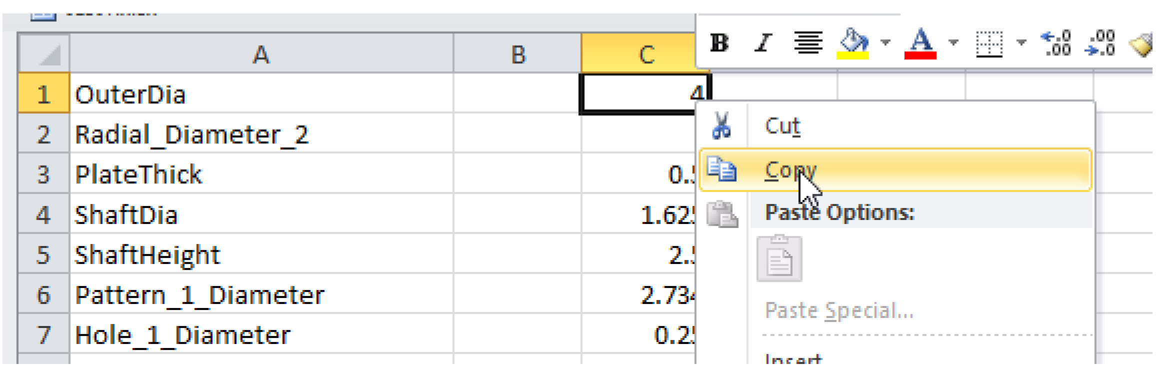
We can control the part using an Excel table. To do this we need to create the table. Open Excel and enter in the following data. These will represent three different versions of our part.



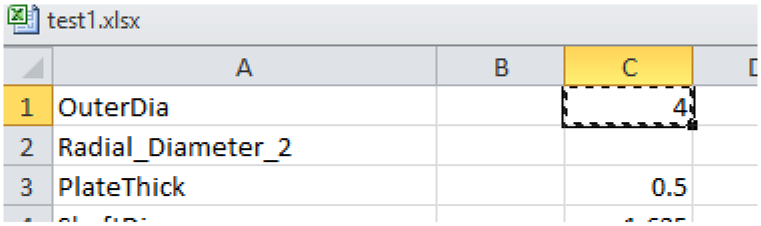
This Excel file contains the information for the part.

Save the file to a location you can easily find. Delete unused sheets.

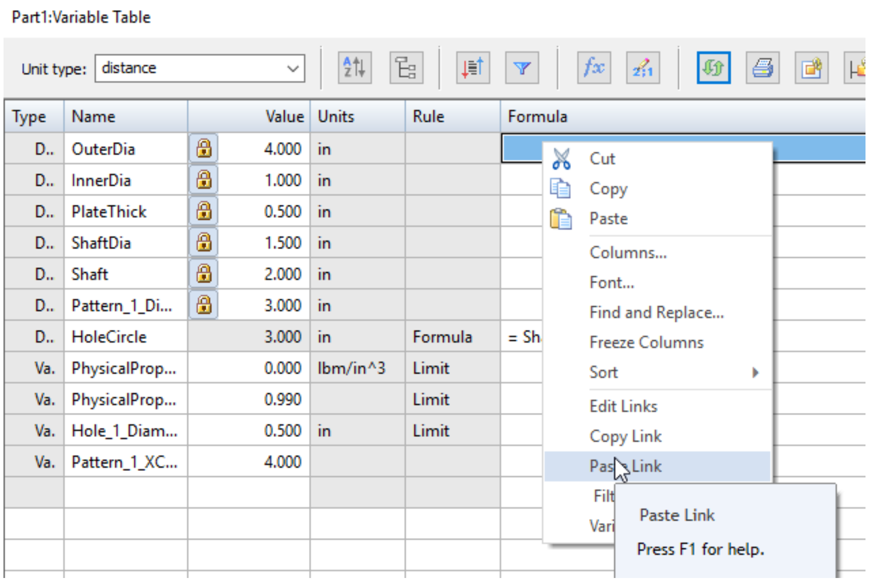
The next step is to assign the cell to the appropriate place in the Variable Table in Solid Edge. Click in Cell C1 on the Excel table, then right click and select copy.



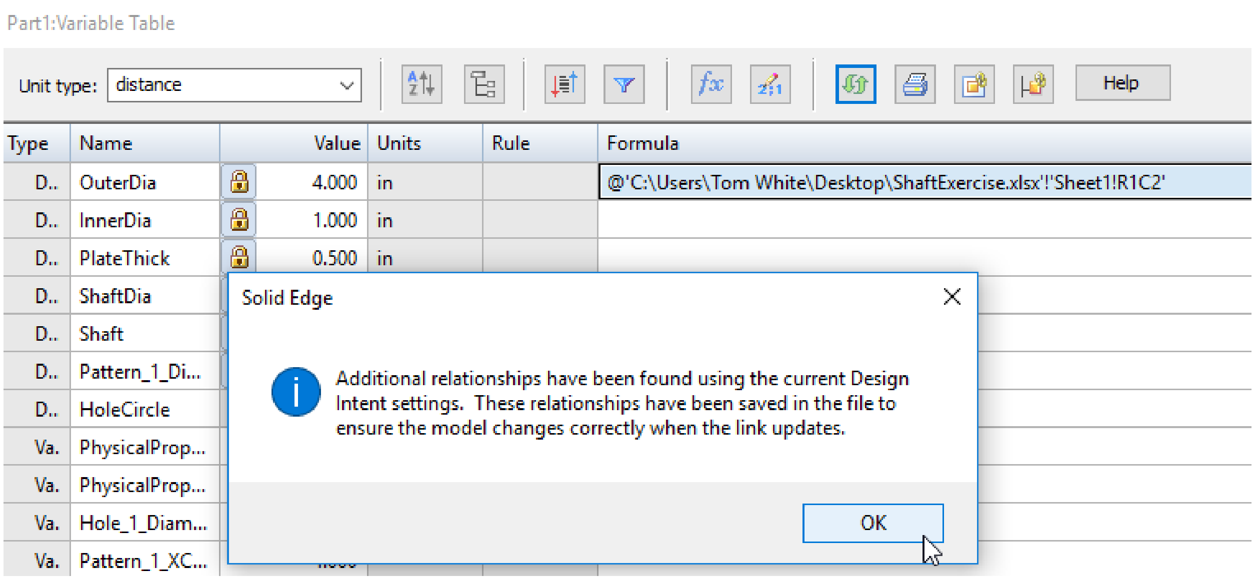
The cell will highlight.



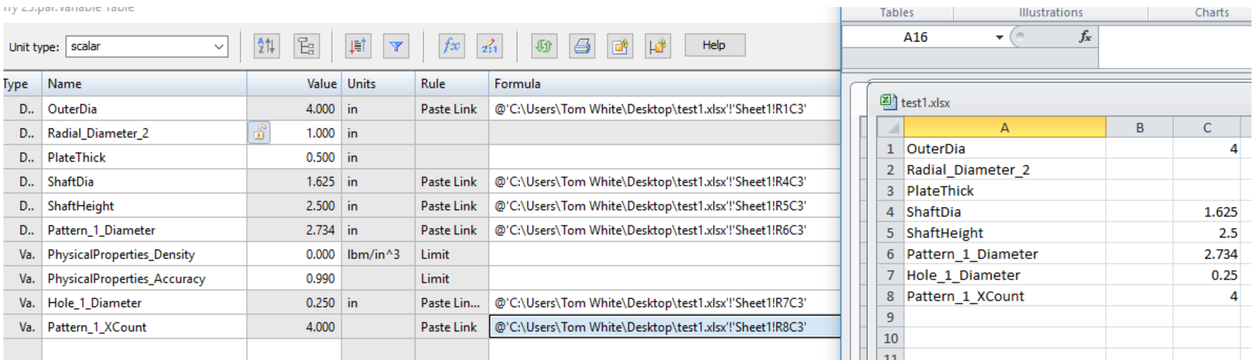
Move to the Variable Table in Solid Edge and find the OuterDia row. Right click in the formula cell and select paste link to create the link into the formula cell.



You will see the formula appear as well as a message from the software. Select OK.



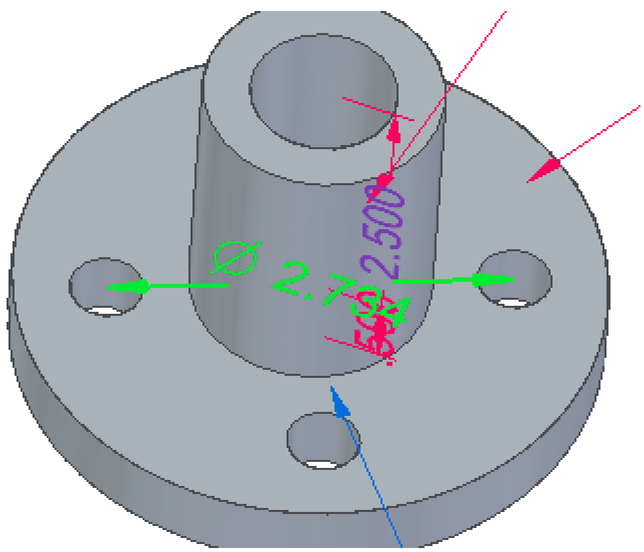
Continue linking the cells in column C in Excel with the appropriate places in the Variable Table.



On your Excel spread sheet change the Hole_1_Diameter to .375. Select Enter

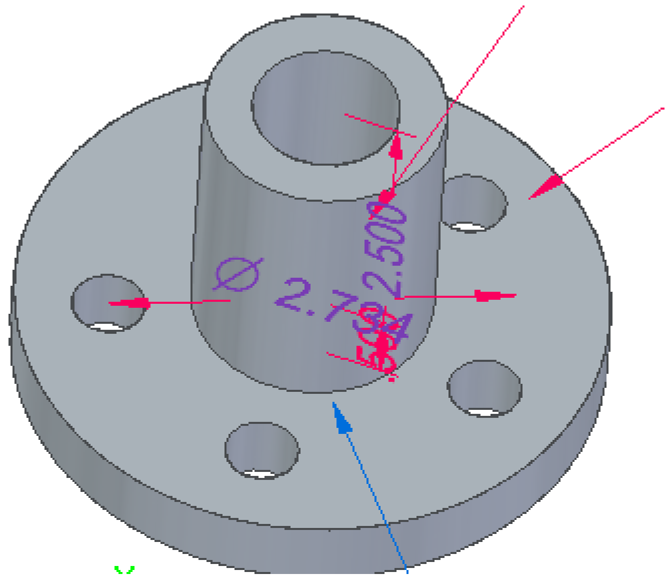
What happens?

Change the dimension to .5 on your spread sheet.

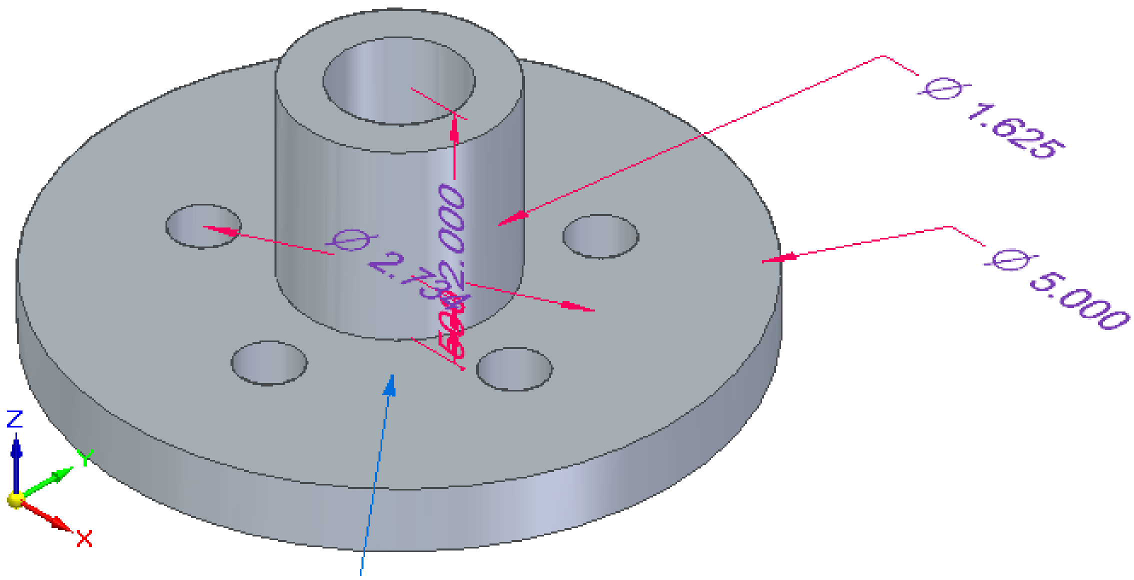


Change the Pattern_1_XCount value to 5 and select enter.

There are times when you must double click on the part to have it refresh.

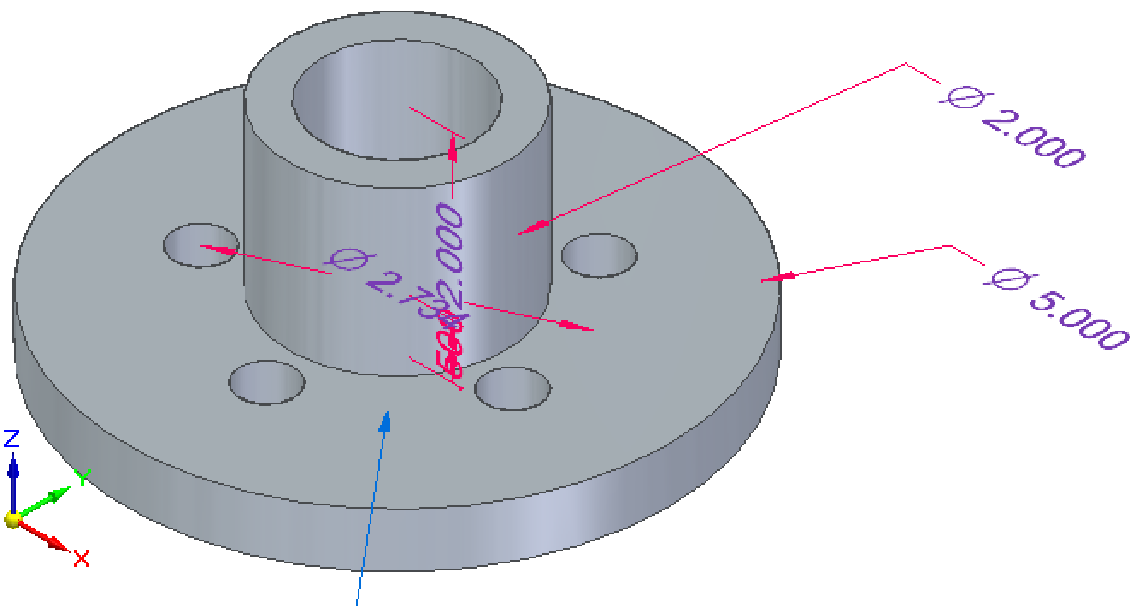


Change the ShaftHeight to 2. Hit enter. Then change the ShaftHeight to 2 and Hit enter.

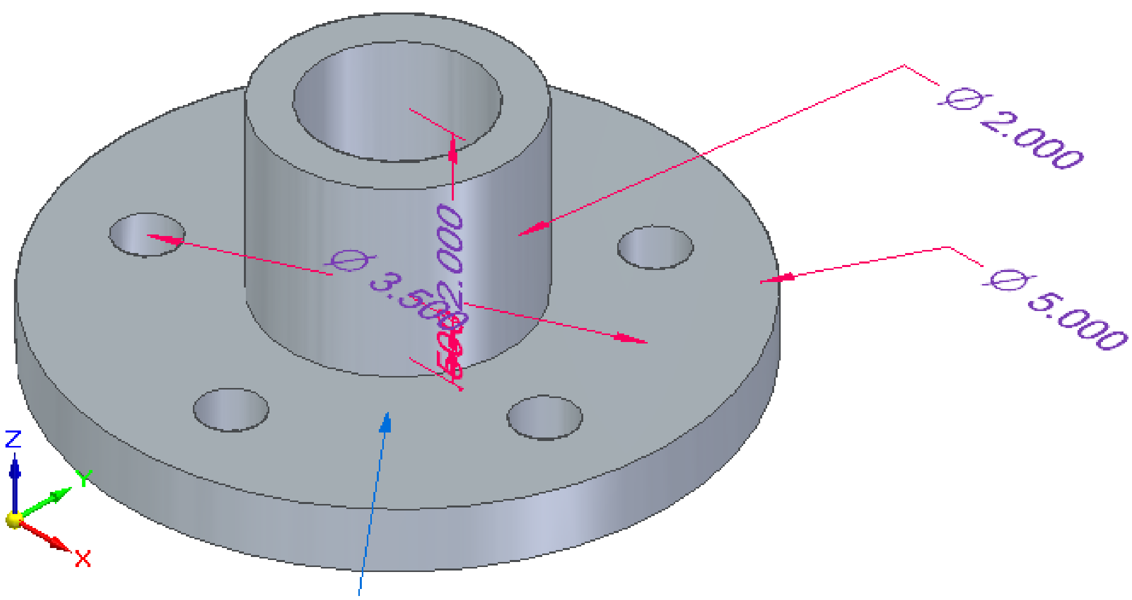


Change the ShaftDia to 2. Hit Enter.

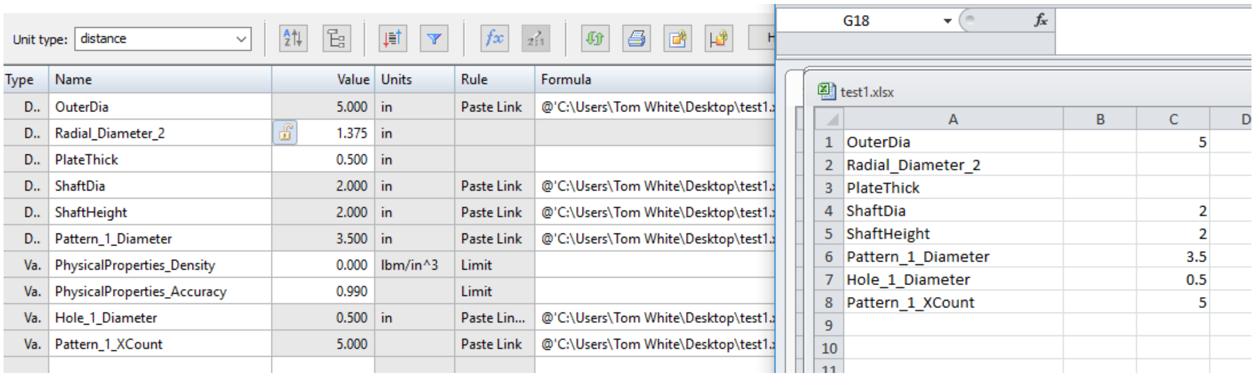
Was there another dimension that automatically changed?



Change the Pattern_1_Diameter to 3.5 and hit enter.



Dimensions must be changed in an order that makes sense. By linking to the Excel table you can make changes to the design faster and can create multiple objects from the same build.


Unit type: distance

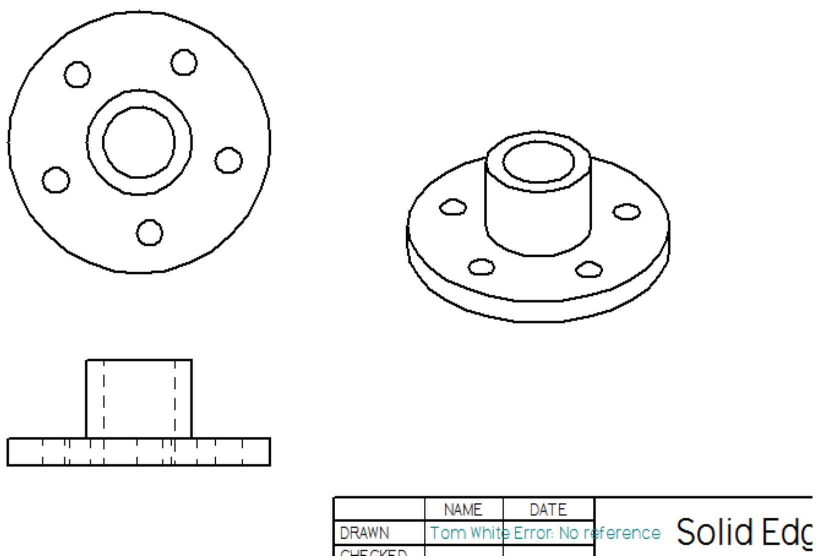
Type	Name	Value	Units	Rule	Formula
D..	OuterDia	5.000	in	Paste Link	@'C:\Users\Tom White\Desktop\test1.
D..	Radial_Diameter_2	1.375	in		
D..	PlateThick	0.500	in		
D..	ShaftDia	2.000	in	Paste Link	@'C:\Users\Tom White\Desktop\test1.
D..	ShaftHeight	2.000	in	Paste Link	@'C:\Users\Tom White\Desktop\test1.
D..	Pattern_1_Diameter	3.500	in	Paste Link	@'C:\Users\Tom White\Desktop\test1.
Va.	PhysicalProperties_Density	0.000	lbm/in^3	Limit	
Va.	PhysicalProperties_Accuracy	0.990		Limit	
Va.	Hole_1_Diameter	0.500	in	Paste Lin...	@'C:\Users\Tom White\Desktop\test1.
Va.	Pattern_1_XCount	5.000		Paste Link	@'C:\Users\Tom White\Desktop\test1.

G18

test1.xlsx

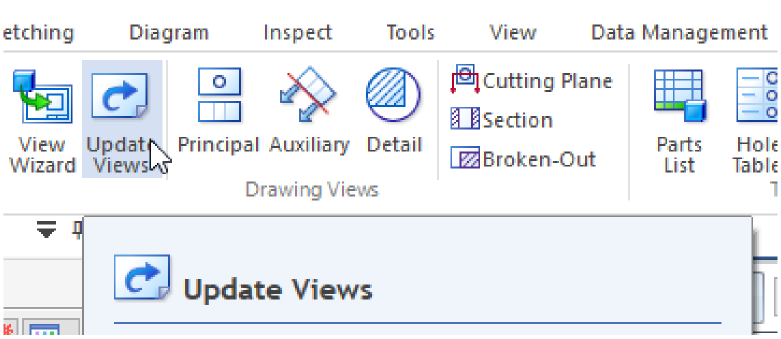
	A	B	C
1	OuterDia		5
2	Radial_Diameter_2		
3	PlateThick		
4	ShaftDia		2
5	ShaftHeight		2
6	Pattern_1_Diameter		3.5
7	Hole_1_Diameter		0.5
8	Pattern_1_XCount		5
9			
10			

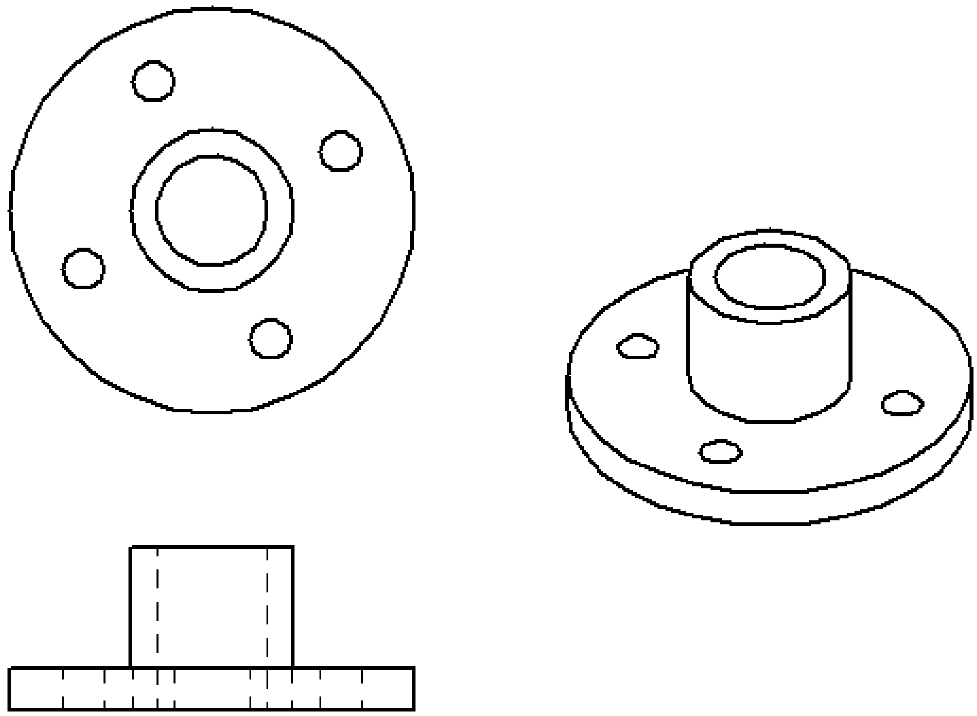
Create a draft from the part you just created. Place a front, top and isometric views of the part. It will resemble the part below.



Return to your Excel spread sheet and change the Pattern_1_XCount to 4 and hit enter.

On your Draft View select the link to update views.





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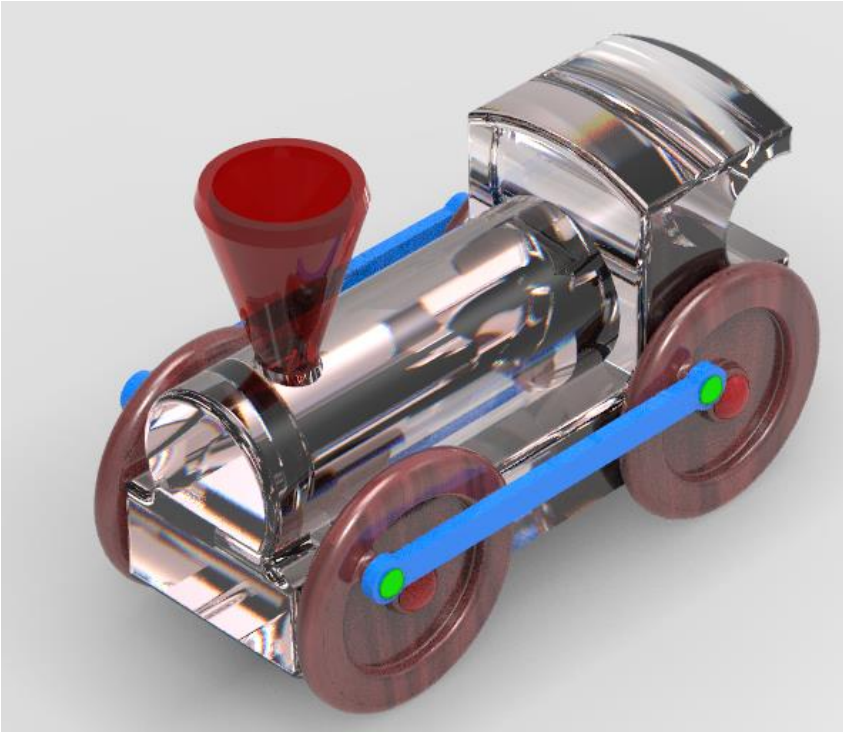
Introduction to Assemblies



Download the components for this exercise from
https://drive.google.com/open?id=0B_7sFhPxnoaXd3N3bGc5OUZzOEU

Extract the part files and place them in a folder where is can be retrieved.

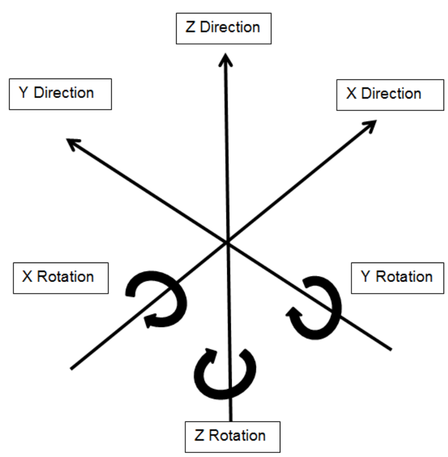
The assembly leads to an understanding of the various types of geometric relationships. The parts will be used to create drawing views, presentation views, exploded assembly drawings, and can be exported to 3D printers.

Customization of the Engine and/or its parts is greatly encouraged as well as the construction of other cars and equipment that might be included with the engine set. One challenge is to create a simple coupling system in order to connect other cars to the engine. Constraining the cars together so normal motion is maintained can be interesting. Different types of track pieces combined with formulas create motion.

Introduction:

To this point we have been using Solid Edge as a 3D solid modeling tool. It has been used to create accurate digital models for analysis and planning purposes. Another function that allows for accurate design and analysis is the assembly modeling process. An assembly is a collection of parts and subassemblies positioned in a meaningful way. This is done by establishing the geometric relationships between the parts. The parts can be in their final orientation, or have freedom of movement in translation and rotation. By defining how the parts go together and establishing the relationships between the parts you can see how the assembly of components will actually behave. You define all aspects or rules of the assembly. Without the relationships between the parts all you would have is a box of parts.

Solid Edge has assembly geometric relationships that describe the relationships between two parts. With no relationships, they move in the X, Y, or Z axis freely as well as being able to rotate about any or all of those axis. The graphic below shows a representation of the six degrees of freedom of parts.



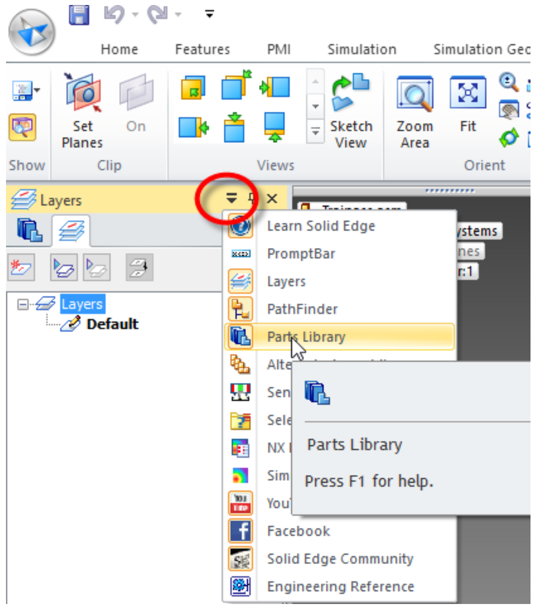
When relationships are applied, the degrees of freedom between the parts are reduced. To permit a part to move, do not apply a relationship that blocks movement. To acquire motion in the x-axis you cannot apply a relationship that defines an exact X position in relation to another part. This leaves a degree of freedom that allows for movement of that part. As constraints are applied they appear in the assembly path finder. To remove a geometric relationship, right click on the relationship and delete it.

Instructions:

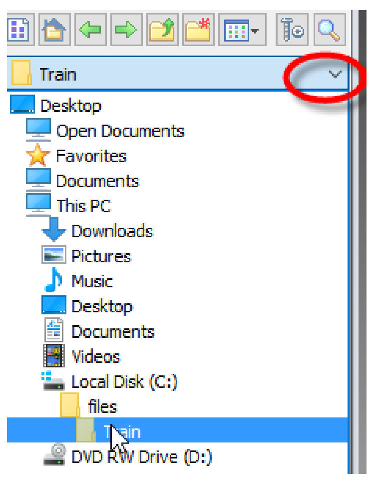
Be sure to have the parts for the engine downloaded before attempting this tutorial.

Create a new Assembly file.

Arrange your window to have access to the Parts Library. The Parts Library is normally on the left side of the screen. If not, select the down arrow next to the pin and select Parts Library from the options.



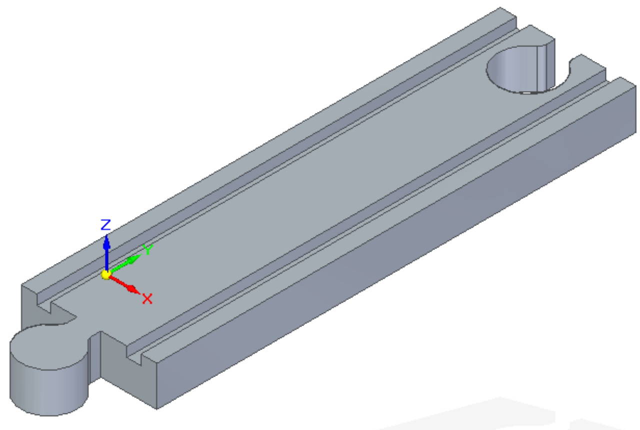
Navigate to the folder where the downloaded files are stored. Select the down arrow next to the existing file and browse to the desired directory.



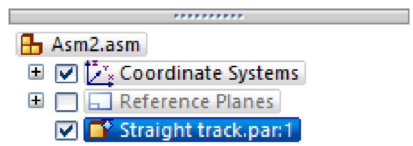
The various parts created are shown in the library.

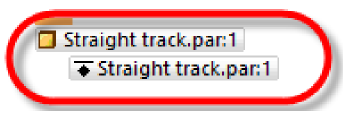
Left click and hold on your straight track and drag it to the screen. Once you are on the work area release the left mouse button. The track will appear.

Once you let go the actual object will be on the screen.

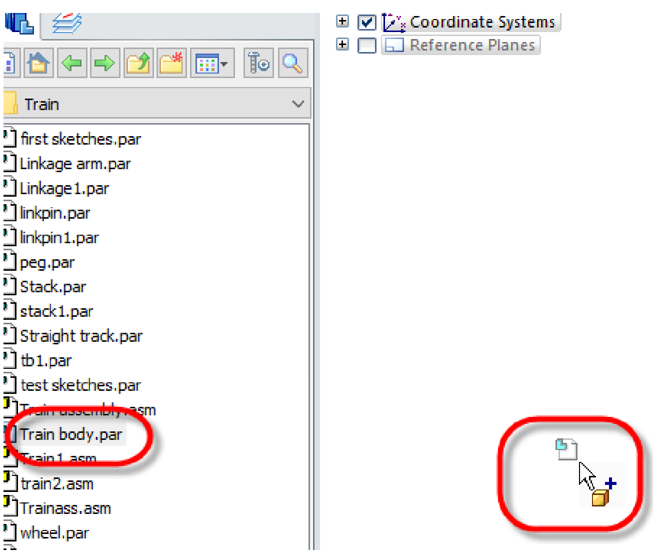


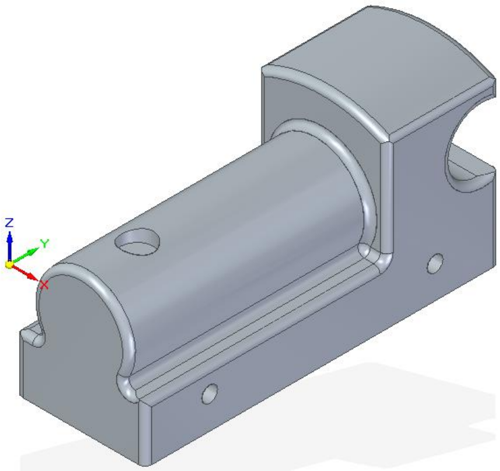
Highlight the track in the path finder. Below you will see the report of the geometric relationships that exist. You will see an icon meaning the part is grounded. This means the part will not move from its position.





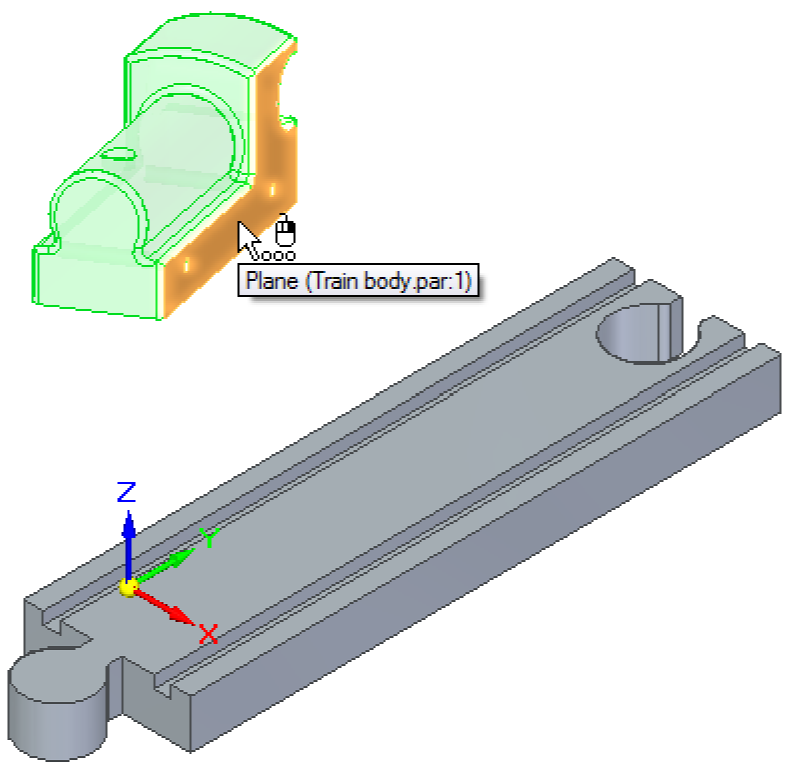
Drag the engine body out from the library.





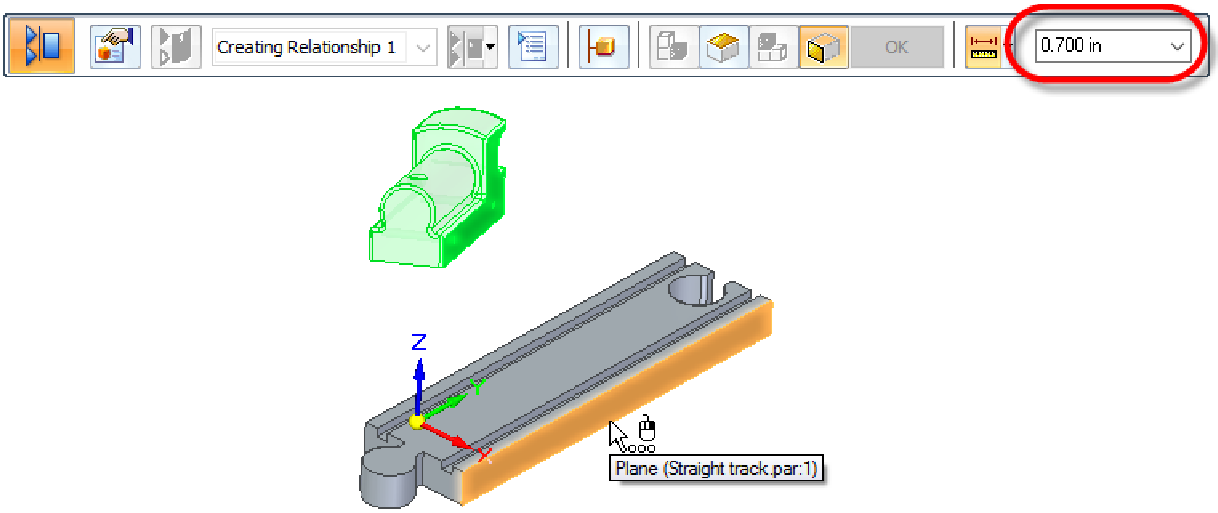
This also opens the relationship dialog box. This dialog box allows us to select how the components go together. The program is intelligent, and can make assumptions on how things go together. By selecting certain geometry the program will figure out the appropriate relationship to apply. This function is flash fit and is the default for the relationship dialog box.

Select the side of the engine body. It will highlight.

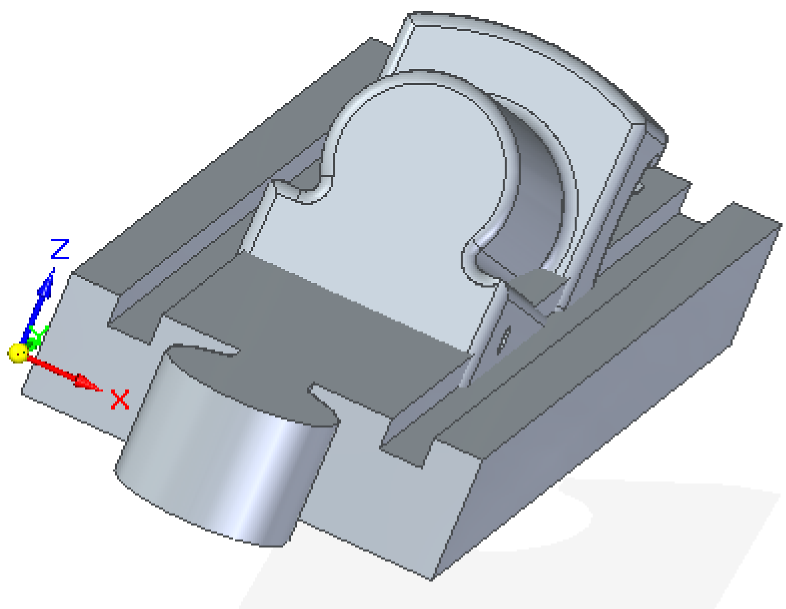


In the dialog box enter .7 in for the offset.

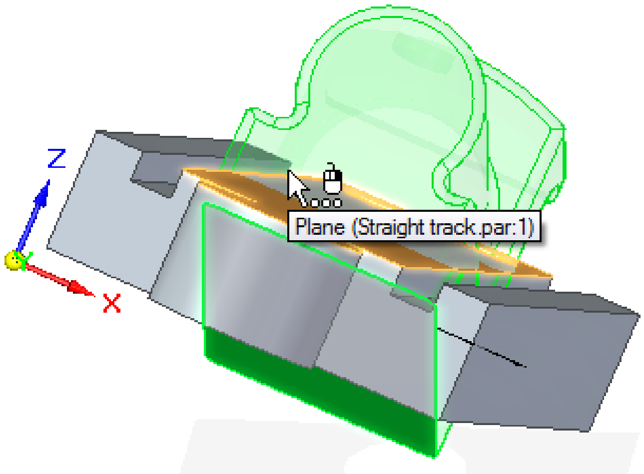
Select the side of the track



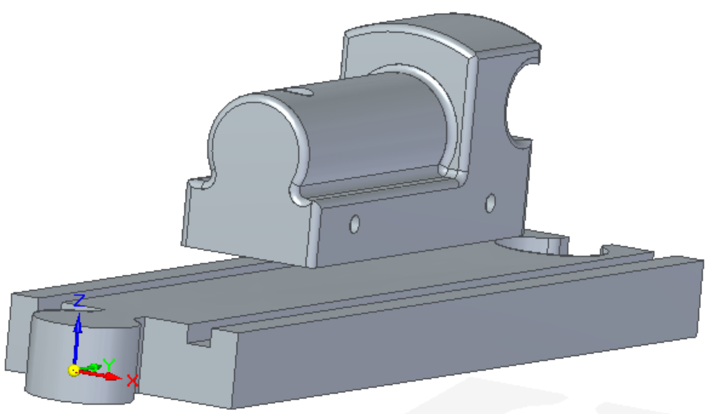
As the relationship takes hold you will see that the engine body is in the center of the track. It is not set above the track and in the case below it satisfies the relationship by sitting in the middle of the track.



Rotate the view somewhat to see the bottom of the train body. Apply a mate constraint with a .500 in offset to the top of the track. Click on the bottom of the engine body and then the top of the track.

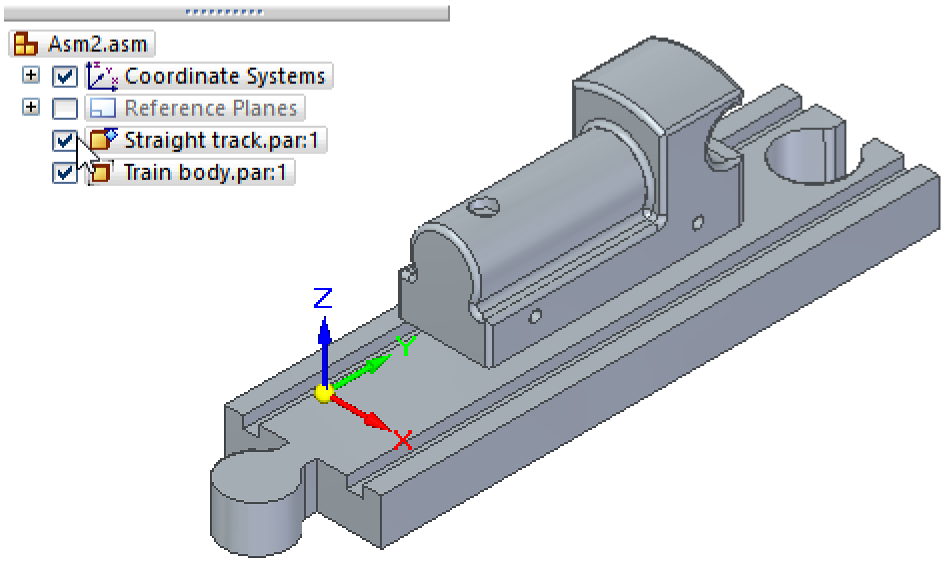


Once accepted you will see the engine body floating above the track. The offset used in placing the engine body allows for the wheels to be added later.

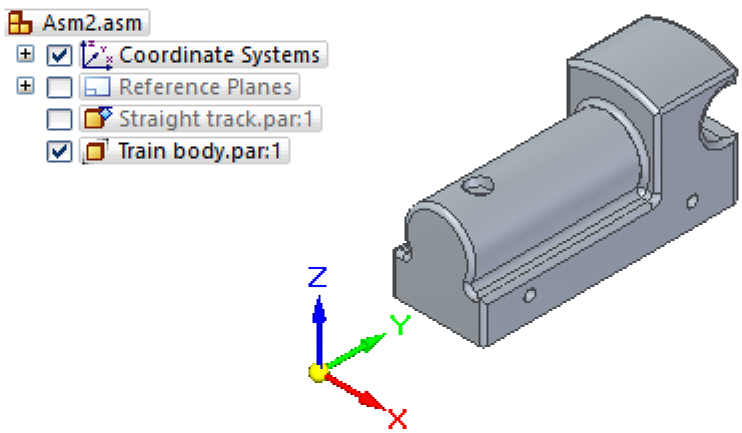


Since the track is in place and working on the rest of the engine components do not require the track, the visibility can be turned off for the time being. This will allow better access to the components you will be working on. We can turn the visibility on later.

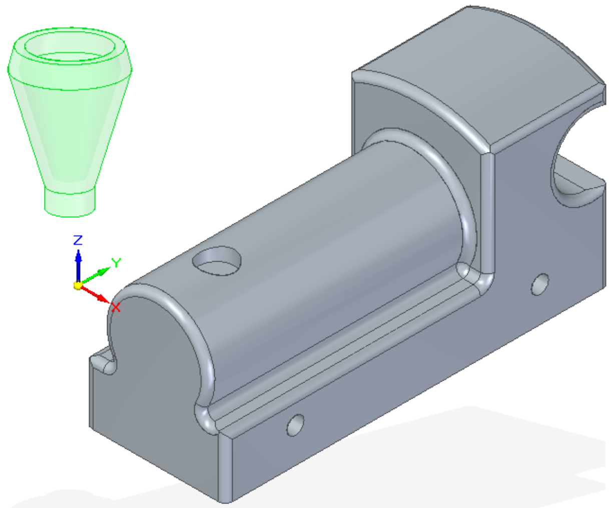
Find the track in the path finder.



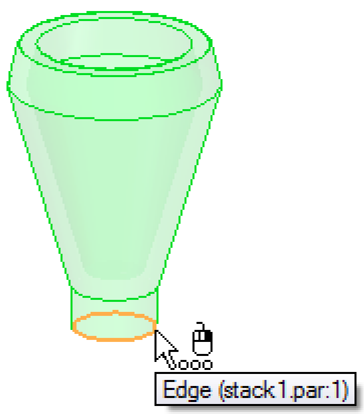
Uncheck the straight track and it will disappear while you work.



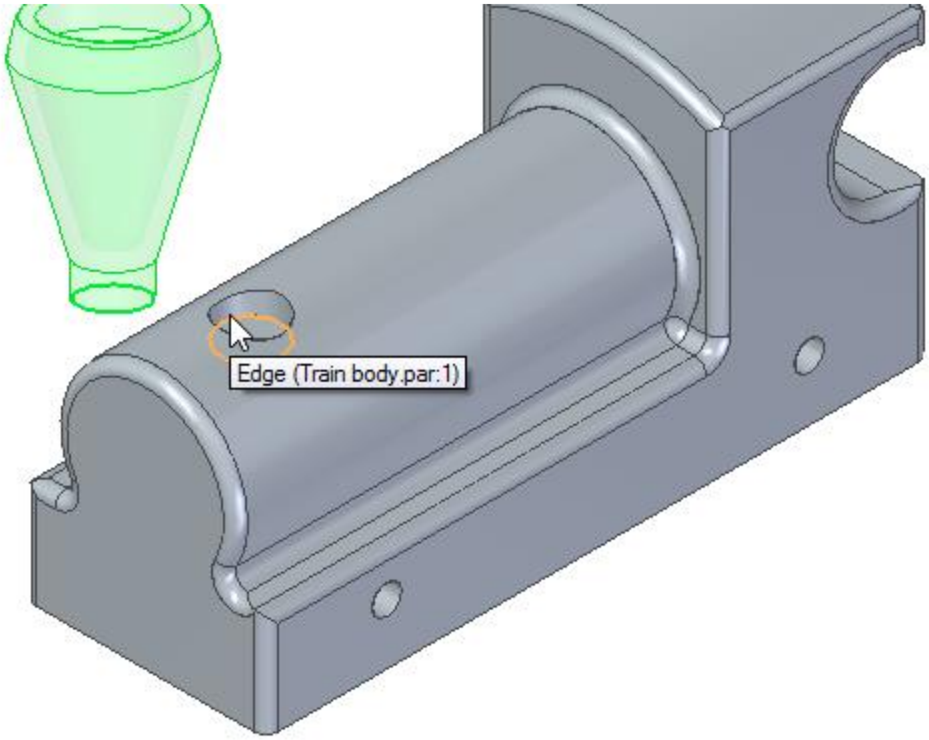
Now drag the stack out of the library and leave it a short distance from the engine body.



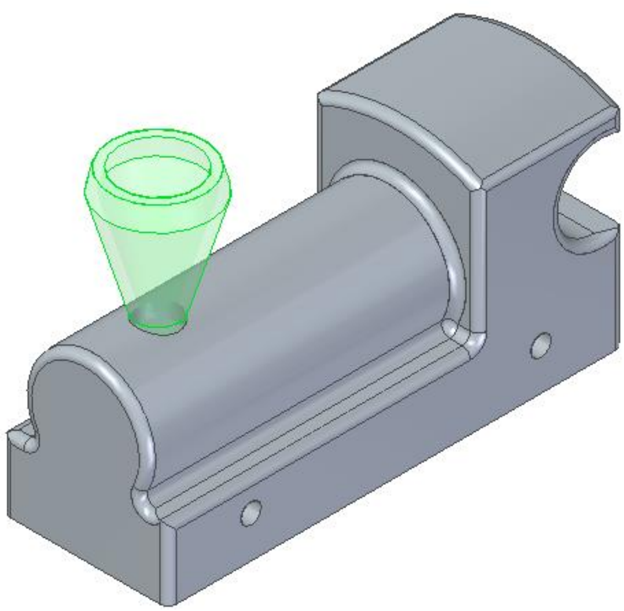
Select the bottom circle of the stack.



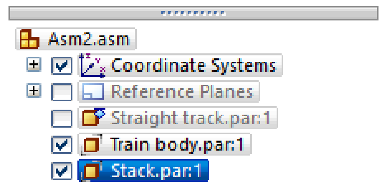
Select the bottom circle of the hole in the top of the engine.

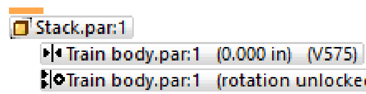


The software then figures out the relationship necessary. It decides the circles should share a center and they should touch.



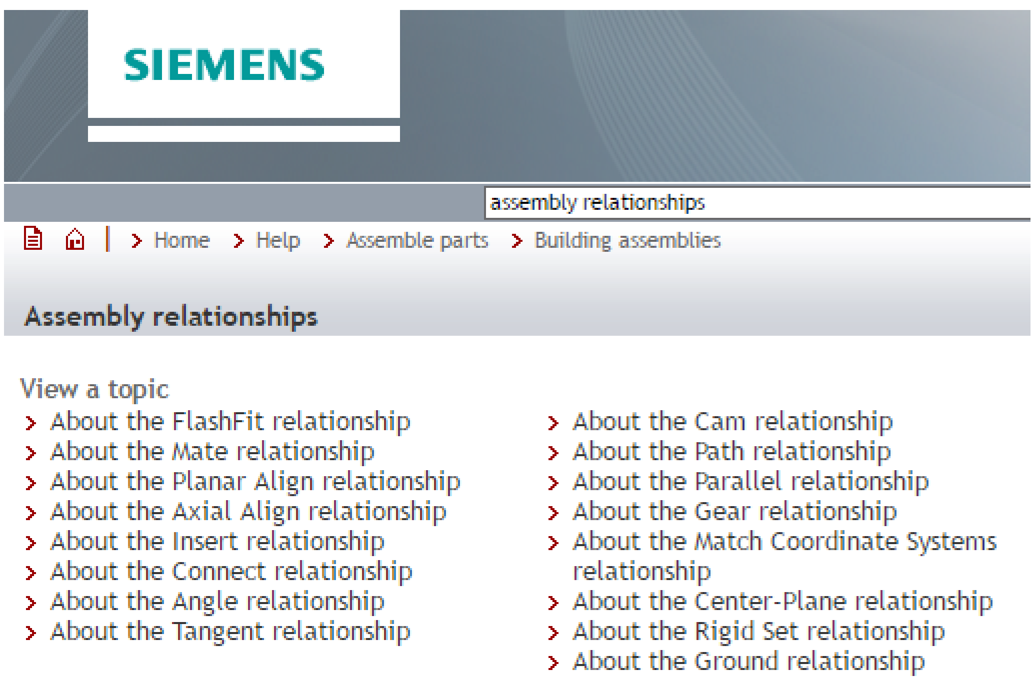
Hit the ESC key to exit the command. In the path finder highlight the stack and the geometric relationships will be applied.





Check the path finder often. When two parts will not connect because of conflicting relationships you can find the part in the path finder and highlight the offending relationship and delete it.

For more information about how components can be assembled, search help for "Assembly Relationships".



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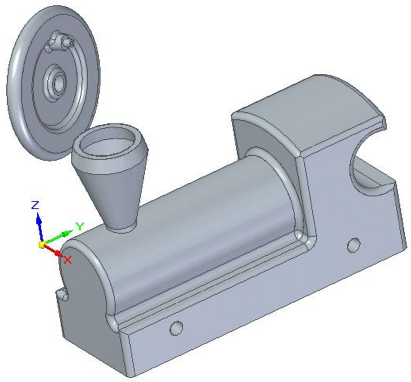
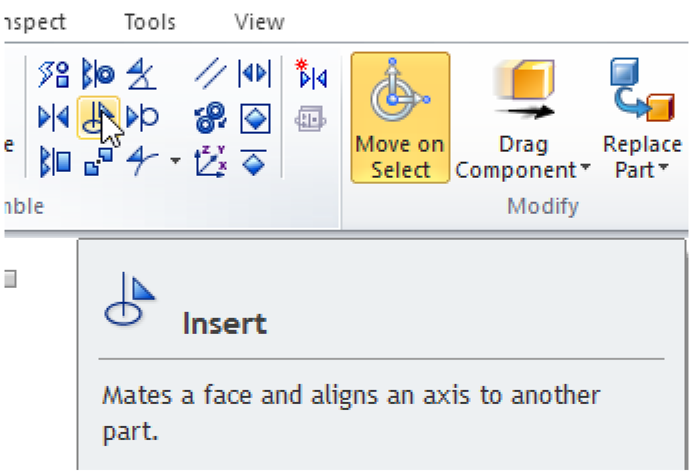
Insert Relationship
Drag a wheel from the library to the work area.

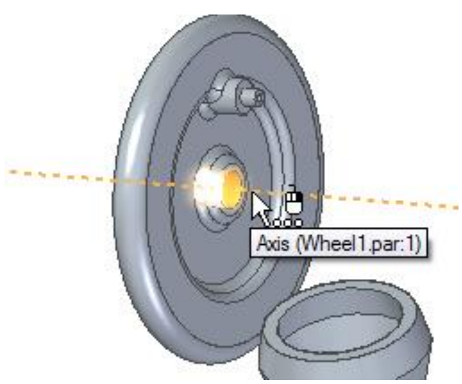


We can define exactly how components fit together by specifying the relationship between the parts. An Insert relationship will line up the axis and mate a face at the same time. Select F1 for more information about the command.

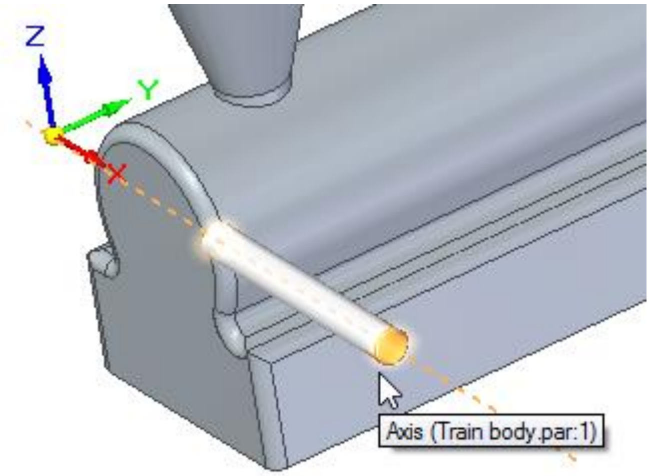
Select Insert from the assemble area of the ribbon.



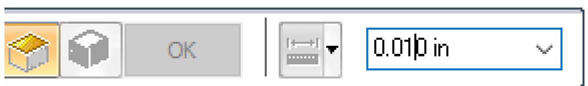
Hover over the wheel until the axis highlights.



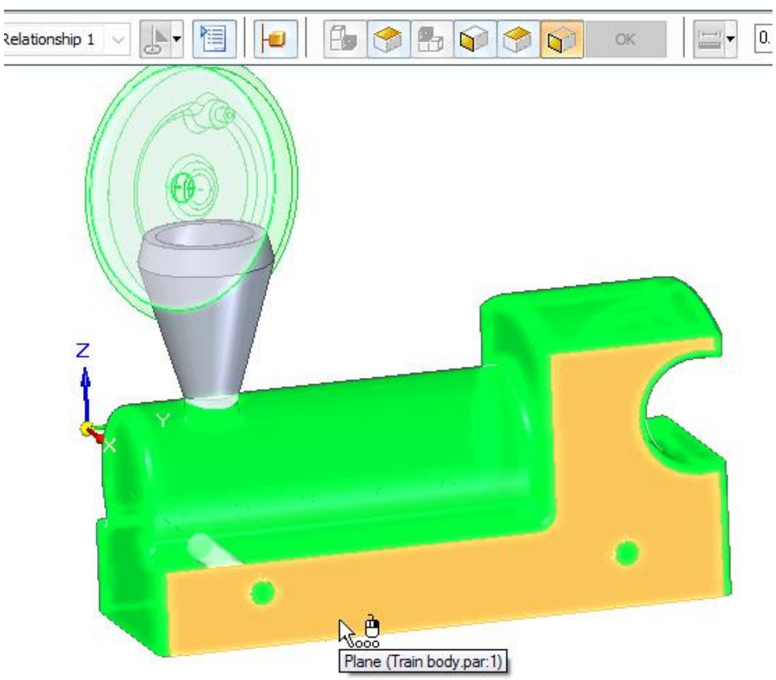
Click to accept. Then hover over the engine body where the hole goes through the body, click again.



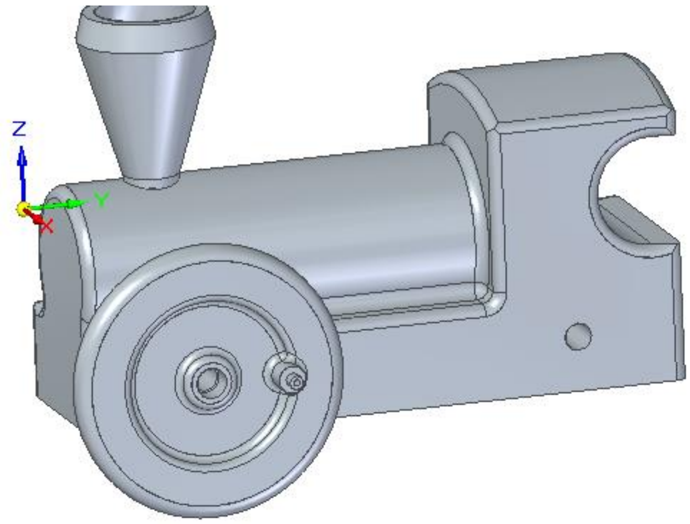
At the end of Assemble tool bar is a section for offset. Set the value there to .010



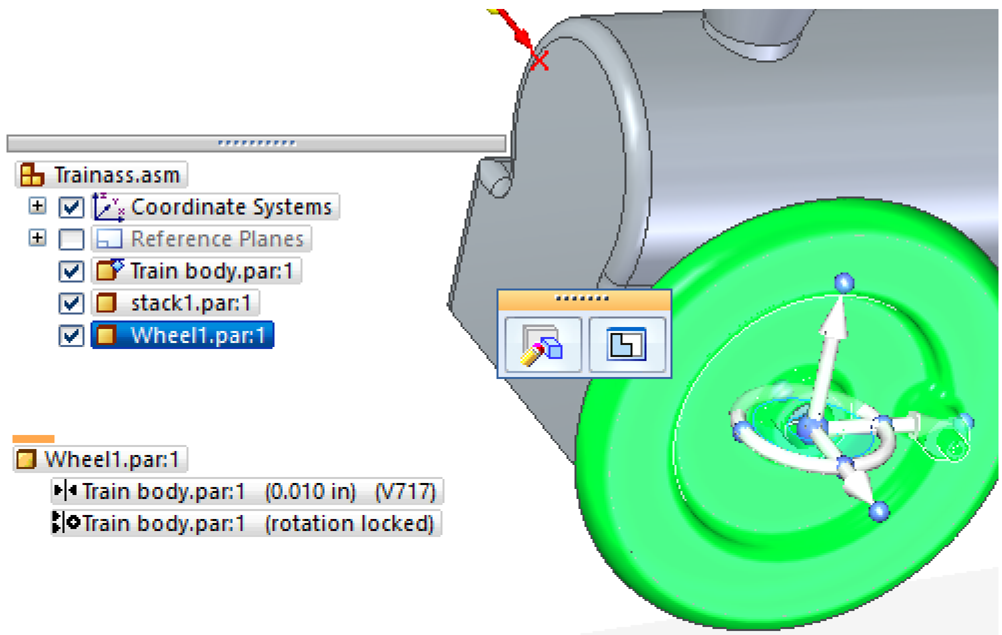
Select the flat side of the wheel and then the flat side of the engine body.



The wheel should now be in place and be set .010 out from the engine body. This will also allow the wheel to move.

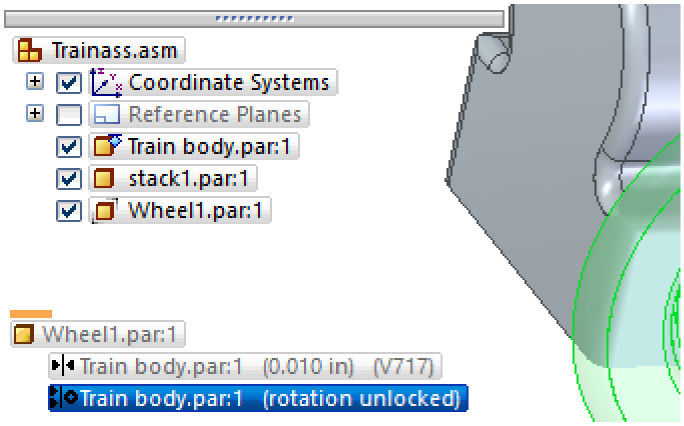


Hit the Esc key to exit the command. In the path finder highlight the wheel and you will see the relationships assigned. You will see the insert command has locked the rotation of the wheel. If we want the wheel to rotate we will need to unlock the wheel.



Right click on the relationship that ends with (rotation locked). Select edit definition from the options. This will open the tool bar. To unlock the wheel, click on the unlock rotation arrow on the right side of the tool bar.

When you check ok, the path finder will report your edit.



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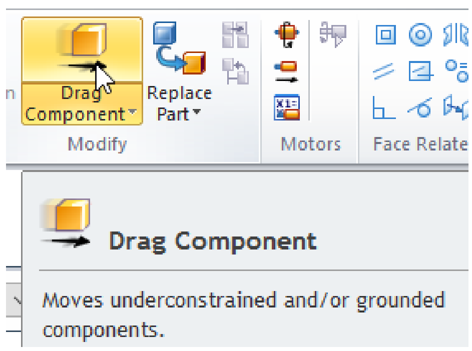
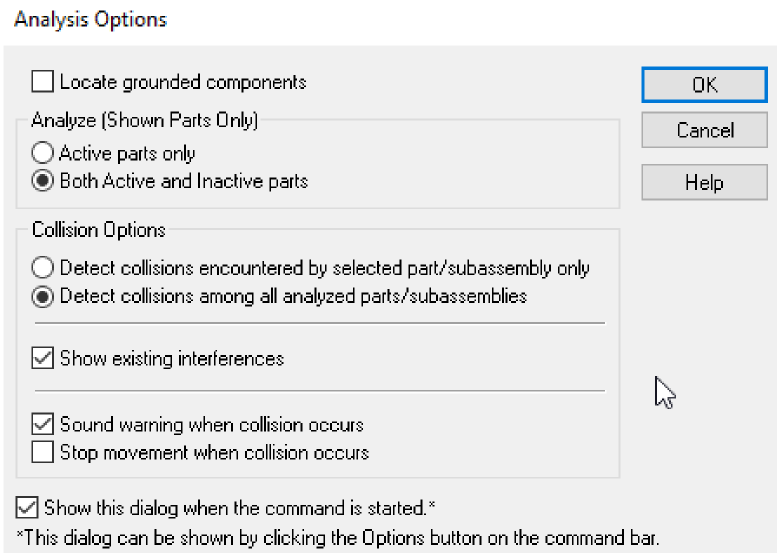
Drag Component

Hit Esc to exit that command. To see the results in real time, select Drag Component from the modify section of the ribbon.

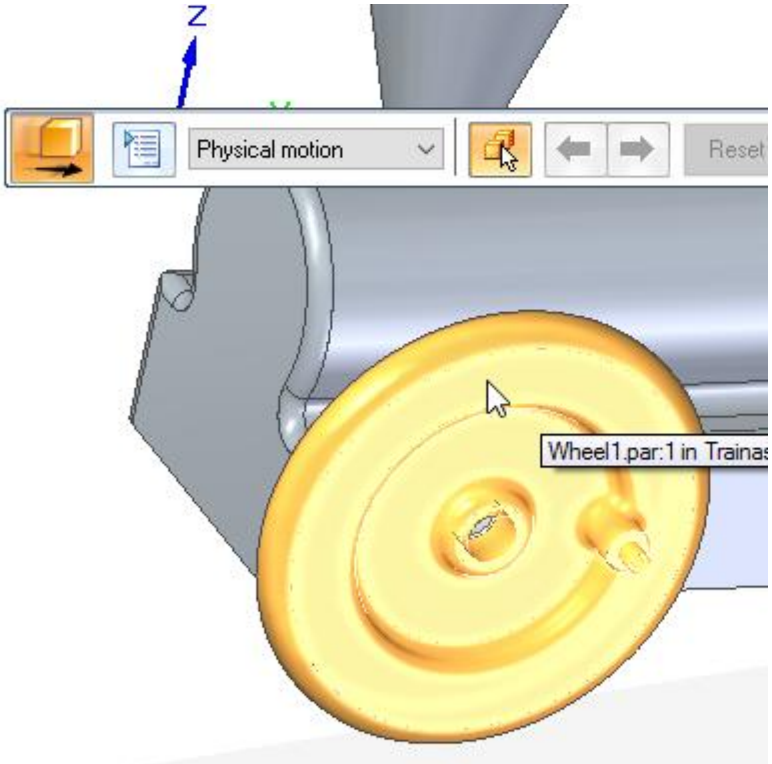


This will open a dialog box for analysis options. Select the options shown below and click ok.

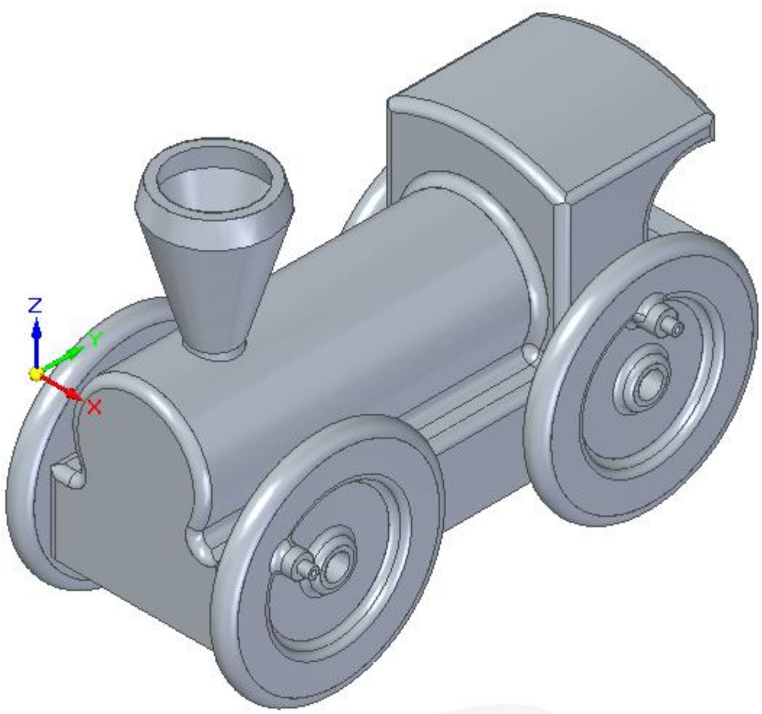


The toolbar opens. Set the motion analysis option to physical motion. Select rotation for the option.

Select the drag component option and then click on the wheel and hold the mouse button down. You should be able to rotate the wheel.



Place the other three wheels and apply the relationships so the wheels are in the proper place. Be sure they are unlocked.



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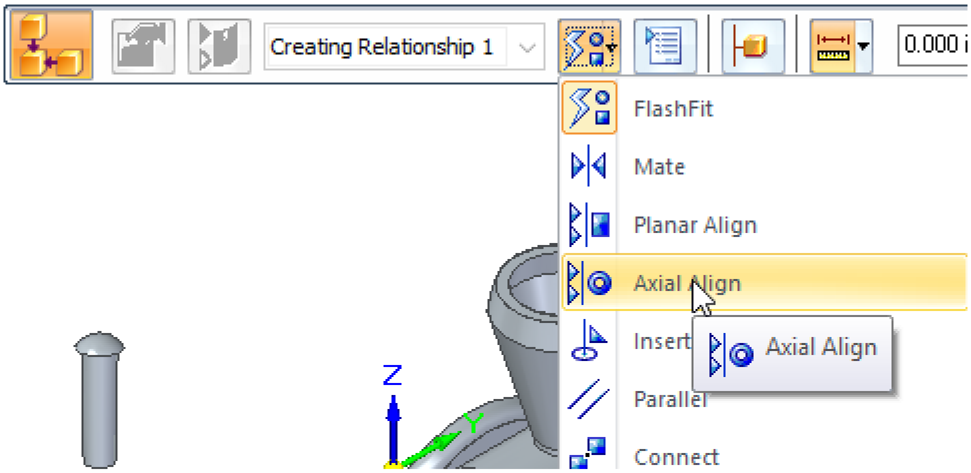
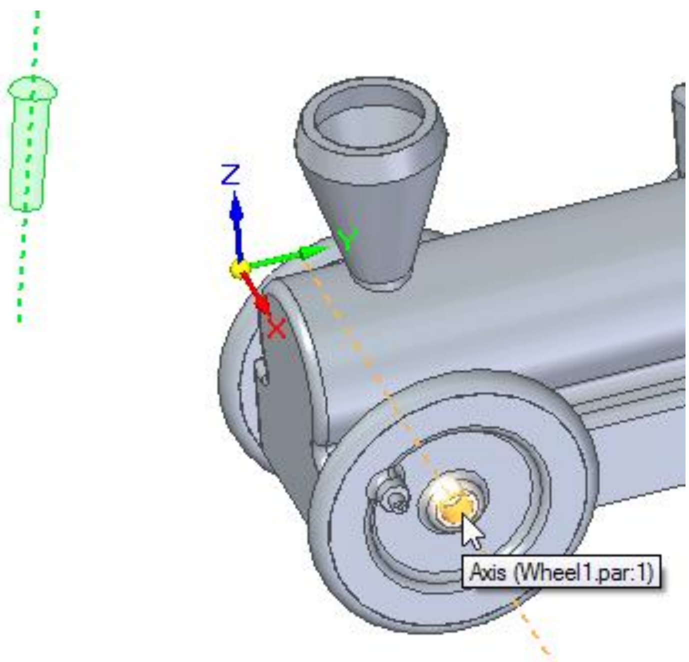
Axial Align

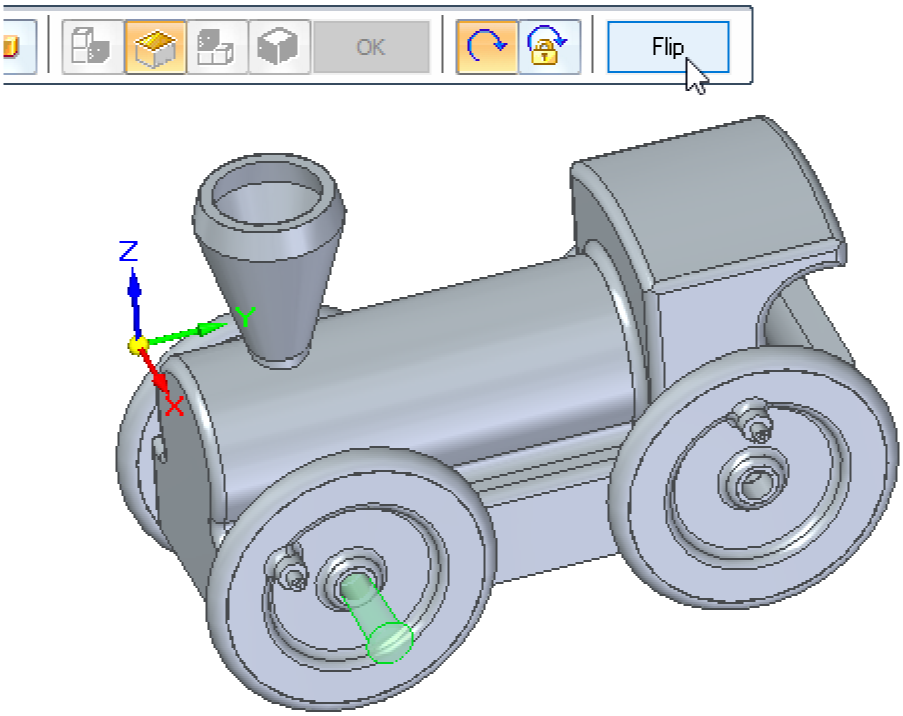
The geometric relationships hold the wheels in place, but in real life you will need to hold the wheel in place. Drag a peg onto the screen. You could use the insert command to place the peg but that will lock rotation keeping the wheel from turning. In this case, use two separate relationships to achieve the same thing. From the Assemble toolbar select Axial Align.



Select the axis of the peg and then the axis of the wheel.



When the peg moves into position, there are two possible ways the peg can position and fit the relationship. If looking at the wrong end of the peg, select the Flip button on the toolbar to reverse the alignment. Be sure it is unlocked.



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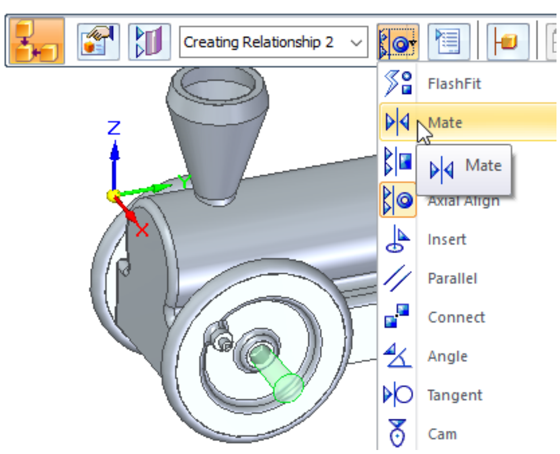
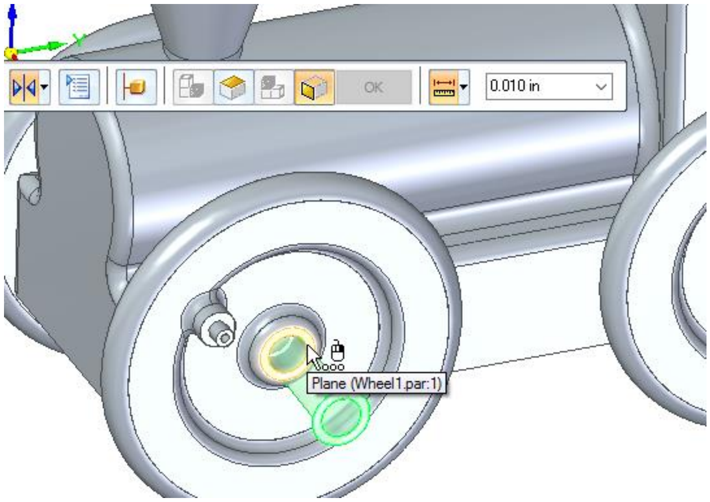
Mate:

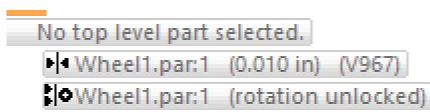
The mate relationship allows two surfaces to be in planer alignment. We can define an offset if desired. In this case, an offset of .010 will allow the wheel to rotate. Select Mate from the assemble toolbar.



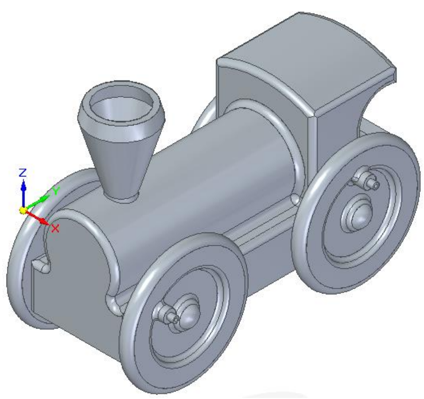
Select the underside of the head of the peg and then the raised boss of the wheel. The peg will slide into place.



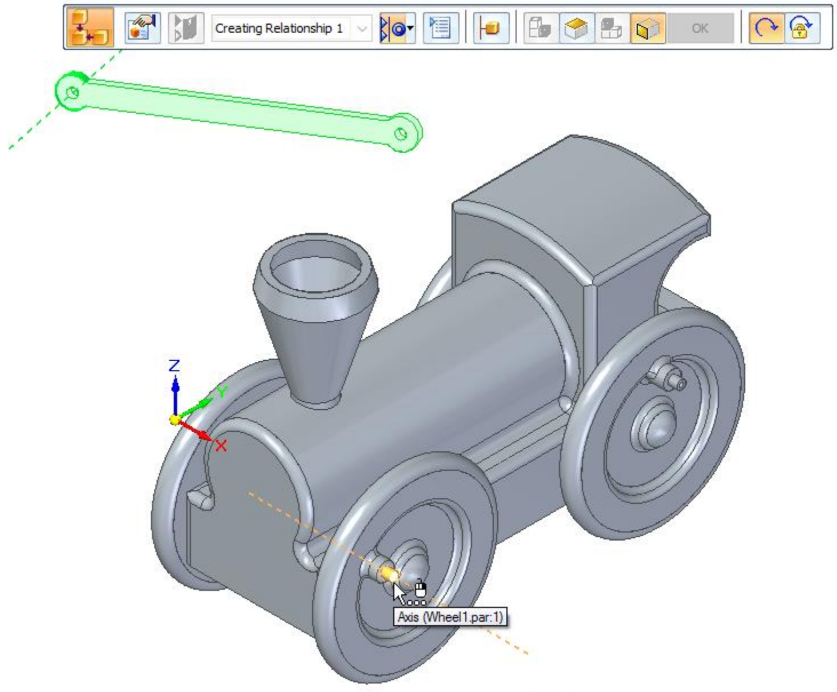
In the path finder you will see that the peg shows the mate with the offset of .010 and the axial alignment with the status of rotation unlocked.



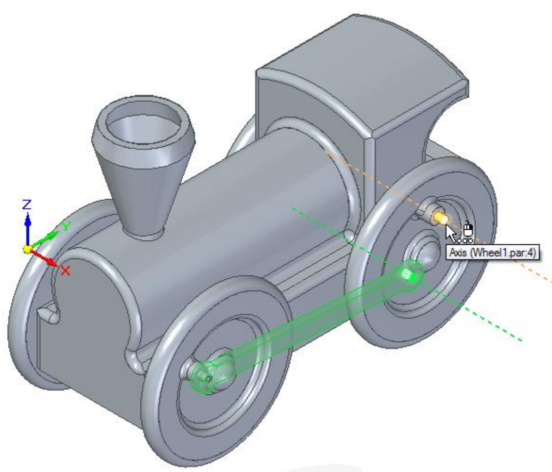
Place the other three pegs and add the appropriate relationships.



Drag the linkage arm onto the screen. Use the axial align relationship to locate the center of the hole with the linkage fitting on the wheel.



Use the axial align relationship to position the other end of the linkage arm.



Notice how the wheels moved to make the relationship possible. If you get an error message that is a sign that one of the wheels is not free to rotate. Find the locked component and edit the relationship so it is free to rotate.

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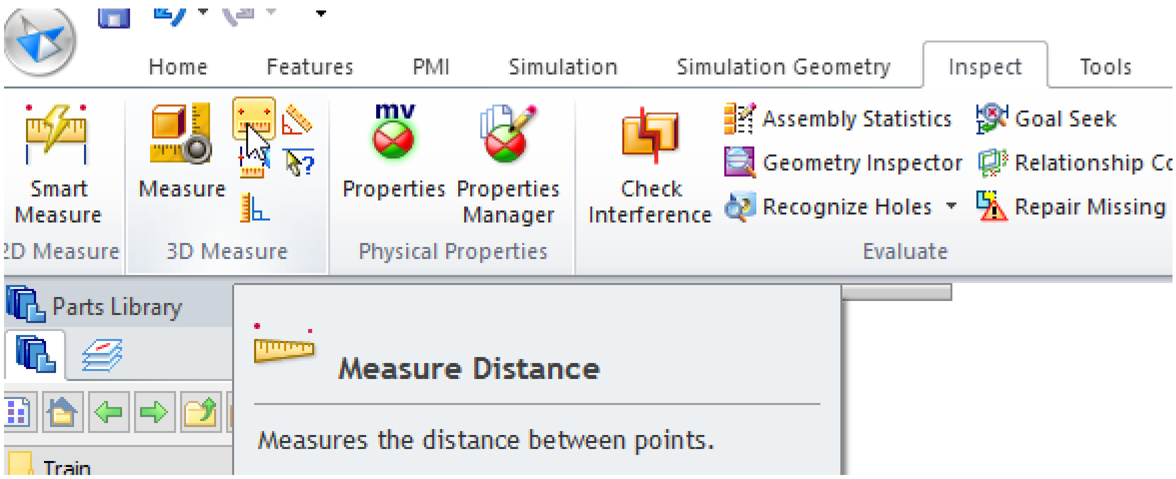
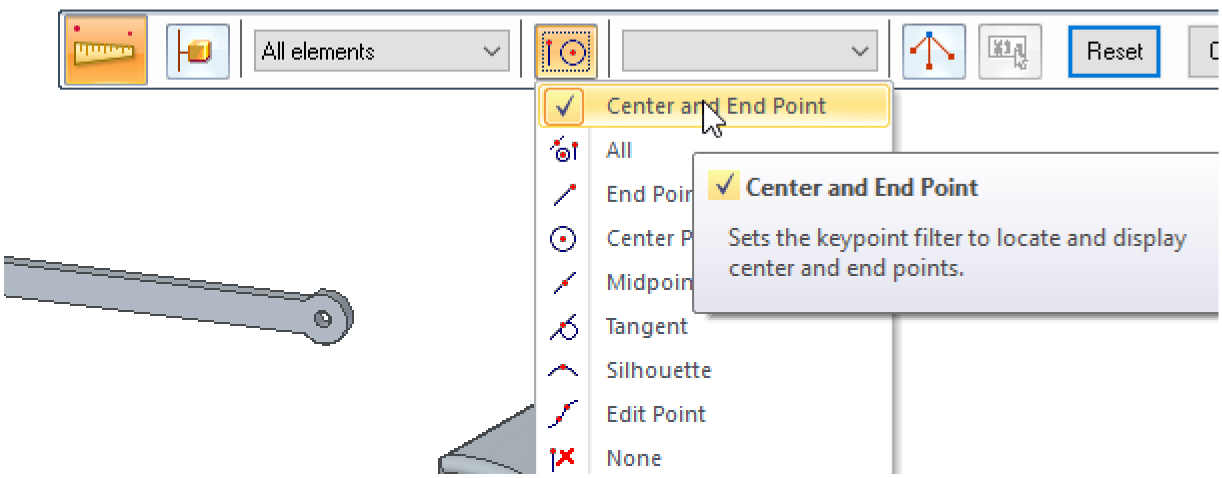
Inspect: Measure Distance

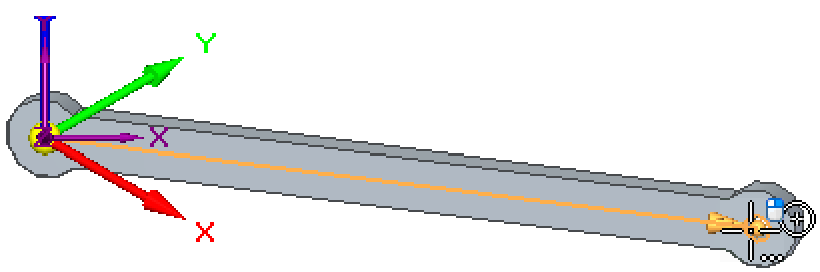
If you are still having trouble that is usually a sign that the distance between the wheels (3.5) is different from the length between the holes of the linkage arm. To check the dimension select the Inspect tab to see the Inspect ribbon. Select Measure.



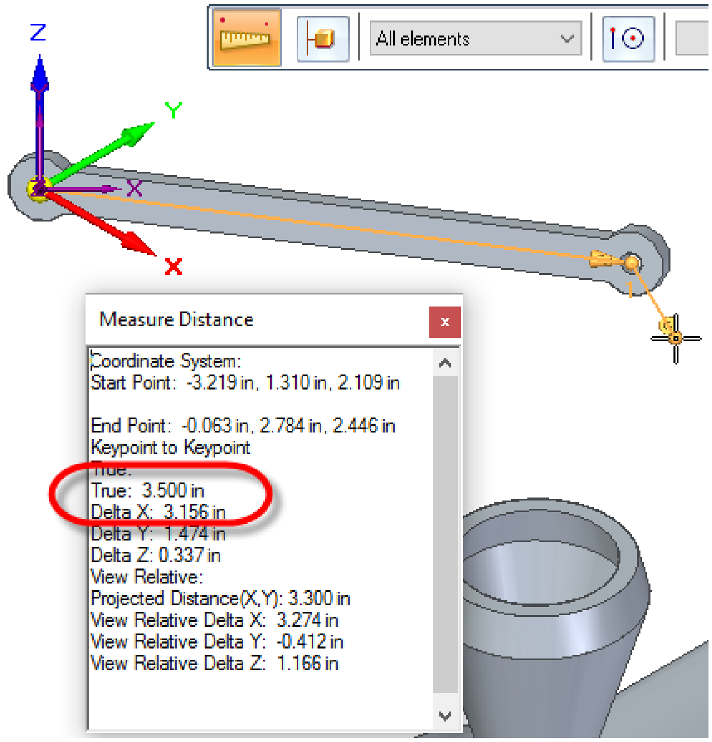
The measure distance tool bar will open. Set the parameters to center and end point.



Select the center of each of the holes.



The computer will determine the actual distance.



Edit the part if it is not correct.

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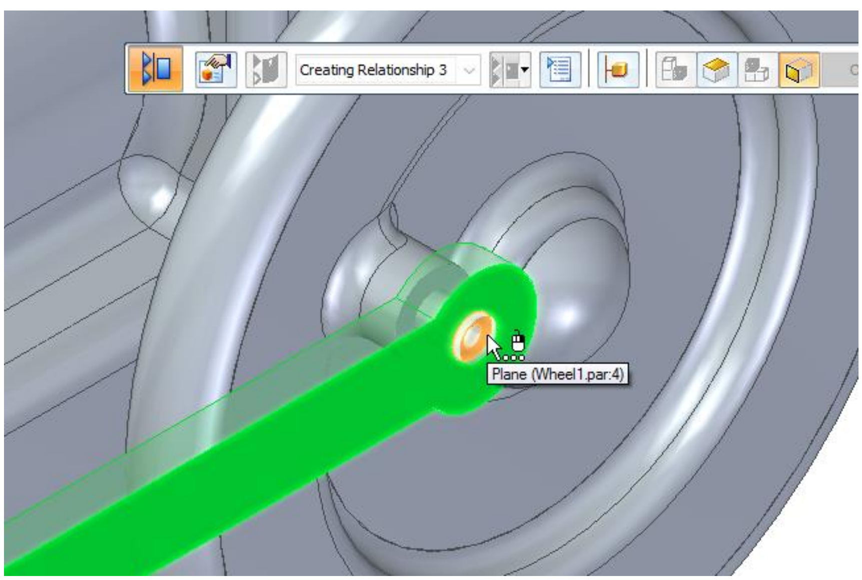
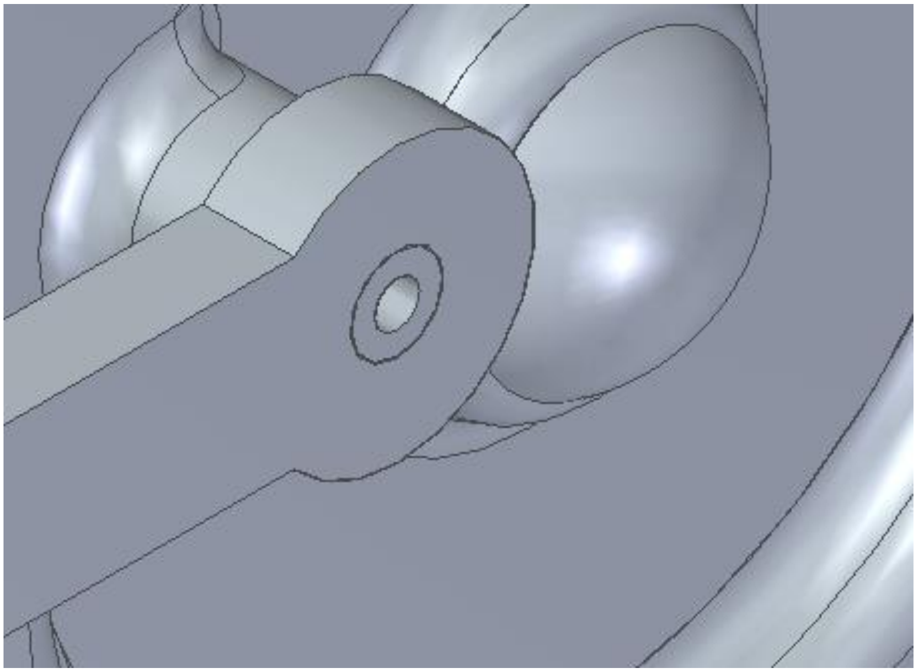
Planer Align

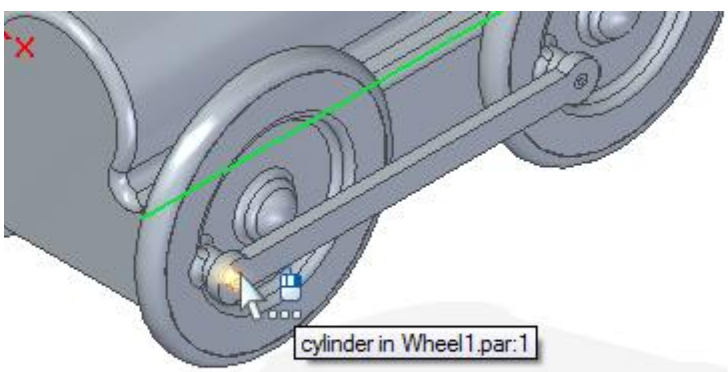
Planer align is a relationship that aligns the faces so they are parallel and facing in the same direction. Highlight the face of the linkage arm and then select the end of the wheel's linkage cylinder.



This aligns the face of linkage arm with the face of the wheel cylinder.



Use the drag component command with the rotate option to see how the parts now work together. Once you select the wheel if you select the cylinder on the wheel you will be able to drag the front wheel in a circle. How does that motion translate to the rear wheel?

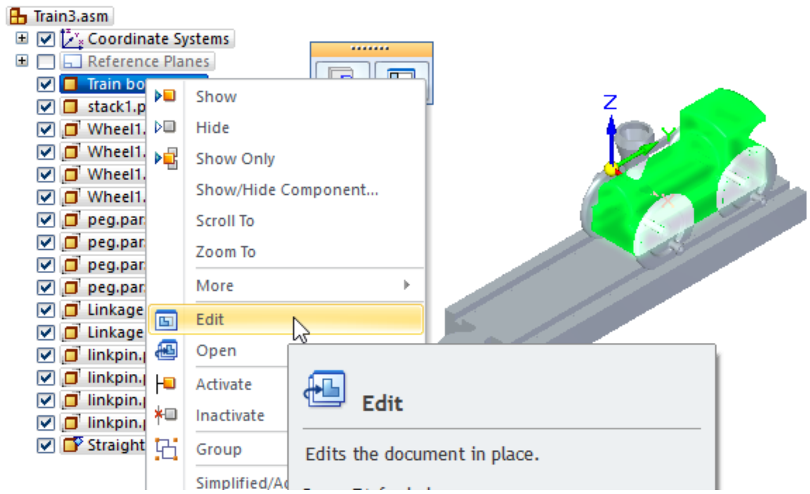


Apply the linkage bar to the other side of the engine.

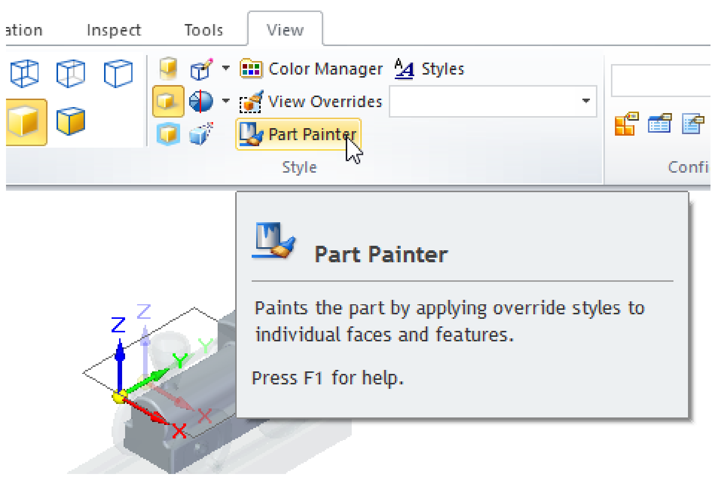
Drag a link pin onto the screen. Using similar relationships to the wheel pegs place the pins to secure the linkage arms to the wheel cylinders.

Color:

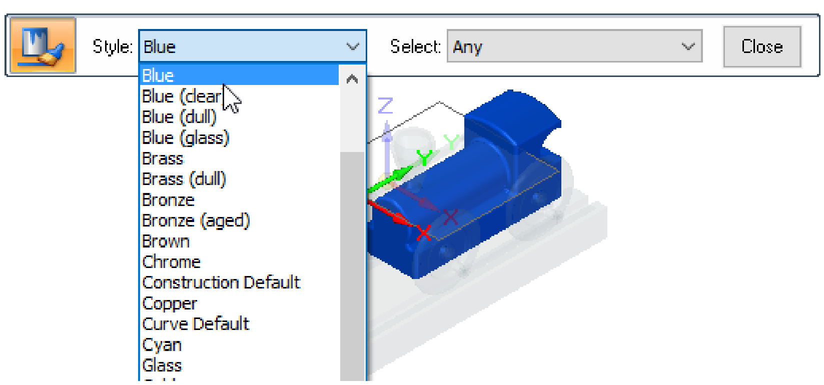
Parts are very generic in color and material. The first step in making an assembly easier to comprehend is the addition of color to the parts. To add detail to a part, right click on the part name in the path finder and select edit. Begin with the engine body. The part will highlight.



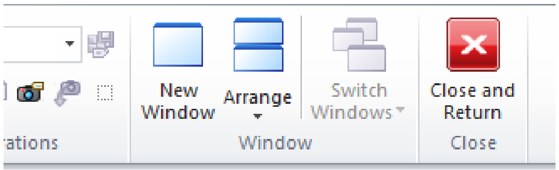
The rest of the parts are dim in the background and only the engine body is bright. Switch to the View tab and select the Part Painter icon from the ribbon.



Color options are available in the style section. Select colors that help people see the differences in the parts.



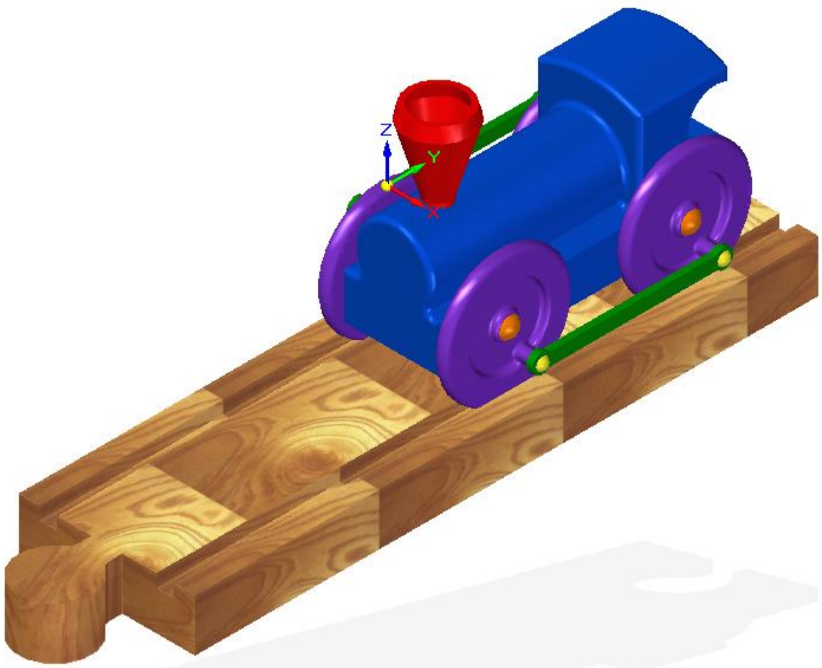
When completed, select Close and the color remains. From the ribbon select Close and Return to bring the assembly up again.



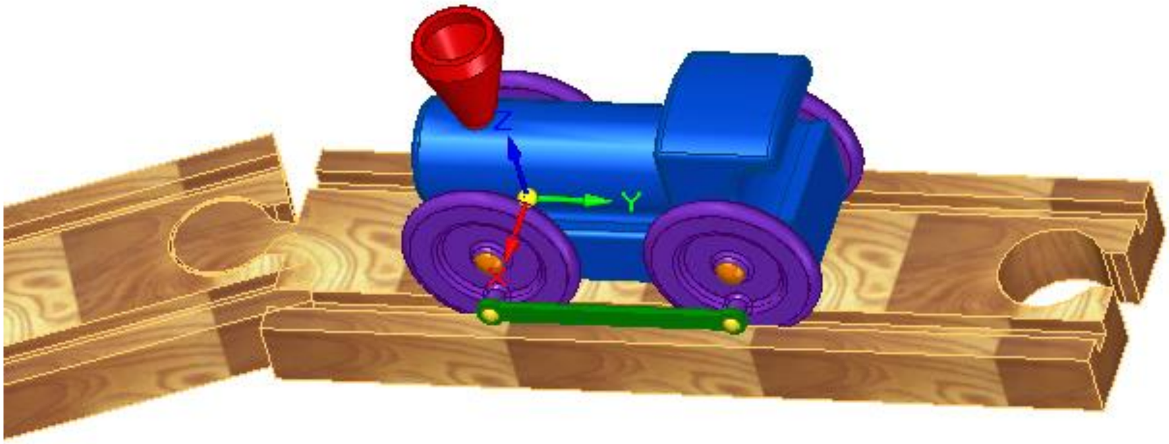
Make the track visible again by placing a check next to it in the path finder.

Add color to all the other components.

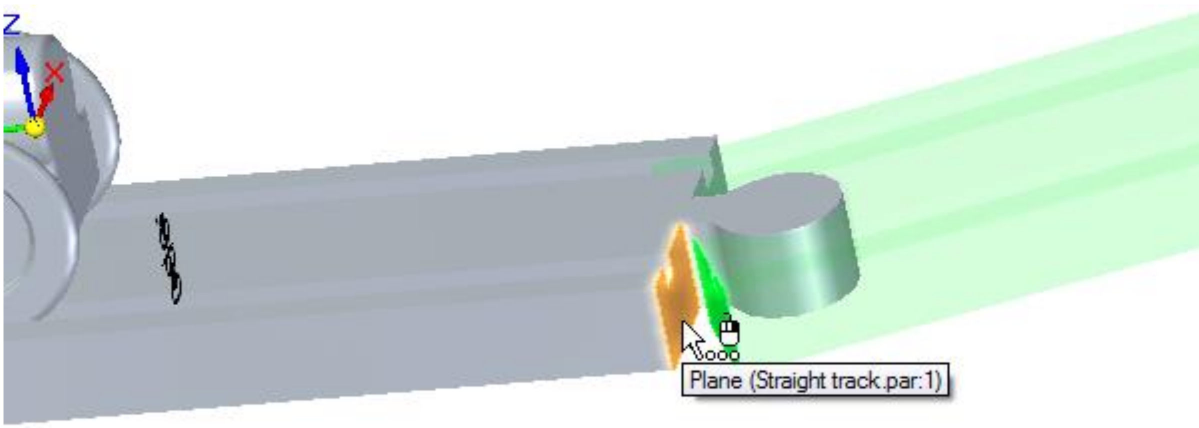
The assembly should now provide an idea of how the various components are located.



Add a second piece of track in front of the grounded one. Use the Planer Align to align the top of each piece of track. Us the Axial Align to line the peg with the slot.



Now use the mate relationship to line up the back of the track with the front of the grounded track.



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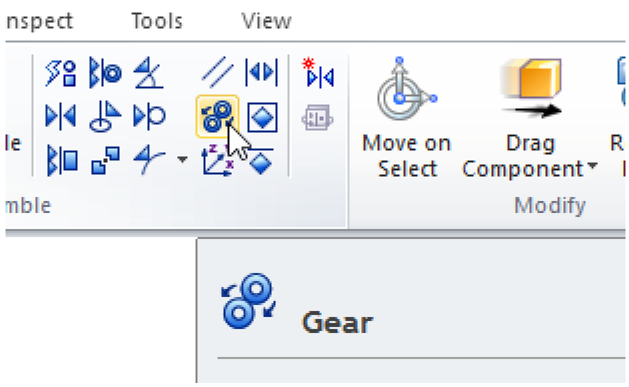
Gear Relationship

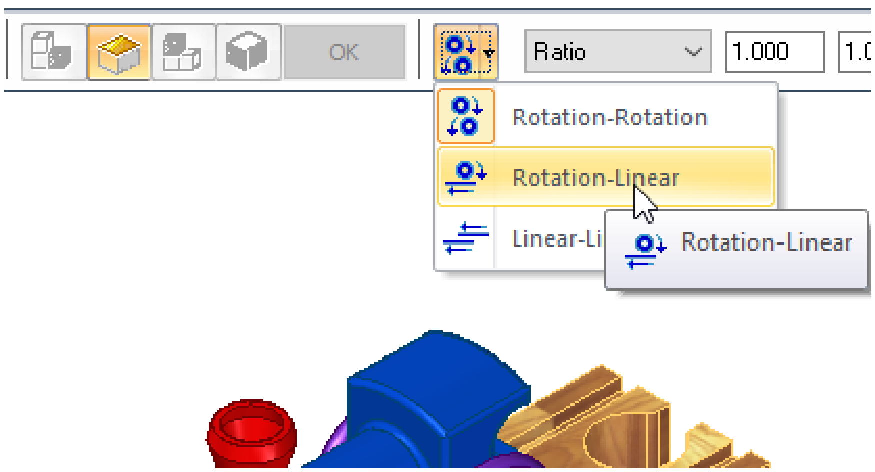
The Gear relationship defines how one part moves in relation to another. It supports rotational-rotational, rotational-linear, and linear-linear type movements.
The Gear relationship is useful when working with assemblies that contain gears, pulleys, parts that travel in grooves or slots, and hydraulic or pneumatic actuators. In the case of the engine we want the wheels on each side of the engine to move together. We also want the engine to move down the track.

The first thing to do is to establish how far the engine should move on one revolution of the wheel. The circumference of the wheel is found by the formula $\text{Circumference} = \pi D$. When we designed the wheel the diameter applied was 2.25 in. Multiplied by pi we find the circumference is equal to 7.0686 inches.

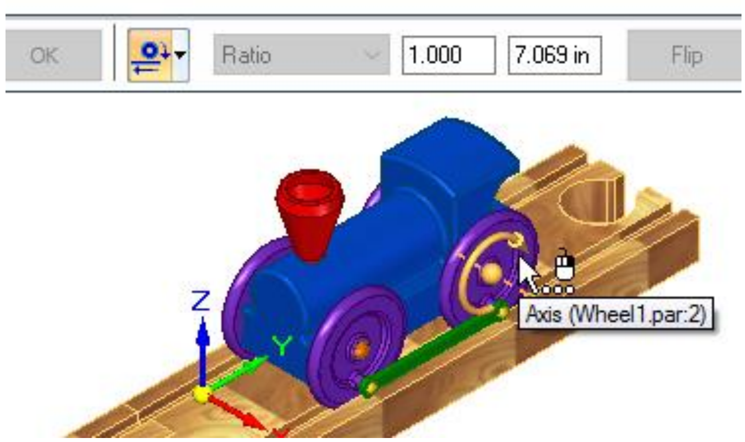
Select the Gear relationship from the Assemble section of the ribbon.



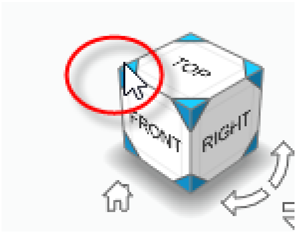
On the toolbar select the option for Rotation-linear.



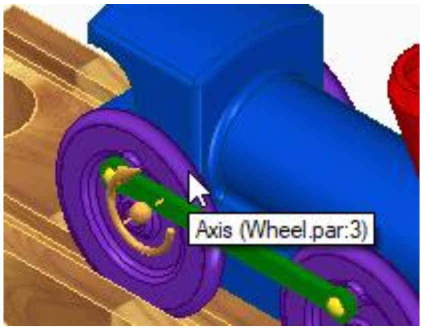
Enter in the distance per revolution ratio. Once the distance is entered select axis of the wheel. Be sure the indicator is reporting the Axis.



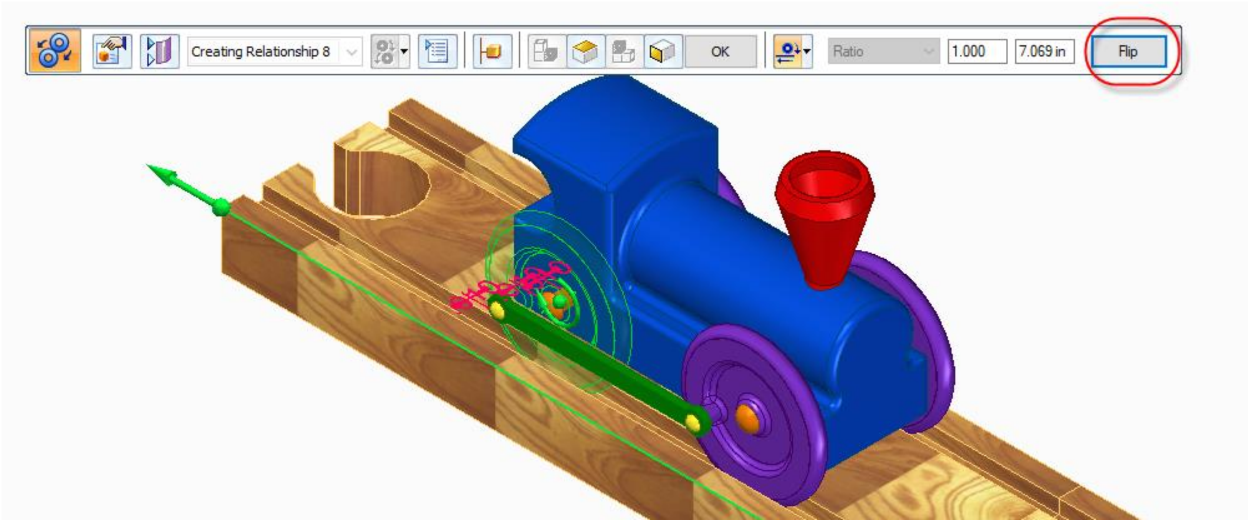
If the arrow is in the reverse direction as in the picture above hit the escape key. Change your view to the isometric from the other direction by selecting the appropriate spot on the view cube.



This will take you to the opposite side. Repeat the Gear Relationship command and the Rotation-Linear Option. Re-enter the 1 and 7.069 dimensions. Select the back wheel on that side.

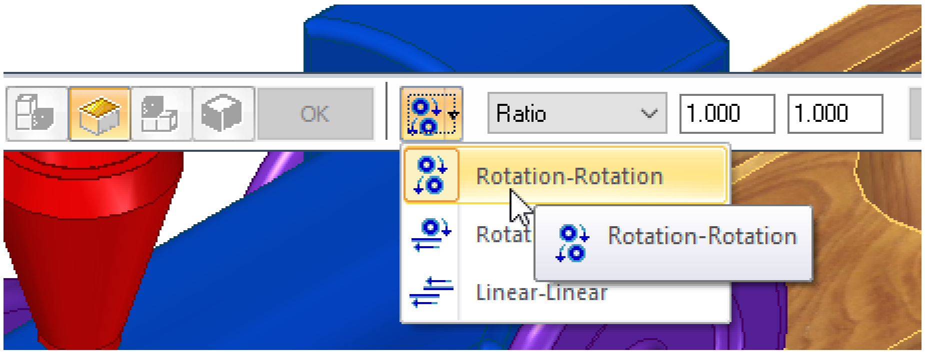


The arrow should point in the correct direction so the wheel will rotate correctly when animated.
Then select the edge of the track to select the direction.

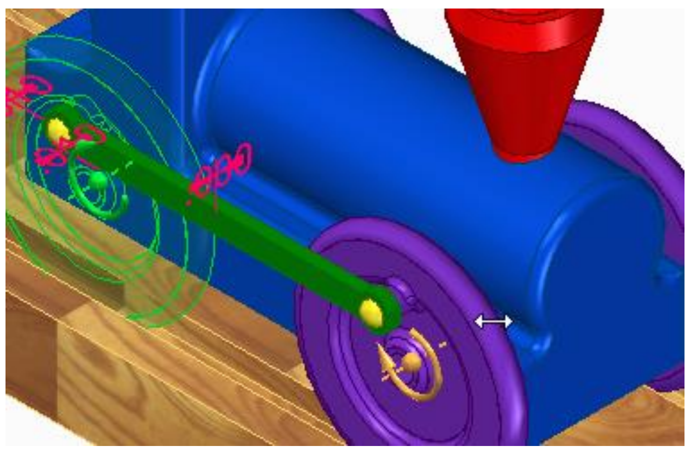


Select OK to apply the relationship. Hit the Esc key to exit the command.

Now work on the other wheels to rotate at the same time in the same direction. Select the gear icon from the assemble section of the ribbon again. This time use Rotation-rotation as the choice and 1.000:1.000 as the Ratio

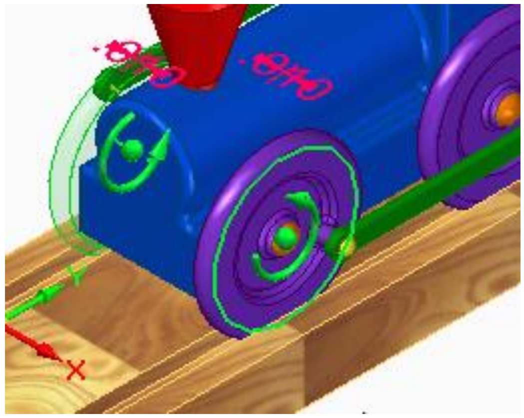


Select the back wheel axis and then the front wheel axis. Be sure the arrows point the same direction.



Select OK. To create movement on the other side of the engine, tie the front wheel on the other side of the engine to the front wheel for which the ratio was just applied.

Select the wheel on one side of the engine. Then select the wheel on the other side of the engine. If the rotation arrows do not agree, select Flip so they will both rotate the same direction. The ratio should be set 1:1 so they rotate at the same speed.



Working on the other side of the engine, apply the gear relationship to the two wheels on that side. This will keep all the wheels moving in the same direction together.

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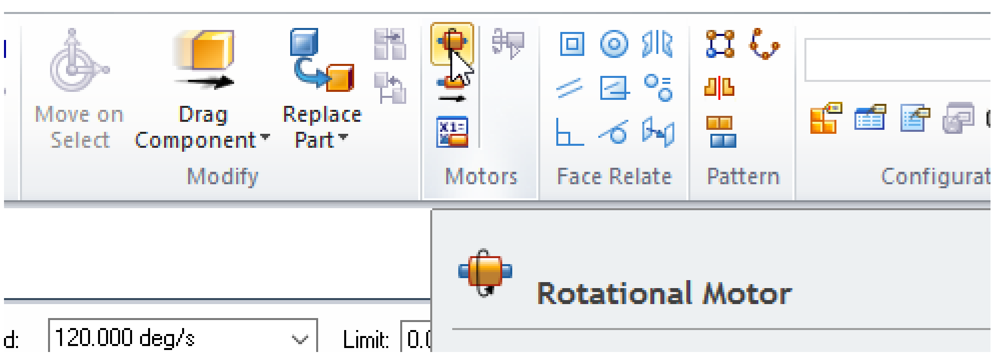
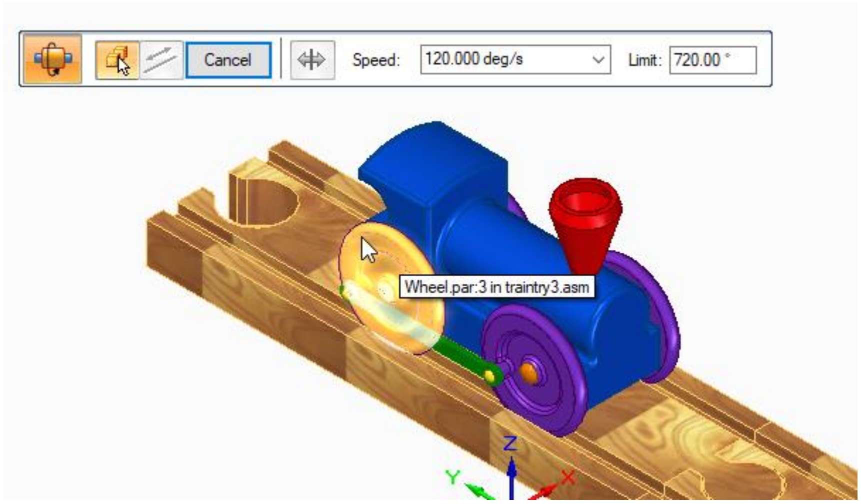
Motors:
Motors allow us to observe how a set of under-constrained parts will move relative to the part you define as a motor. This allows the design and simulation of complex mechanisms to observe the movement of a set of interrelated parts. The motor will cause movement in one part and we can observe how the system behaves.

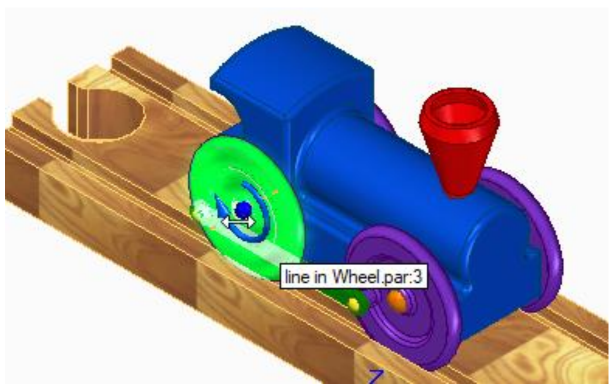
Select Rotational Motor from the Motors section of the main ribbon.



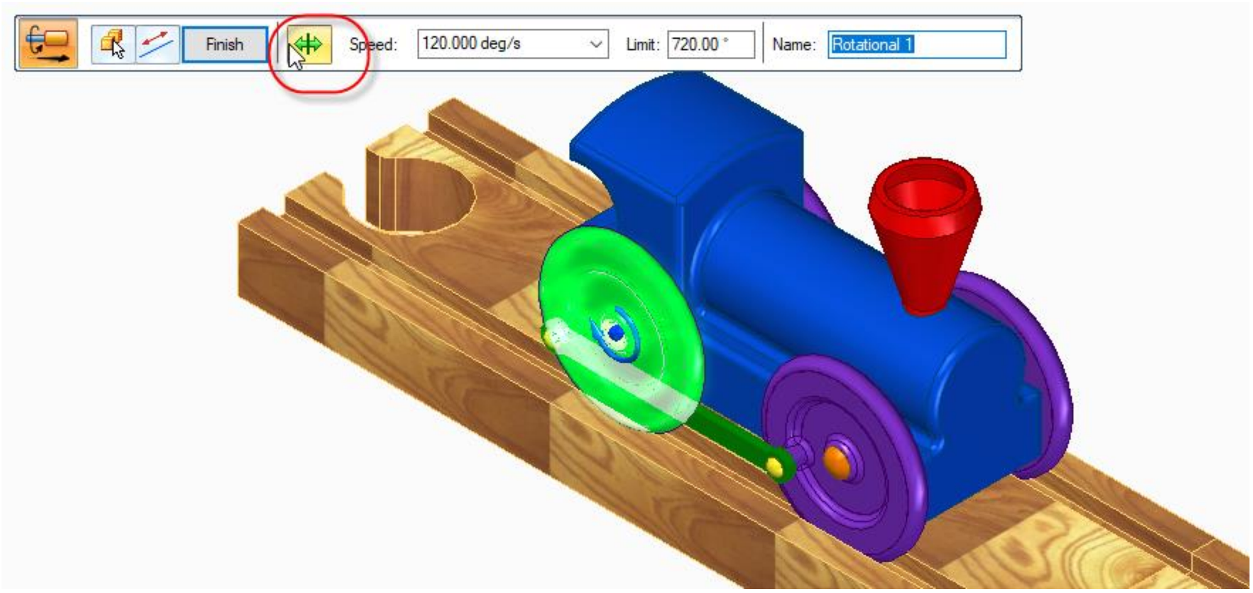
This will bring up the tool bar. Set the speed to 120 degrees per second. This means it will take 3 seconds for a revolution. Set the limit to 720 degrees which will limit the travel to two revolutions. Then select the rear wheel of the engine.



Then select the wheel axis for the axis of rotation.



Flip the arrow on the wheel if needed by selecting the Flip arrows on the tool bar. Select Finish. Click Esc to exit the command.



Save your file.

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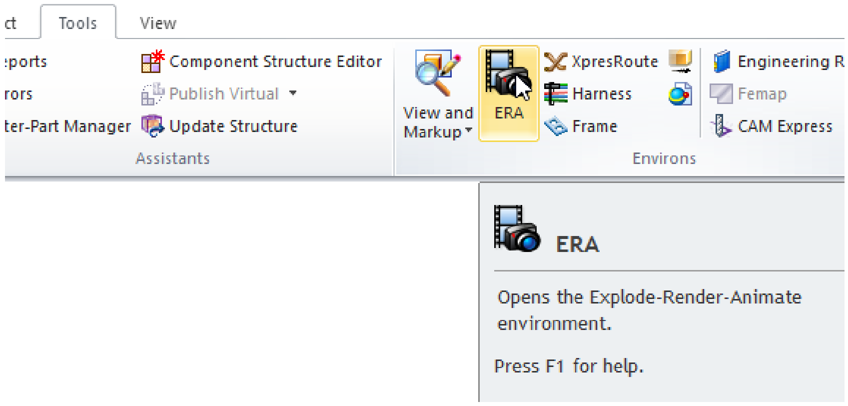
Exploding and Animation Of Assemblies

Assemblies show how the components go together. Many times it is difficult to see the order of assembly or how details of the assembly are accomplished. 3D solid modeling programs allow designers to show information about assemblies. The tool sets help communicate information by making it easier to understand.

Animating an Assembly

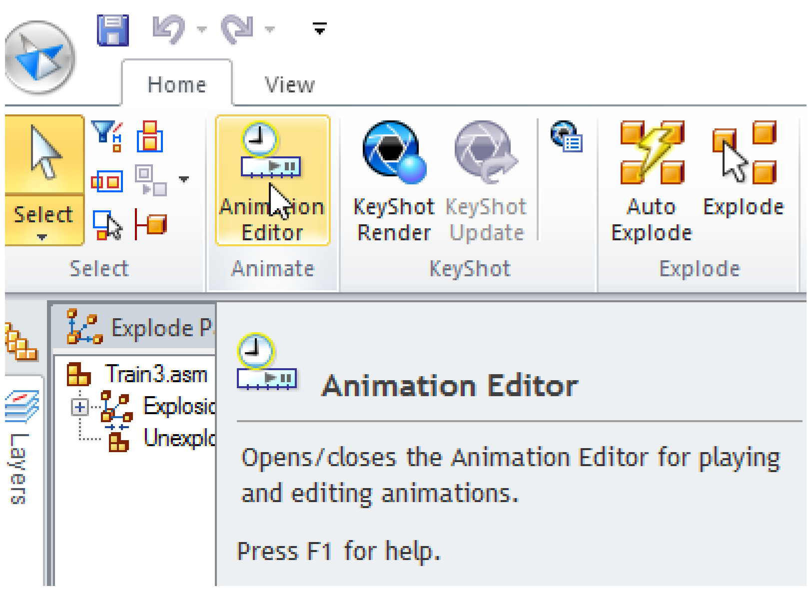
If you have properly set up your assembly you can see how the components will all work together. The animating process allows us to observe and analyze how parts work together or cause issues when in motion. We can also record what happens so we can watch later or use the animation as part of a presentation.

From the Tools ribbon select the ERA icon. This stands for Explode-Render-Animate. Select the F1 Key to see the help menu for this section.

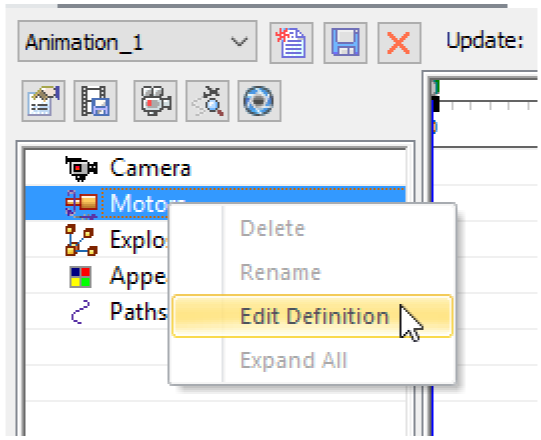


This will open up the ERA section of the program.

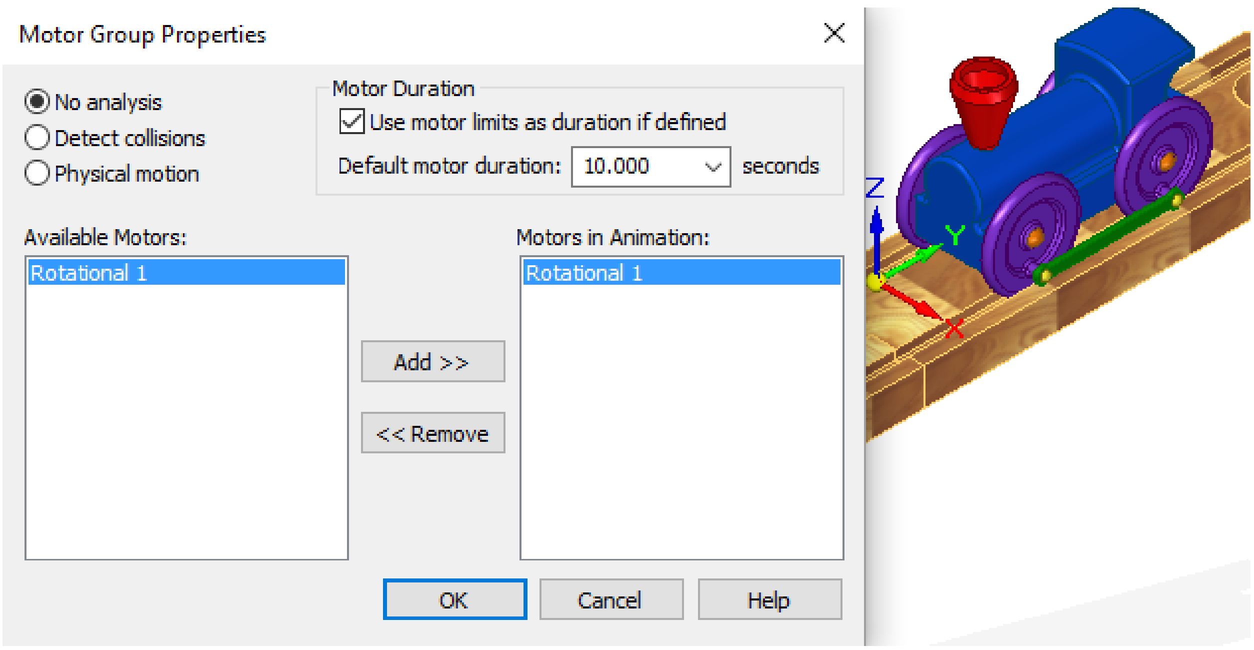
Select the icon for the Animation Editor from the Animate section of the ERA ribbon.



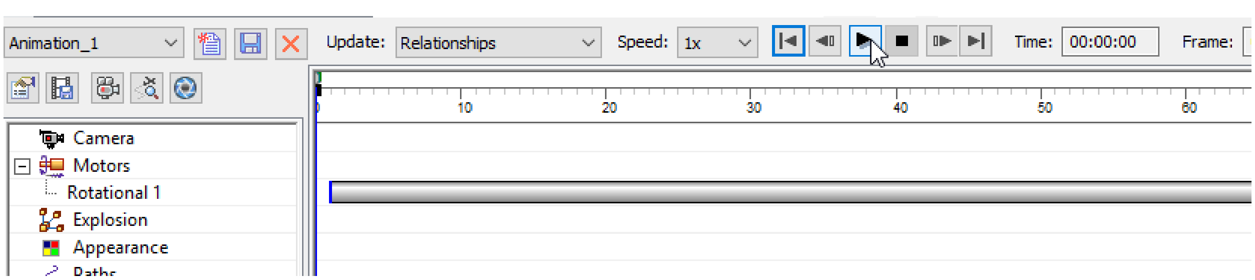
The Animation Editor appears on the screen. Right click on Motors and select Edit Definition.



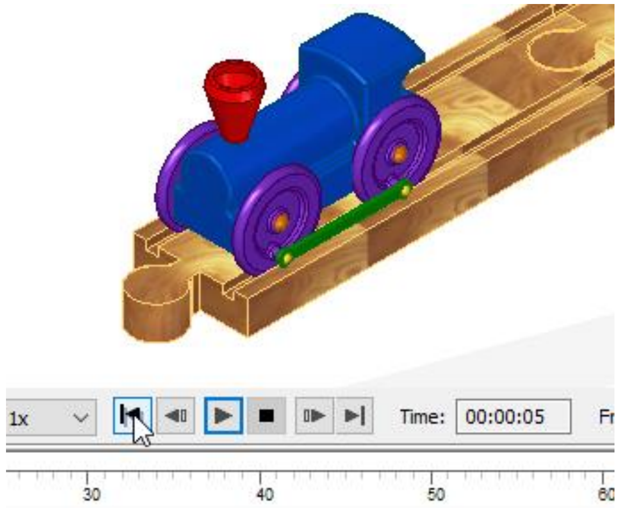
The Motor Group Properties dialog box opens. Since we placed only one motor,that is the only one that is visible. Be sure it shows on the right hand side so it will appear in the animation.



Select OK and see the Animation Window populate. Select Play and the engine should begin to move and the wheels turn.

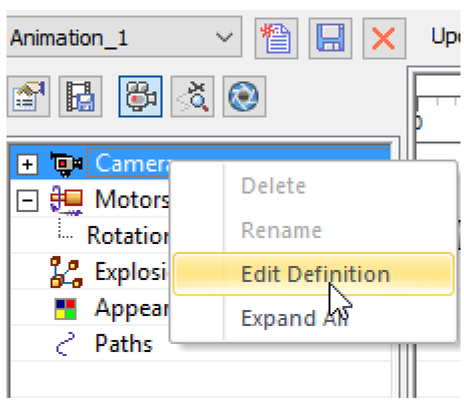


Click the Go to Start button and the engine will return to its original position.

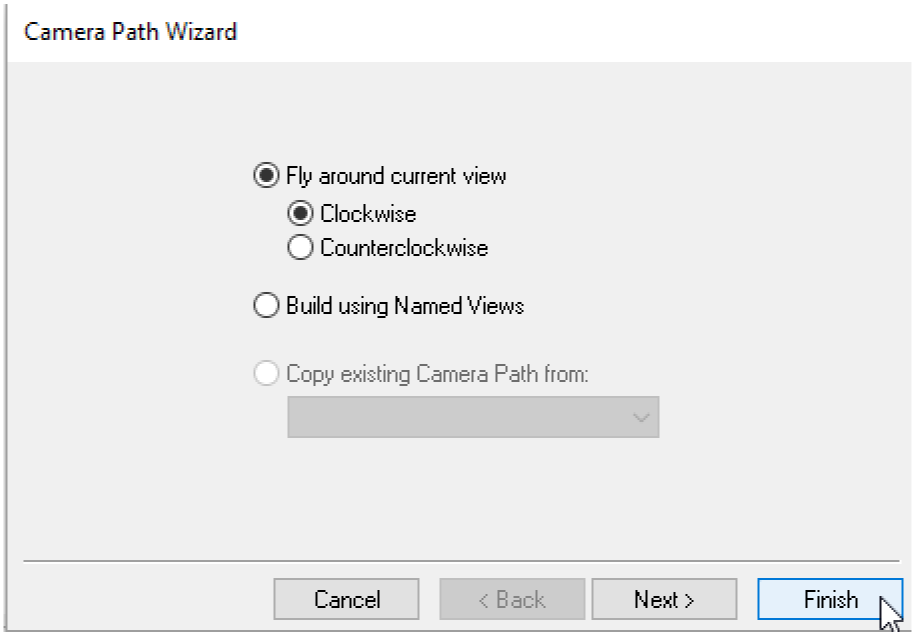


Now that you have seen the engine move, we can add a camera so we can watch from different angles.

In the Animation path finder right click on the Camera. Select Edit Definition.



In the Camera Path Wizard, select Fly around current view and Clockwise. Click finish.



Play the time line again. You will see the animation and the camera flying around the track.

You can create custom paths or use known views when you create the path. For more information click on the camera and press F1.

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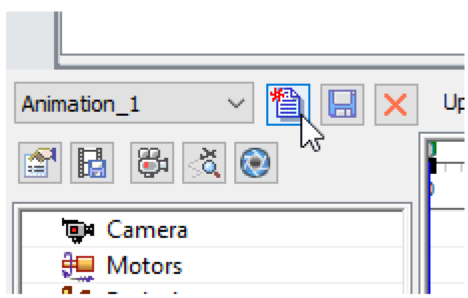
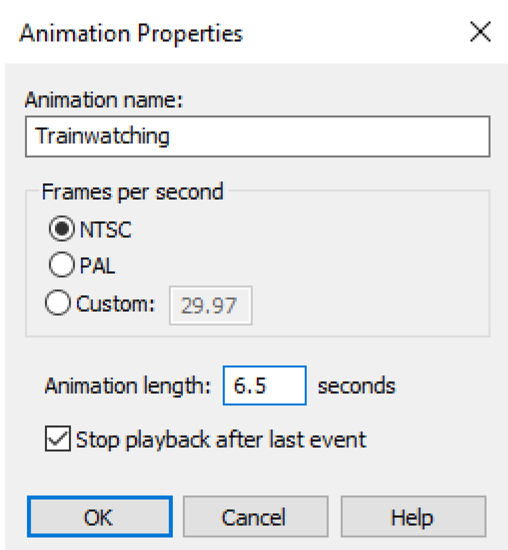
Creating the Custom Animation Movie

Create a new animation by selecting the icon for New Animation on the toolbar.

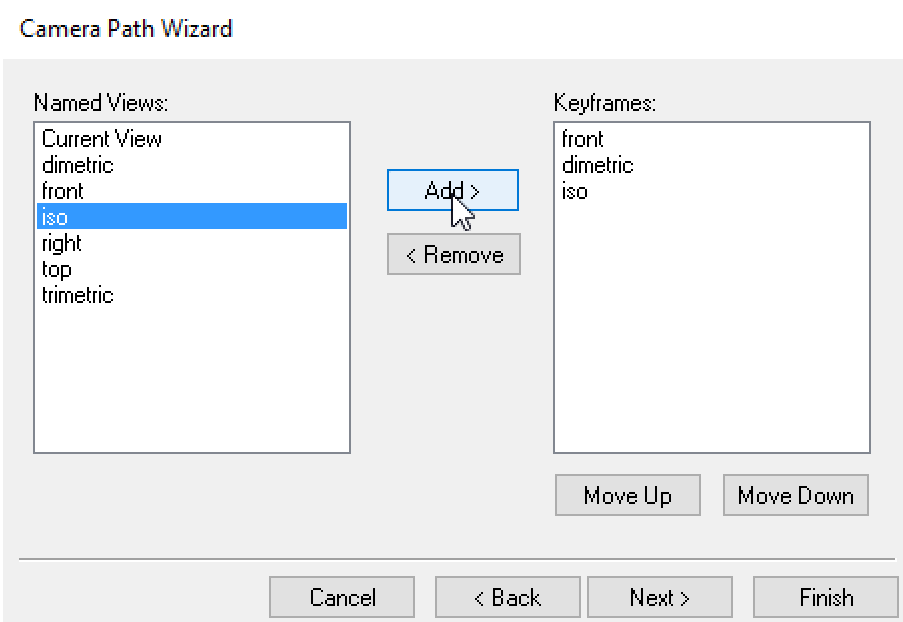


Since we want to make a video presentation of this we need to adjust the settings as well as giving our animation a name. In the Animation Properties dialog box give a name to your animation. Set the Frames per second to NTSC. This is a setting used in the US. Set the length to 6.5. We know the wheel will turn twice and it is moving at 120 degrees per second.

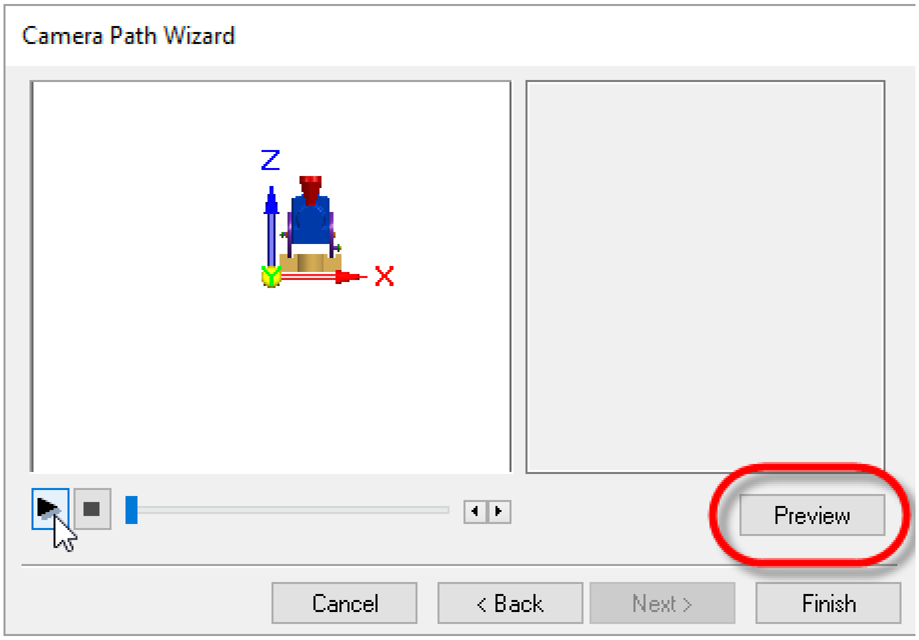


Click OK. Your name should now be in the animation window.

Right click on the Camera in the Animation Window path finder. Select Edit Definition. In the Path wizard select the option to Build using named views. Click next. In the Camera Path wizard add front “dimetric” and “iso” by highlighting them and selecting the Add button.



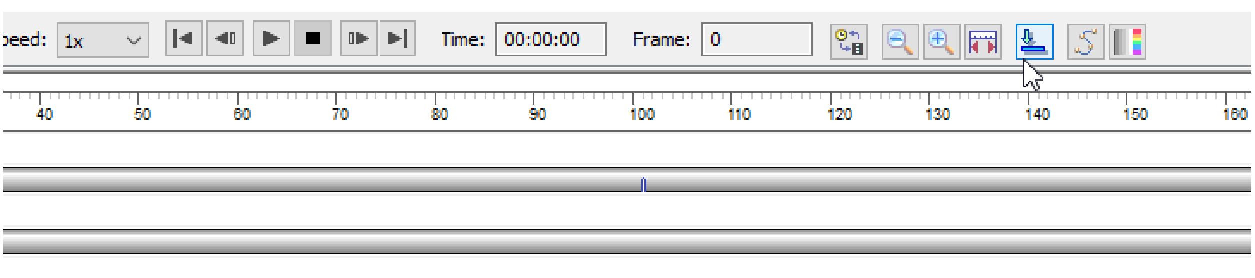
Select next. Click the Preview button. Then click the Play button and see the path the camera will take.



Click Finish. If you are satisfied, select Finish. If not, select back and edit the path.

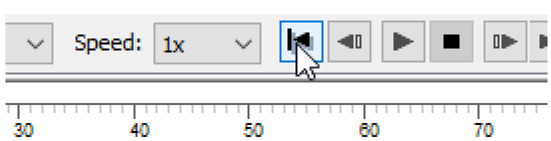
Right click on the Motors in the path finder and select Edit Definition and add the Rotational Motor.

Click on the Toggle button to minimize the Animation Editor.

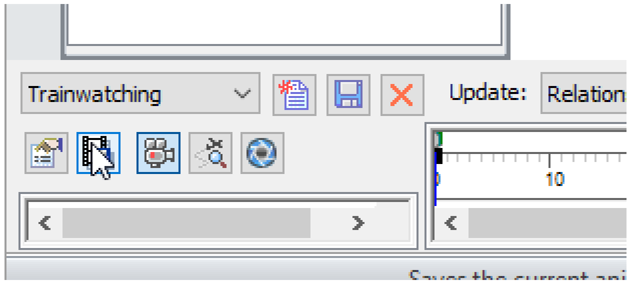


Play the animation and be sure it is what you want.

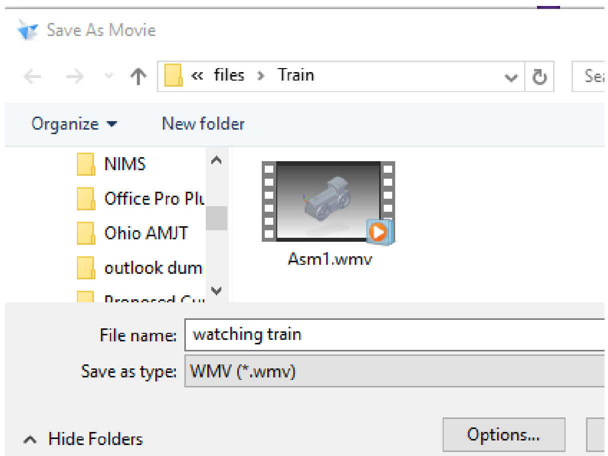
Click the Go to Start button.



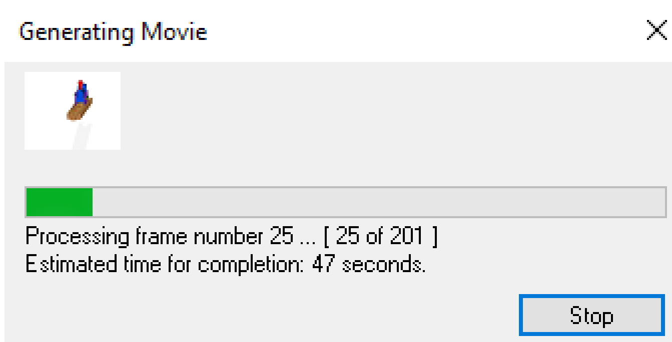
Select the icon for Save as Movie. This saves the current animation in a format that can be played back, uploaded to the cloud, or saved as part of a presentation.



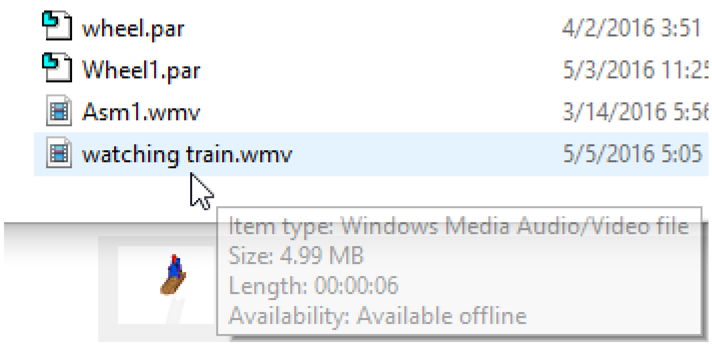
In the dialog box select where you would like to save the movie and provide a name.

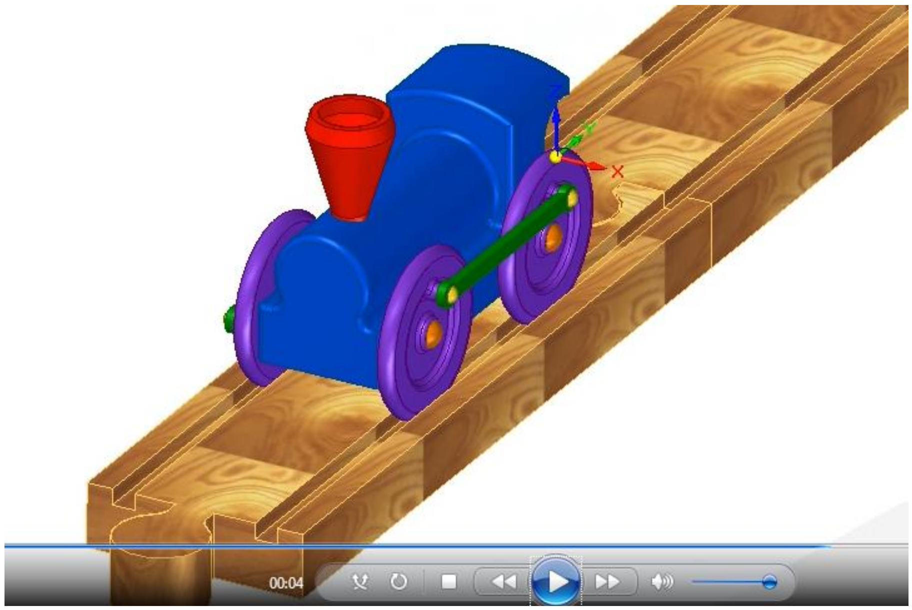


When you are ready, select Save. See the generating movie dialog box and watch the progress.



When done, browse to the folder where the movie is saved and be sure you can open it.





Save your file and exit the Animation Editor and the ERA.

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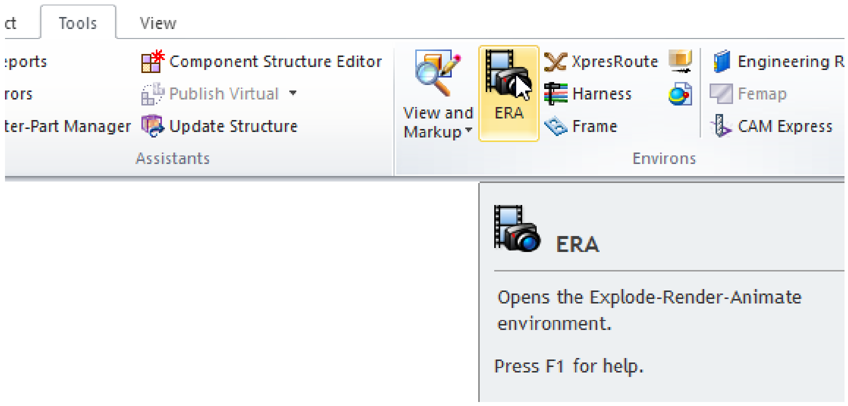
Exploding the Assembly

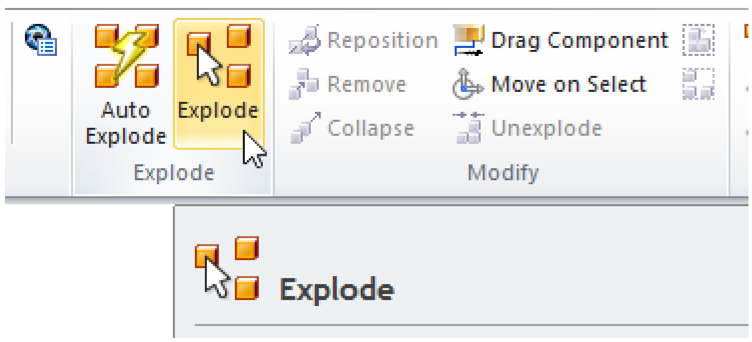
Another way to see how parts go together is to take them apart and leave a trail the parts will follow. This allows the viewer to see the relationships between the parts and also see the order in the assembly process.

From the Tools ribbon select the ERA icon. This stands for Explode-Render-Animate. Select the F1 Key to see the Help menu for this section.

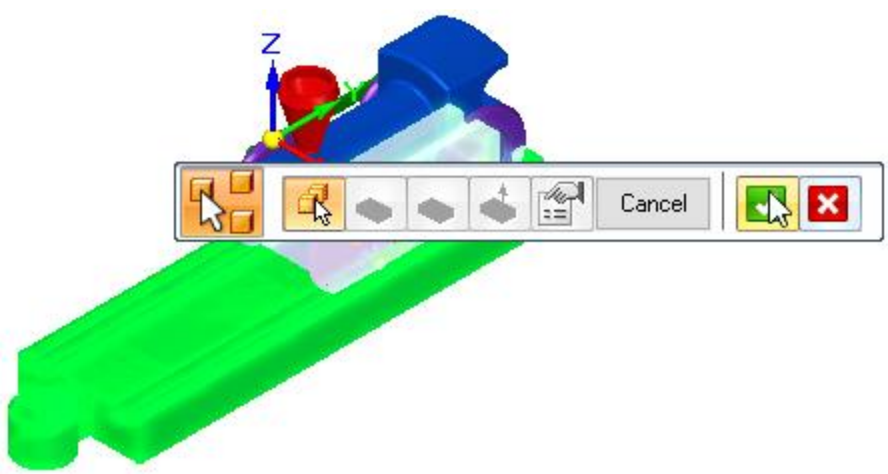


This will open up the ERA section of the program.

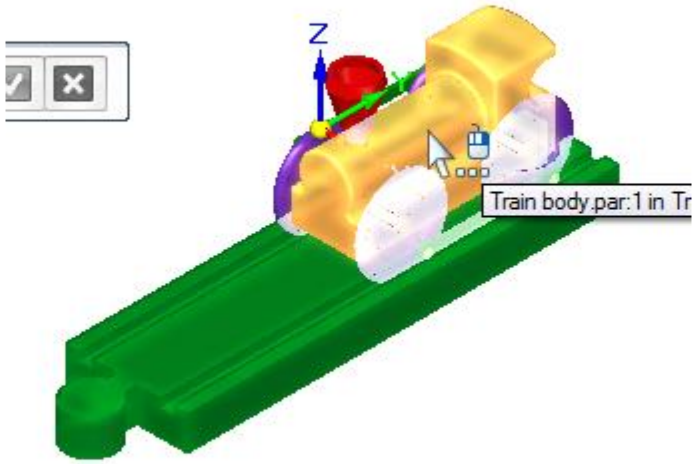
From the ribbon select the icon for Explode.



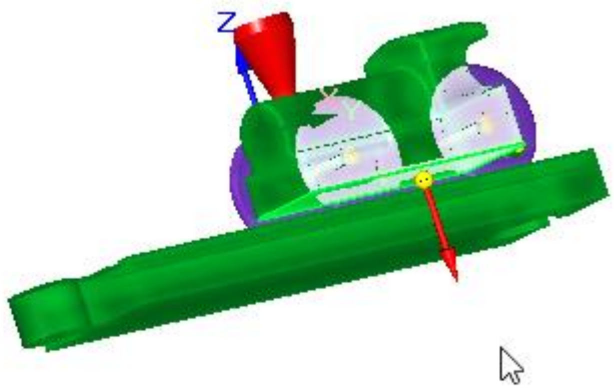
The Explode dialog box will open. Select the track. It will highlight.



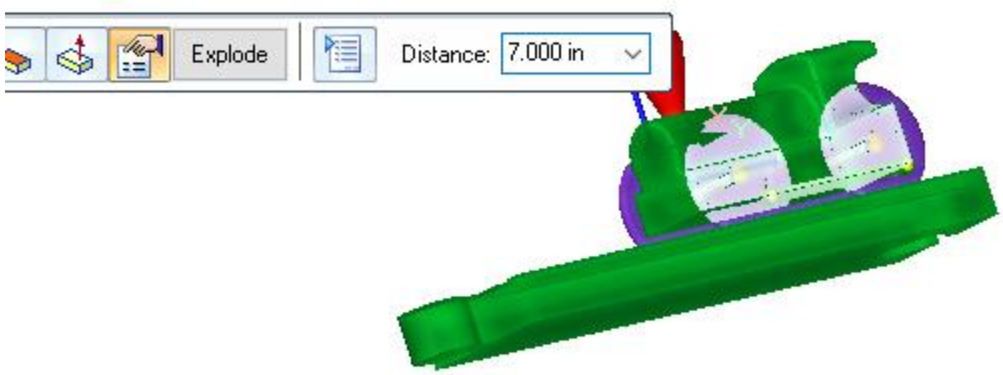
Select the green check to let the program know you are done with the selection process. The prompt is asking for the part that will remain stationary. Select the engine body.



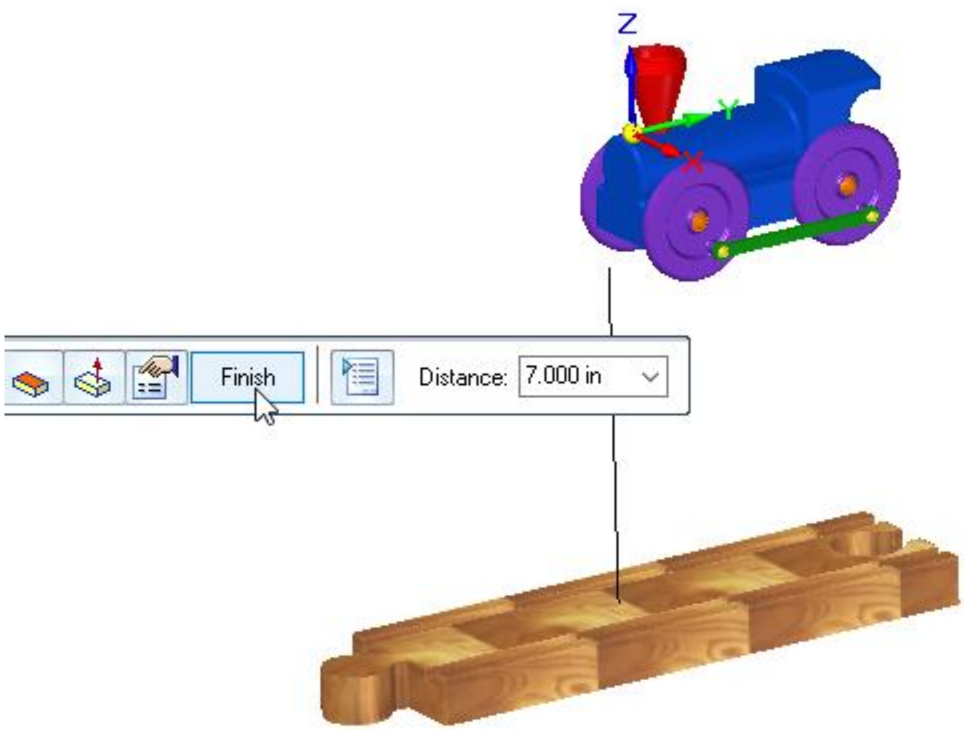
The prompt then asks what surface represents the plane. Rotate the view so you can select the bottom of the engine body.



The direction arrow will appear. Move the mouse below the track and click. This selects the direction the track will move. Enter 7 for the distance.

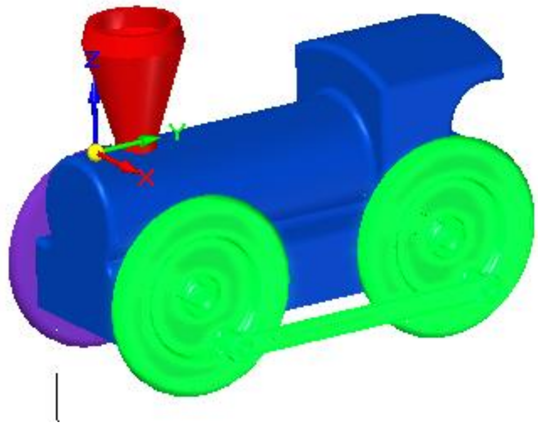


Select the Finish icon on the dialog box.

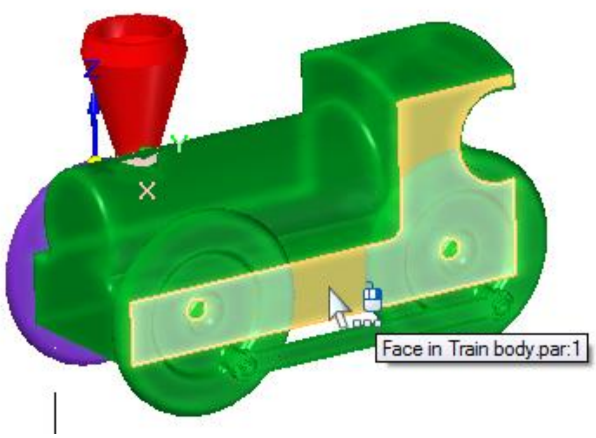


Select the Cancel on the tool bar to exit the explode command.

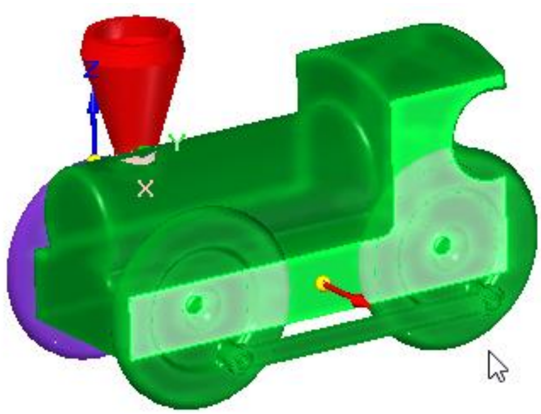
Zoom in so you can see the wheels of the engine. Select the Explode icon again. This time click on each wheel on one side along with the pegs, linkage arm and link pins. All should highlight.



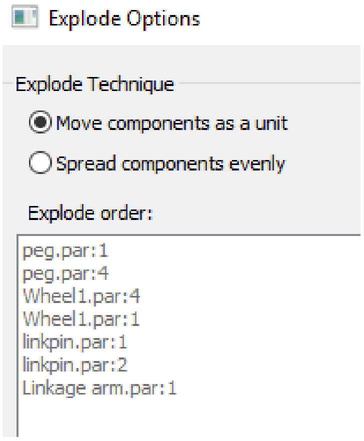
Accept the selection with the green check mark. Pick the engine body for the stationary part. Then select the side of the engine body to be the face from which to explode.



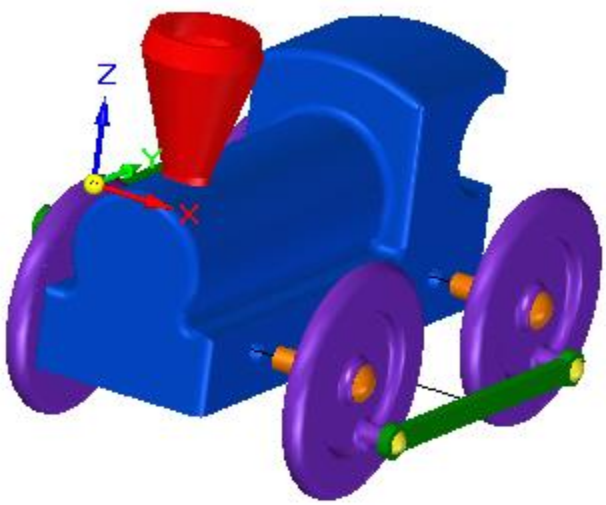
Click on the blank area to select the direction of the explosion.



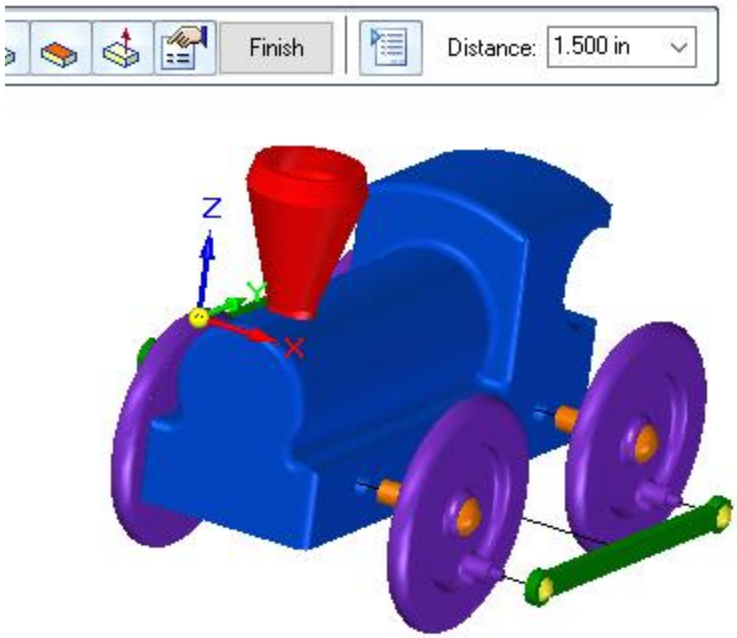
A dialog box will ask what to do with all the parts. Select Move components as a unit. Select OK.



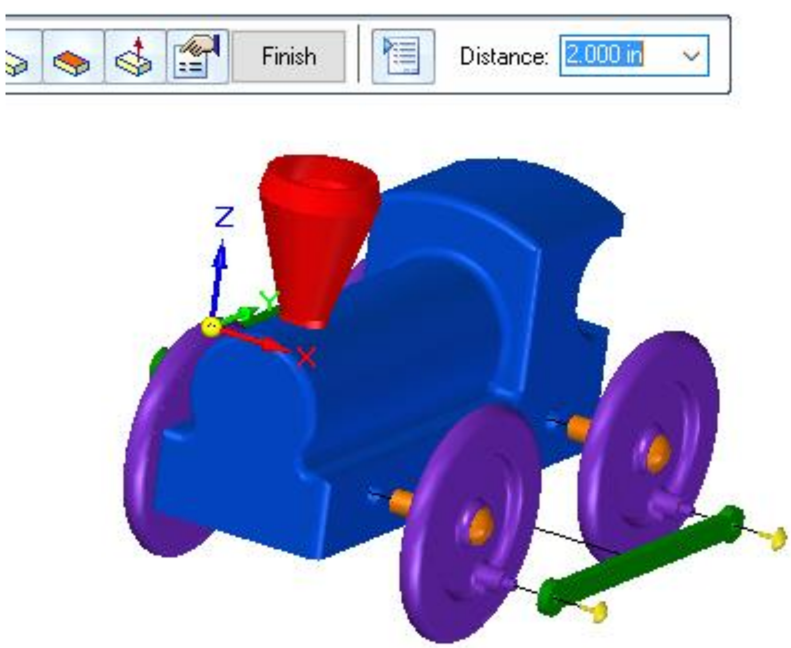
Enter 1 for the distance. Select Explode. Then select Finish.



Select cCancel to exit the command. Select Explode. This time select the Linkage Rod and Link pins. Follow the process and send them out from the face of the engine body 1.5

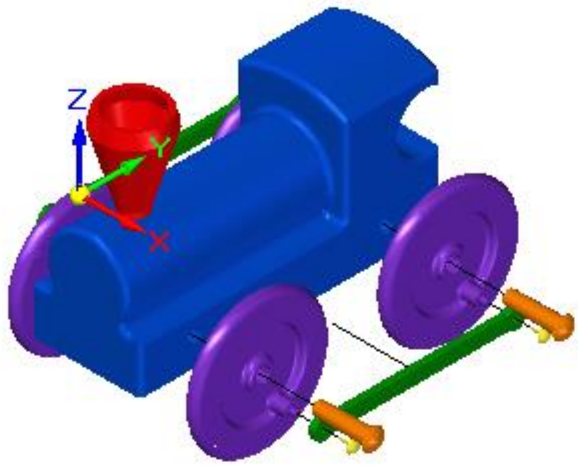


Select Finish and then cancel. Use the Explode command to move just the link pins. Set those 2.0 from the face of the engine.

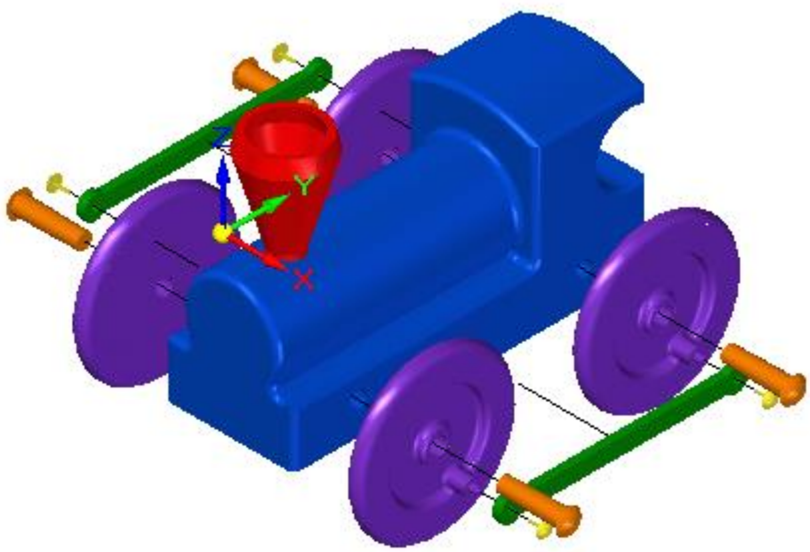


Select Finish and then Cancel.

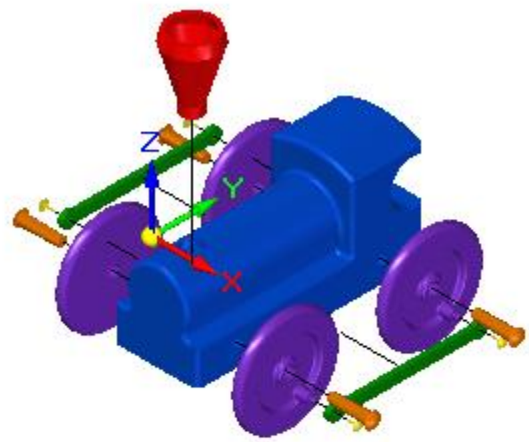
Select Explode and then select the Wheel Pegs. Move them 3” from the engine body.



Spin the assembly around and repeat the same process on the other side.

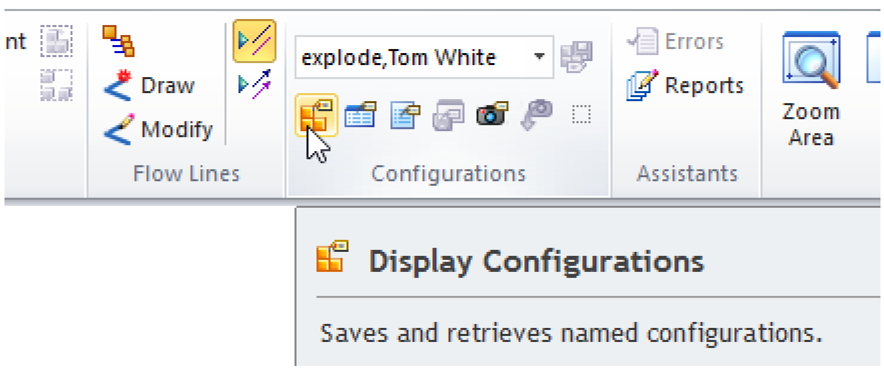


Now select the stack. Use the top face of the track as the face to control the Explode command. Use a distance of 10.

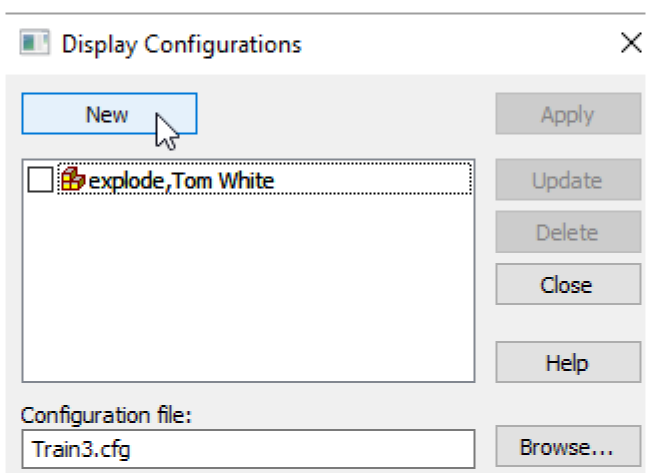


Now that the assembly is exploded save the configuration. This way it will be available for future use.

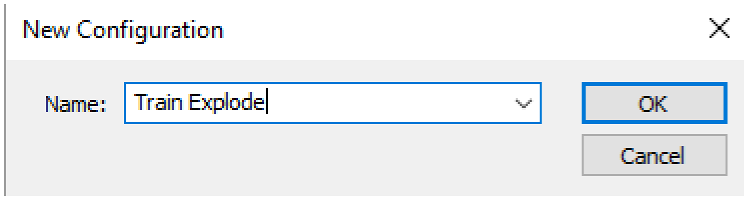
Select the Display Configuration icon from the ribbon.



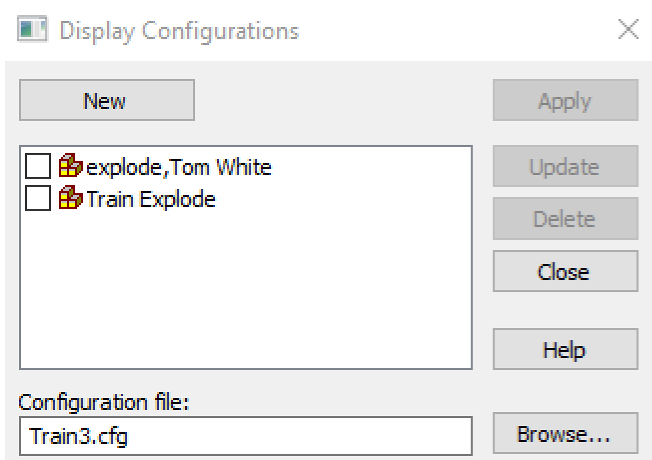
In the dialog box select New.



Type a unique name for the explosion.



Select OK. It will appear in the Display Configurations dialog box.



Select Close.

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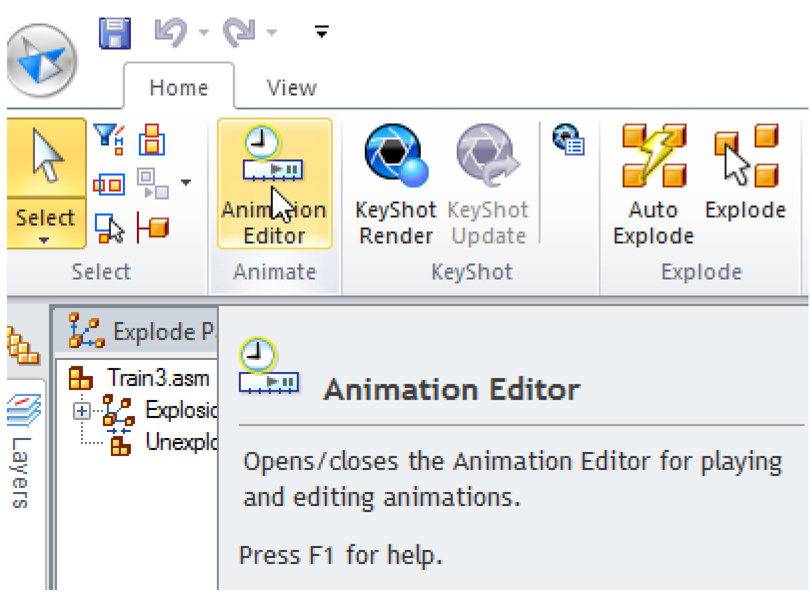
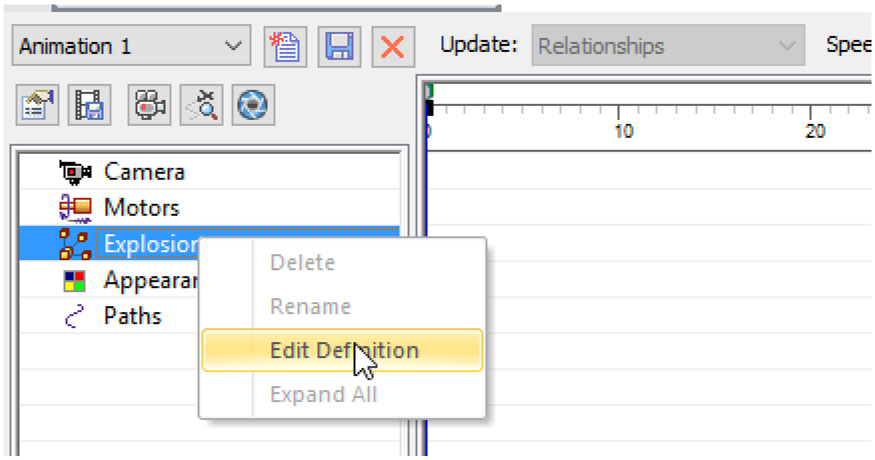
Animating the Explosion

Animation is a useful tool to display information to others. Select the icon for the Animation Editor from the Animate section of the ERA ribbon.

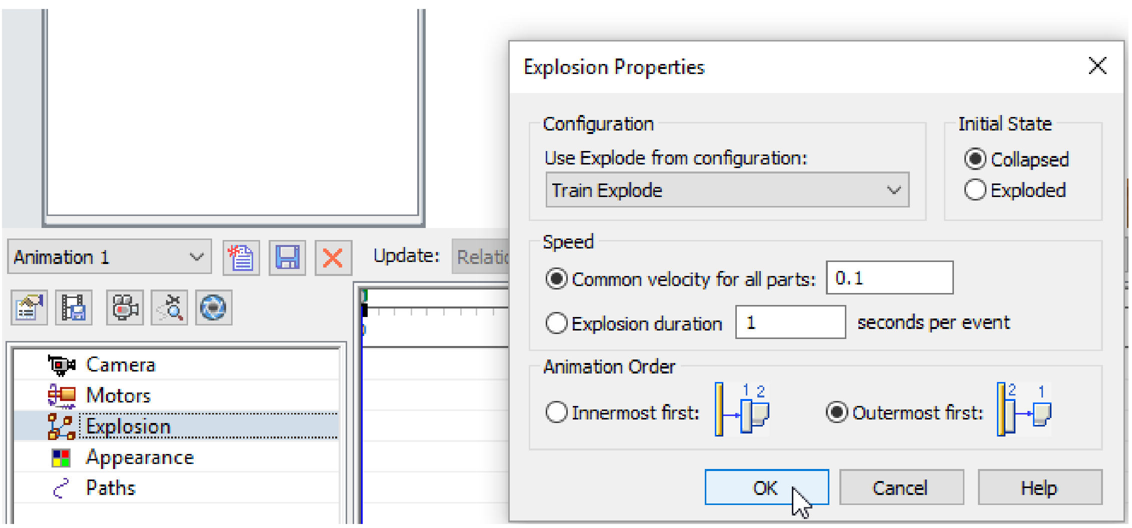


The Animation Editor appears on the screen. We will animate the explosion.

Right click on the Explosion in the path finder. Select Edit Definition.

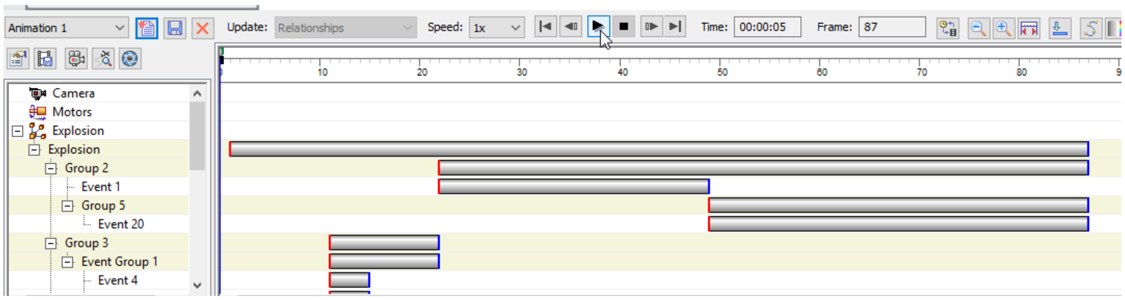


Select the name of the saved configuration. In this case we will watch the explosion happen from the assembly so set the initial state to Collapsed. Select the Outermost first.



Select OK.

In the Animation Editor select Play. Watch the explosion animation.



Close the ERA. Save the assembly.

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Exploded Views

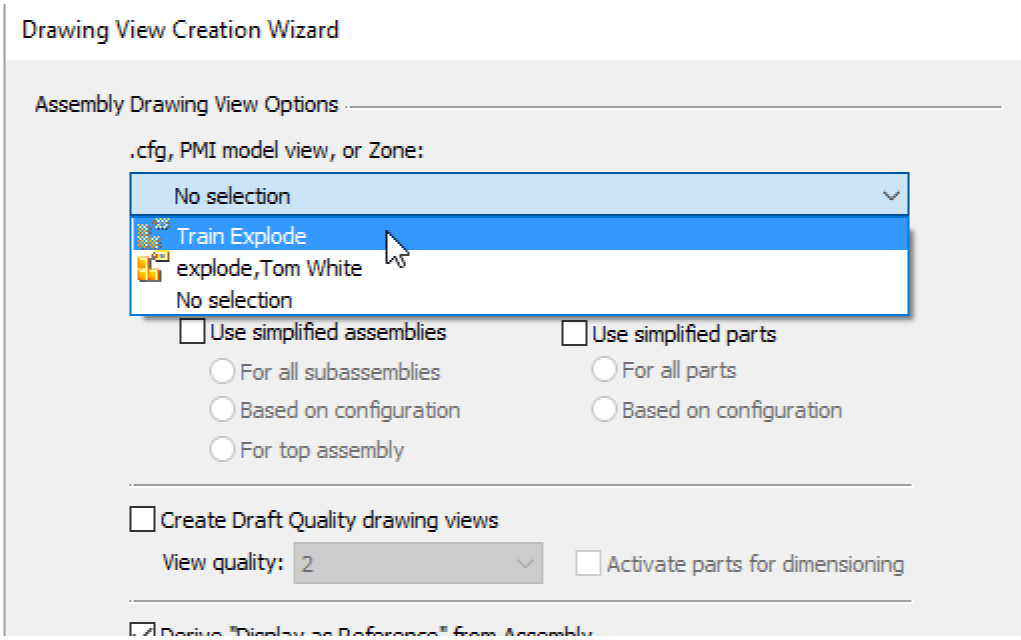
Exploded views are an important part of a set of working drawings. This drawing shows all the components that make up an assembly and how they go together. These drawings are also used in brochures showing all the parts in a parts list and the order in which they should be assembled.

Create a new sheet in your engine working drawings set. Apply the background you designed.

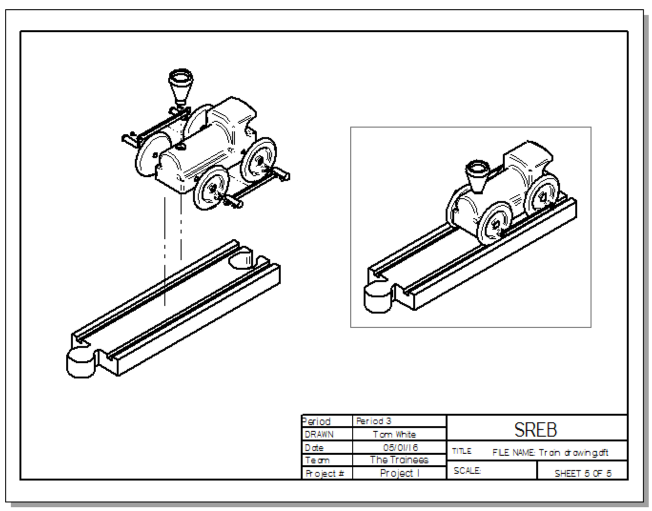
Drag a copy of your assembly from the library to the sheet.

Change the Scale to 1:4 and then select the Drawing View Creation wizard. This will allow us to configure how you want to see the assembly.

In the wizard click the down arrow next to the window that asks for .cfg, PMI model view, or Zone. Select the configuration saved when exploding the assembly.



Select OK at the bottom of the dialog box.



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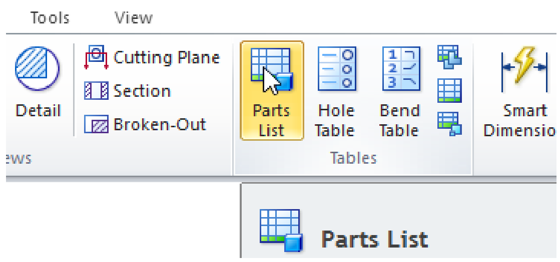
Bill of Materials/Parts List

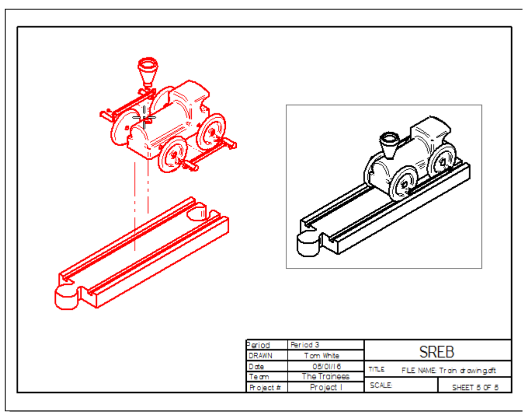
People will look at a drawing and can identify the component they are looking for. They might need to know what the name of the part is or what the material is. The bill of materials allows the user to access data that you determine necessary.

Select Parts List from the tables section of the home ribbon.

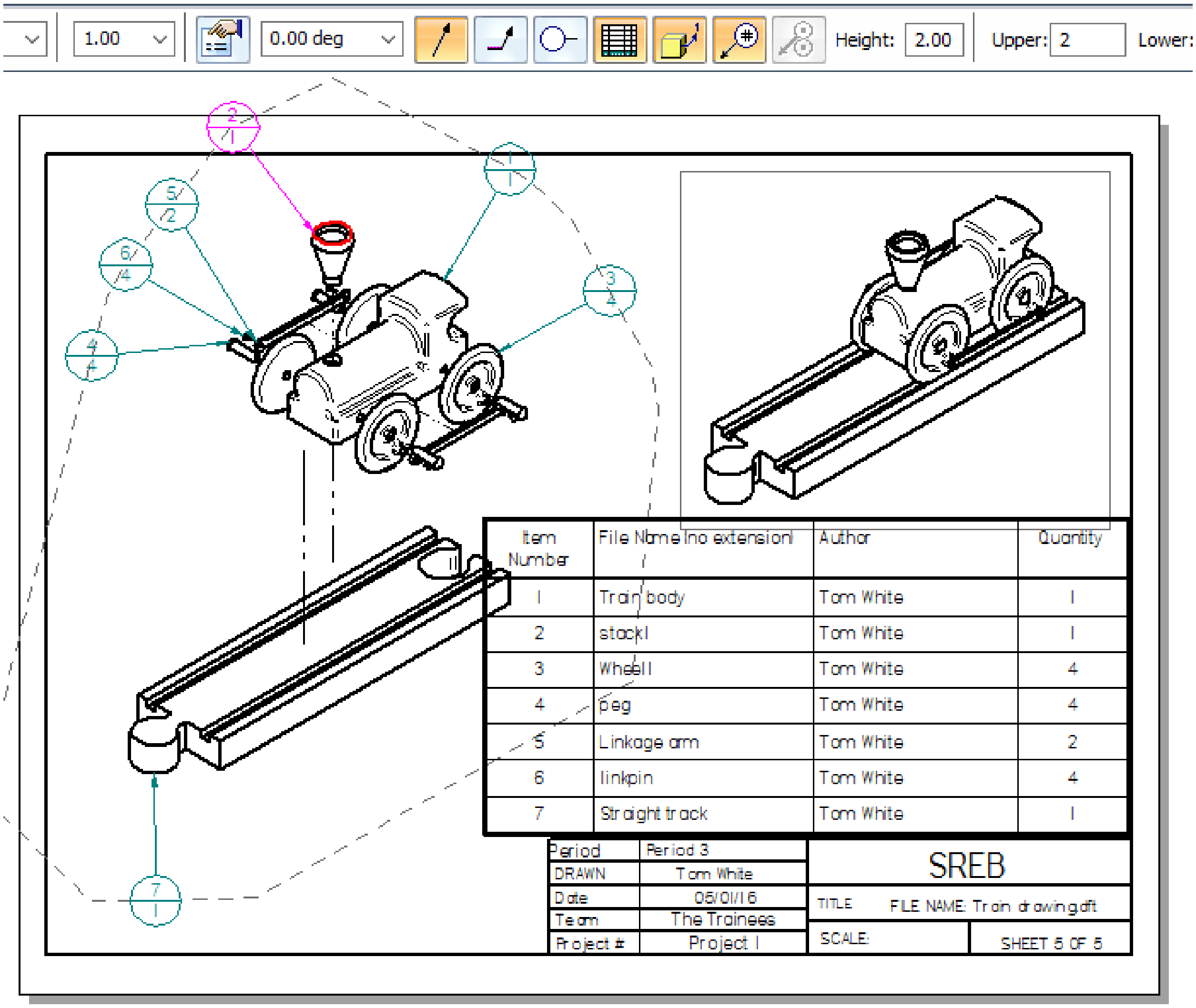


This will create the table from the components in the assembly and apply a balloon to the pieces for easy identification.

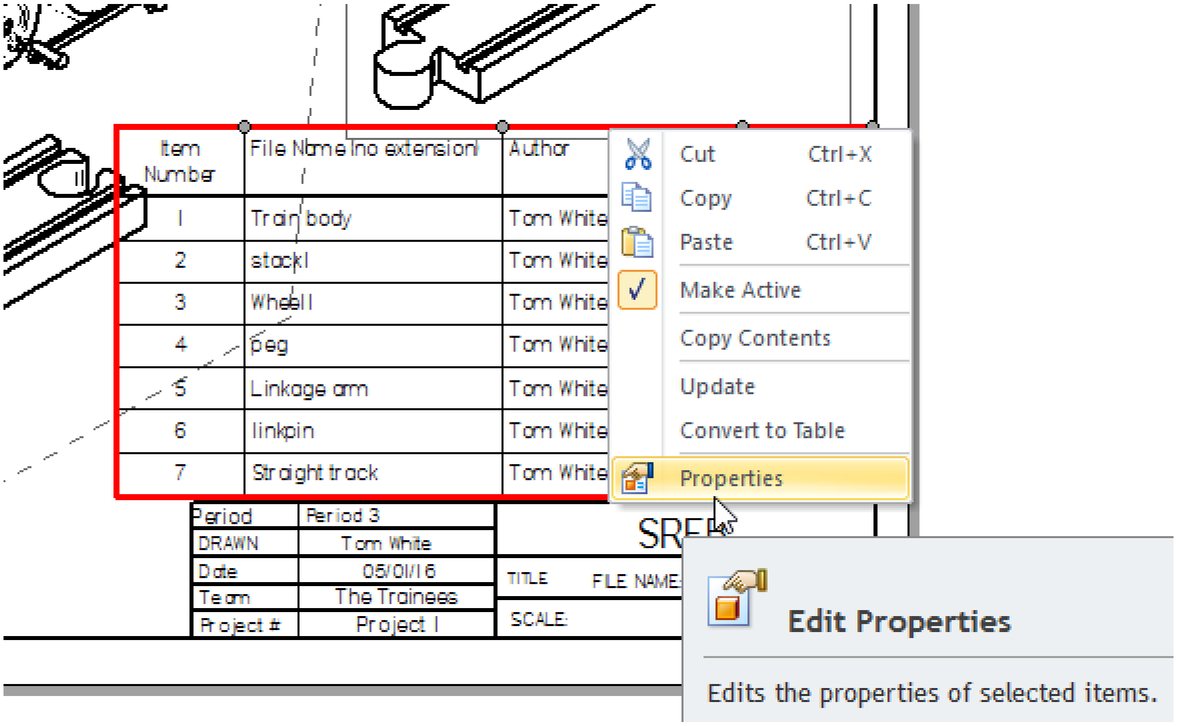
Click on the Drawing View you would like to use.



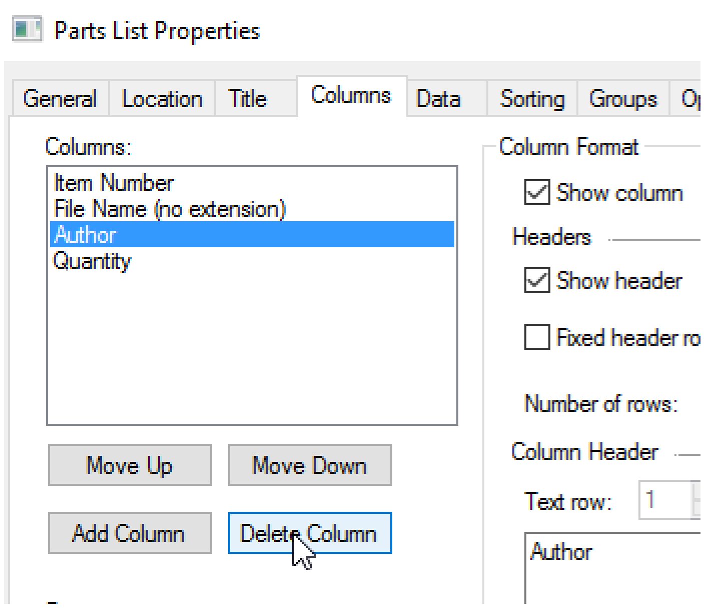
The list will appear as a square. Move the square to an open space on the drawing view.


1.00
0.00 deg
Height: 2.00
Upper: 2
Lower:
Item Number | File Name (no extension) | Author | Quantity
1 | Train body | Tom White | 1
2 | stack1 | Tom White | 1
3 | Wheel1 | Tom White | 4
4 | peg | Tom White | 4
5 | Linkage arm | Tom White | 2
6 | linkpin | Tom White | 4
7 | Straight track | Tom White | 1
Period | Period 3
DRAWN | Tom White
Date | 05/01/16
Team | The Trainees
Project # | Project 1
SREB
TITLE
FILE NAME: Train drawing.dft
SCALE:
SHEET 5 OF 5

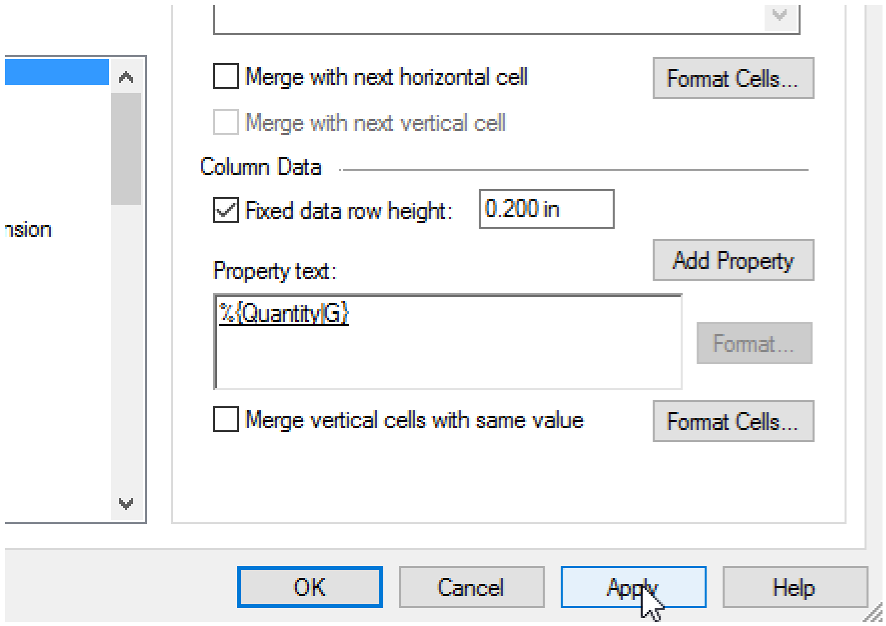
Things are having trouble fitting on the page. Left click on the table to highlight it. Right click on the border and select properties.



In the dialog box select the tab for columns. Since we do not need to see the author displayed remove it from the columns by highlighting it and selecting delete column.

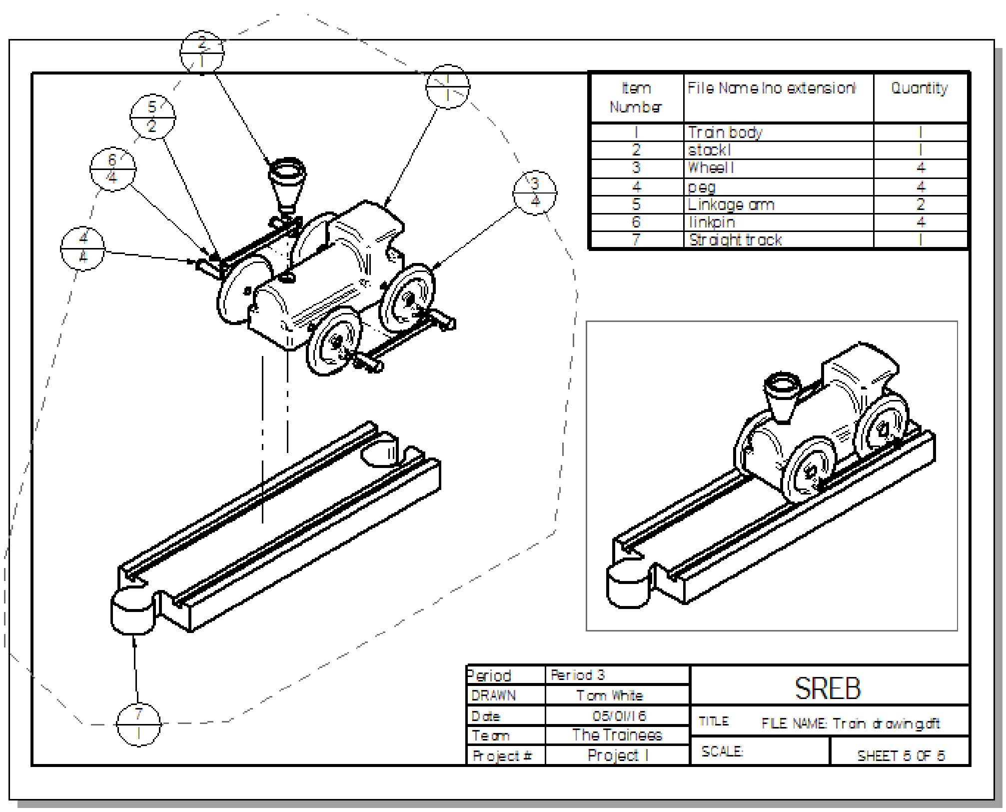


In the lower left hand corner of the columns tab find a section for column data. Place a check in the Fixed data row height and set the value to .200.

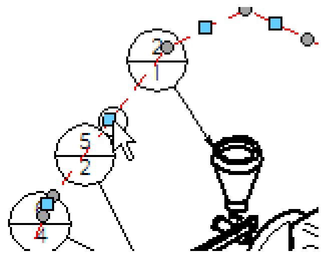


Select Apply.

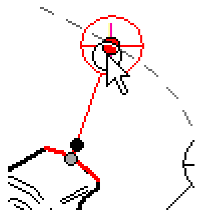
Move the table to a location where it is out of the way.



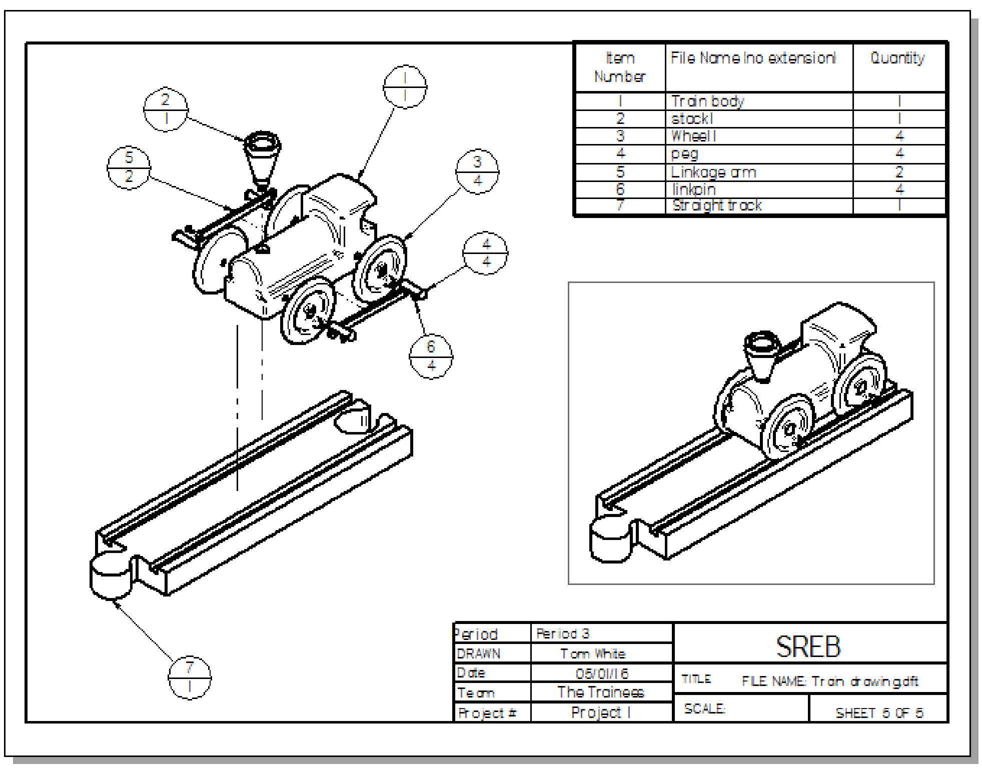
As shown, some of the balloons are not in the paper space. There is a dotted line that controls where the balloons appear. Click on the dotted line and you will observe blue grip points. Clicking on a blue dot will allow you to reset the position of the dotted line.



Clicking on the center of a balloon will allow you to drag just the one balloon along the dotted line.



Move things around the drawing to make them easy to read. Save your work.



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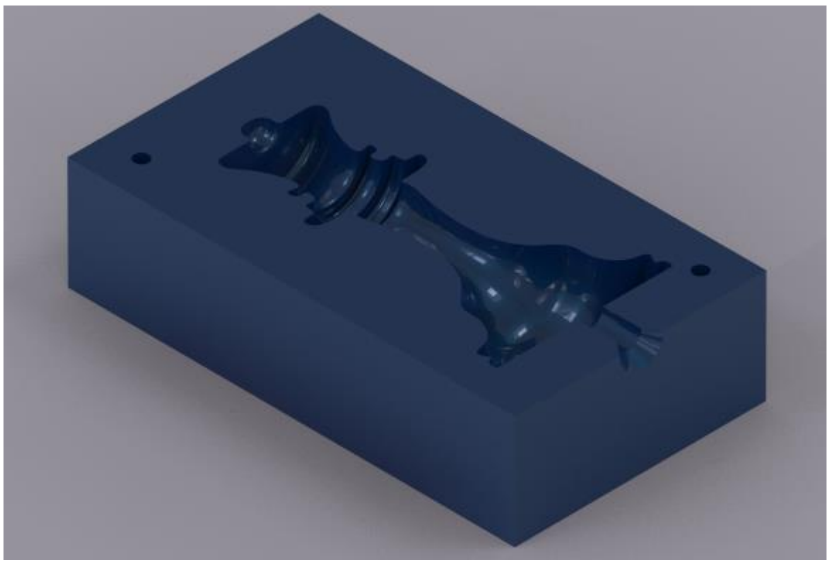
Working with Bodies

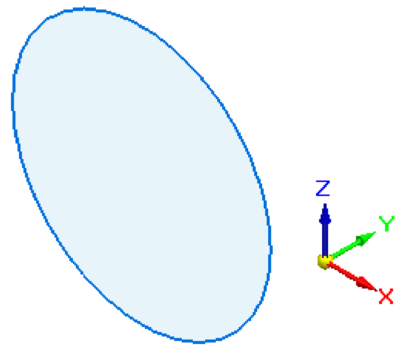


A normal part file only contains a single solid body. Most of the time if you want multiple parts an assembly is used. There are times when a second body is used to make changes to a part. For example, if you wanted to create a solid with a particular shape removed, the second part would be added to the file and then a Boolean function would be used to remove it. You will see this in molds for example. The same idea holds true if you had an existing part and wanted to add features from another part. If you had an existing part design and wanted to add a base from a Lego™ block, the part could then be utilized to connect different building sets.

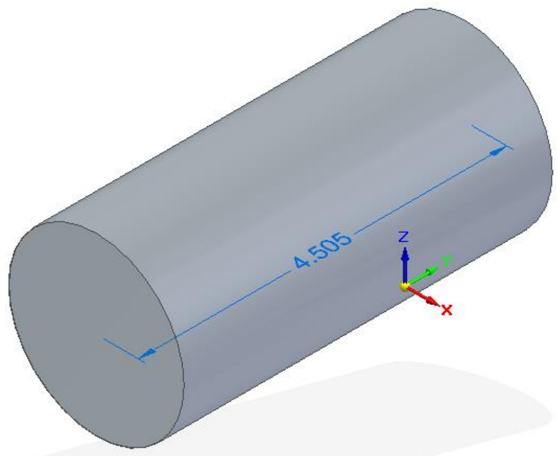
There are some basic skill sets that make this process easier. This exercise is designed to introduce some of the ways bodies can be utilized. The Path Finder is indispensable for following what is going on with your various drawings.

Begin a new part file. This is an exercise where the size and positioning of the shapes is not important.

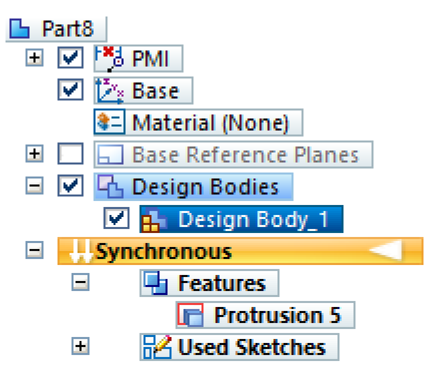
Draw a circle on the XZ plane



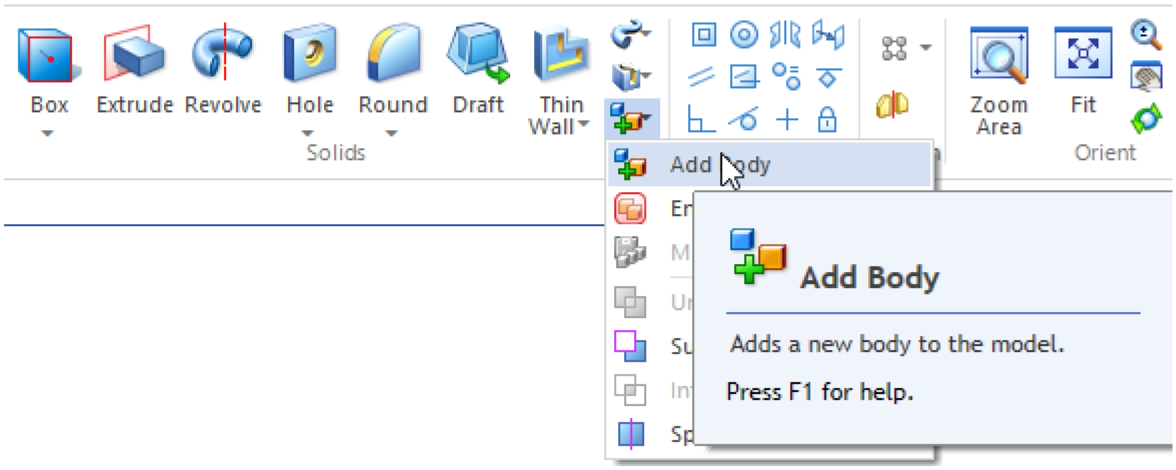
Extrude the circle into a cylinder.



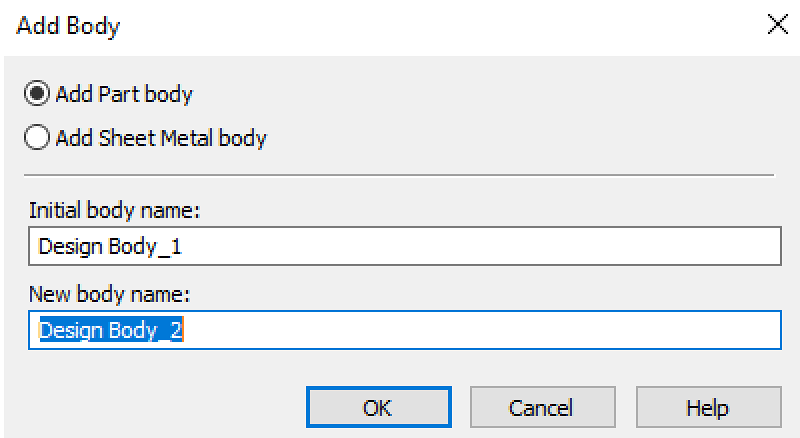
Check in the Path Finder. Under Design Bodies there will be a listing for Design Body_1. This is a default name for the first body in a part.



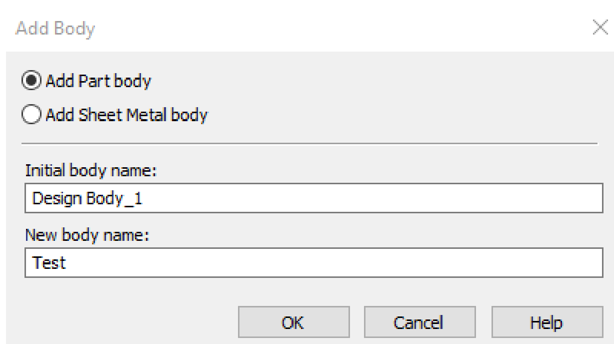
On the Home ribbon, in the solids section, select the Add Body command from the Bodies menu.



The dialog box opens and the new body name has the name of Design Body_2.



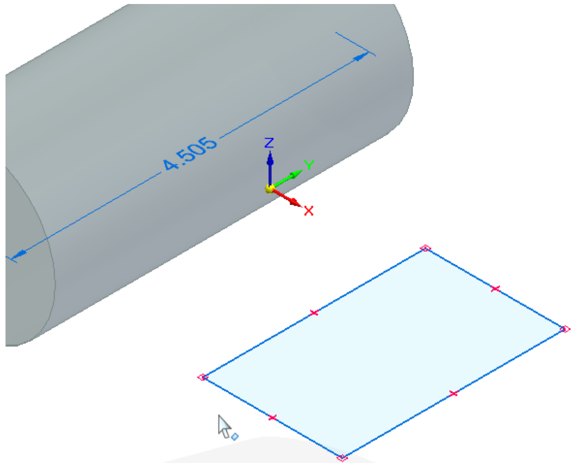
Rename the design body if you wish. In this example it is renamed Test.



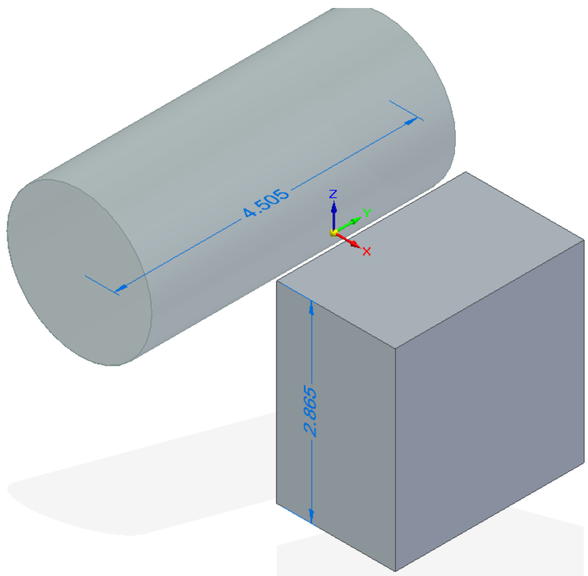
Select OK.

Nothing appears to happen but anything drawn now becomes part of the new design body.

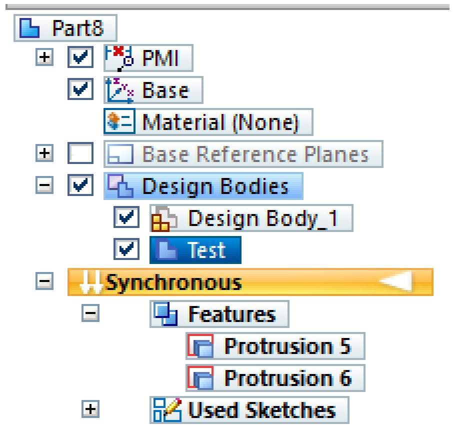
After selecting the Add Body command draw a rectangle on the XY plane.



Extrude the rectangle.



Checking the Path Finder reveals the second design body has been added using the name assigned.



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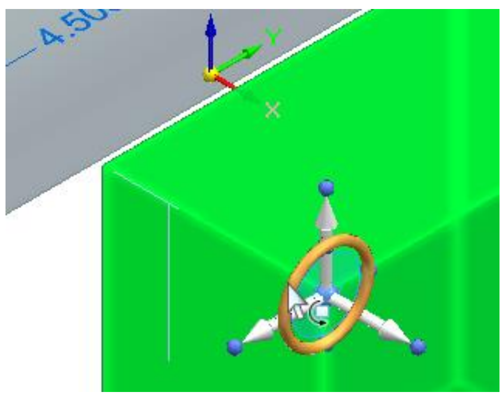
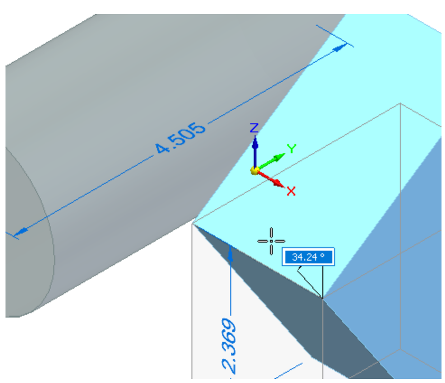
Moving Parts

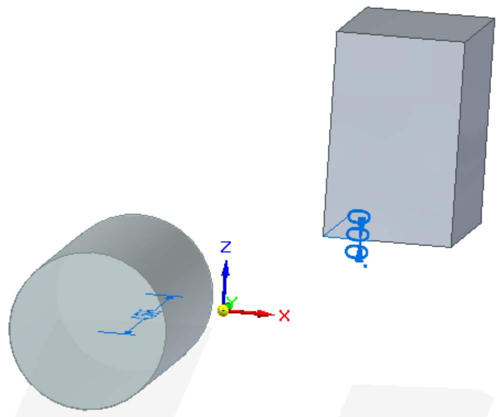
By highlighting one of the design bodies in the Path Finder, the part will highlight the Design Intent window and the steering wheel appears on the part. Uncheck everything on the Design Intent. We can now move and reposition the parts. Select the steering wheel similar to the picture below.



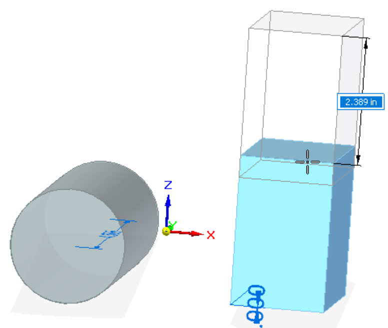
This will allow rotation of the part in relationship to the other part.



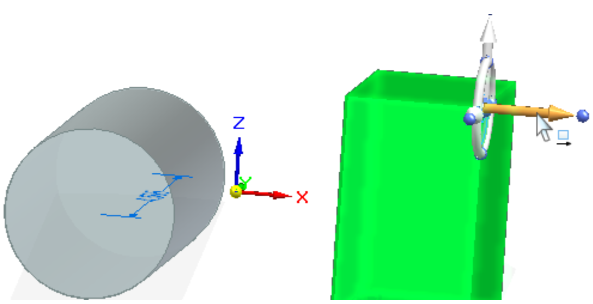
Enter 90 which will rotate the part counter-clockwise 90 degrees.



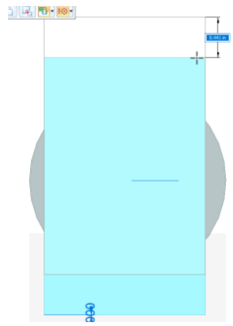
Highlight the part in the Path Finder. Click the X, Y, or Z arrow to select the desired direction. Drag the arrow to move the part to a new location in reference to the other part. The goal in this example is to place one part inside the other.



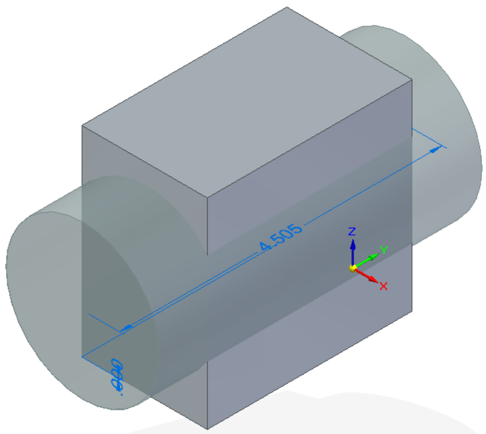
Moving with or against the arrow will take the body different directions. Entering Distances will allow the objects to move a specific amount.



Center the cylinder in the rectangular prism.



Your screen should resemble the one below.



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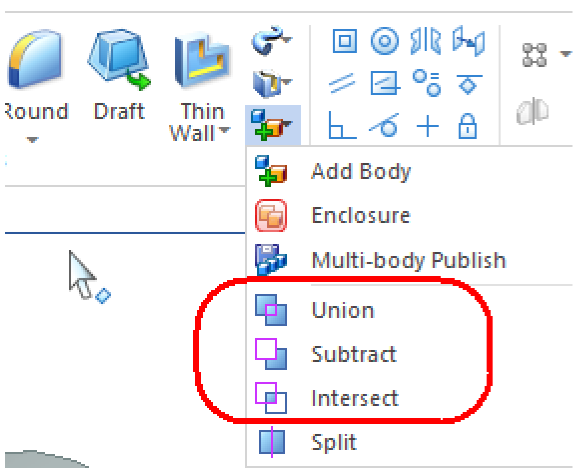
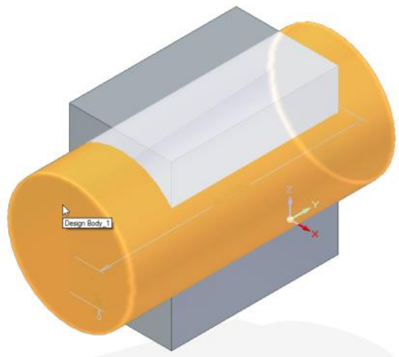
Boolean Operations

There are three main Boolean operations available; Union, Subtract and Intersect.



This section of the exercise will show how the functions work.

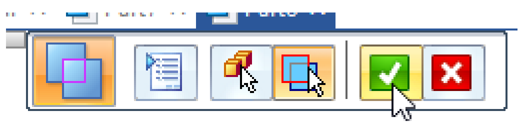
Select Union first. Highlight one of the bodies. The target is the first one you select and the one you want the changes to show.



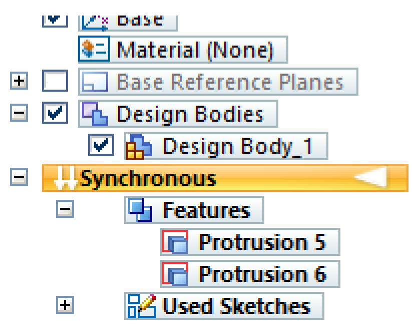
Right click to accept your choice.

Now select the other part. This is known as the tool.

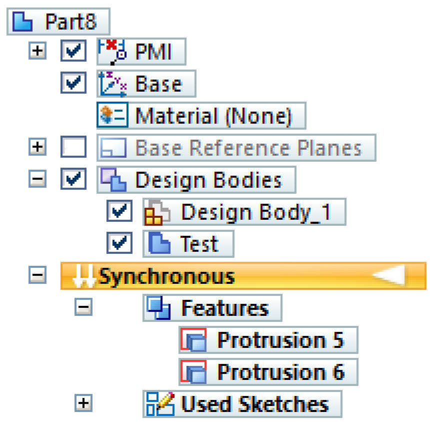
The green check shows up. Check the green check box.



Checking the path finder will show that the two parts have been combined into one.

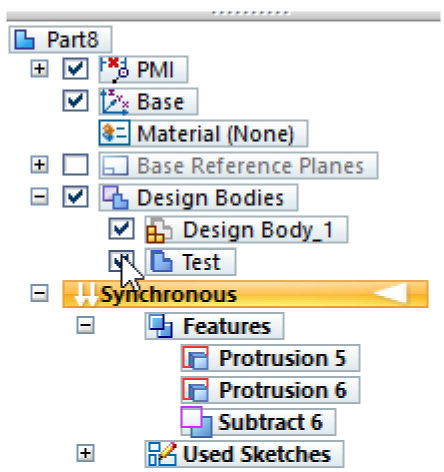


Undo the previous step and you should see the two design bodies again.

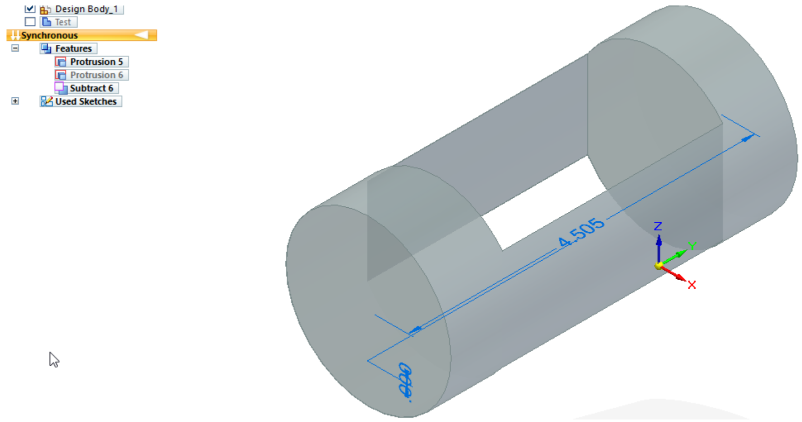


Now select Subtract from the options on the bodies pull down menu. Select the cylinder as the target body. Right click to accept. Then select the rectangular prism as the tool body. Check the green check mark on the subtract tool.

Go to the Path Finder and uncheck the box for Test which was the name of the part we used as the tool body.

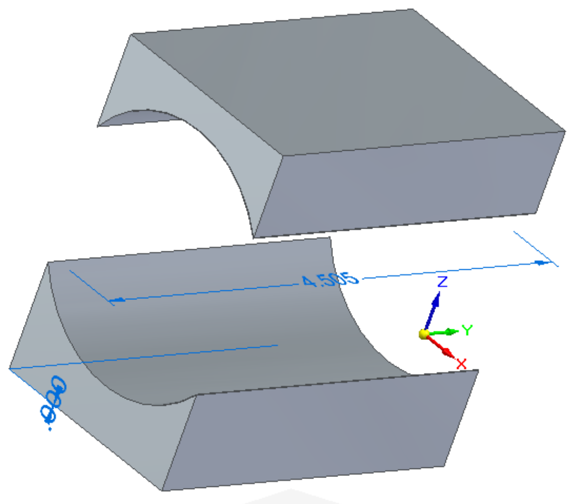


You can then see the results of the subtraction.



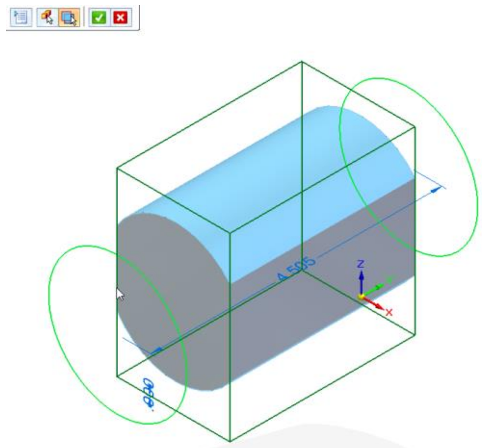
Undo the action. Recheck the second design body so they both show. Now do the subtraction, selecting the parts in a different order. Select the rectangular prism as the target body and the cylinder as the tool. When you are done uncheck the first design body. Yours should look similar to the picture below.

You will see the cylinder has cut the rectangular prism.



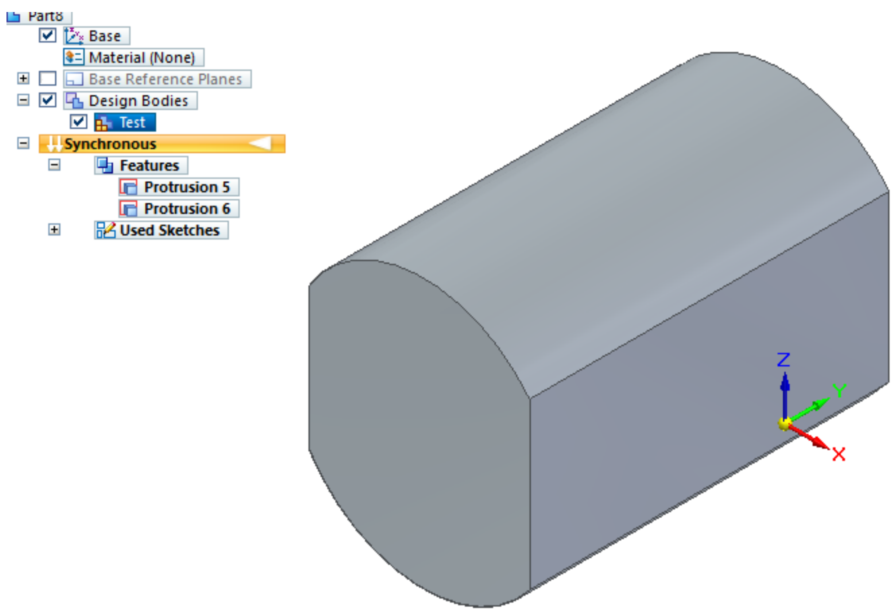
Undo this command

Select the Intersect Boolean tool from the Bodies menu. Highlight one of the shapes. Right click and then highlight the other shape.



Select the green check box.

You will see the results and the design body will be named the first one selected.



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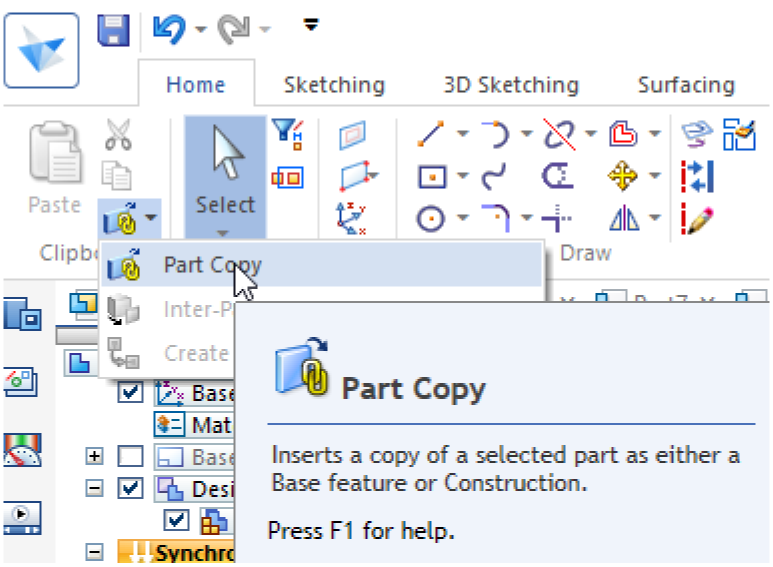
Creating a Two Part Mold

We can use the body tools to create a complex mold from a selected part. In this case we will be using a chess piece created in an earlier project.

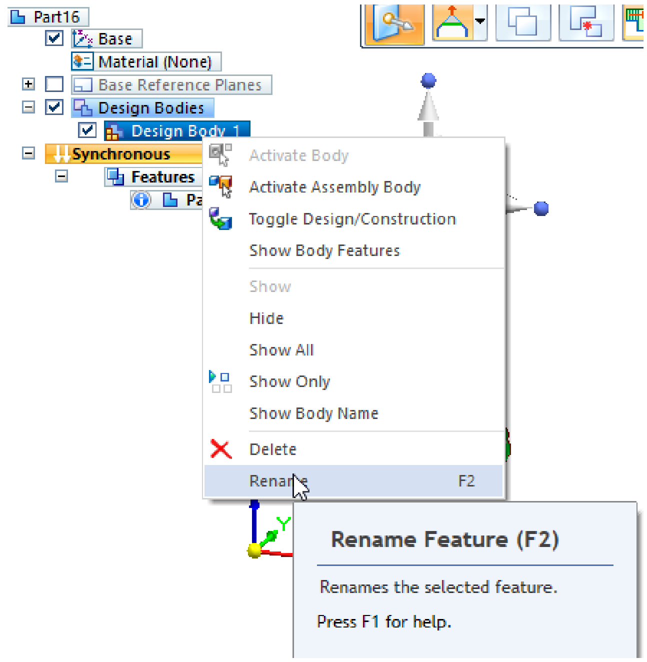
Begin a new part file.

On the home ribbon select the Part Copy command from the clipboard. At the Browse window navigate to the directory where your chess piece is saved. It will appear on the screen.

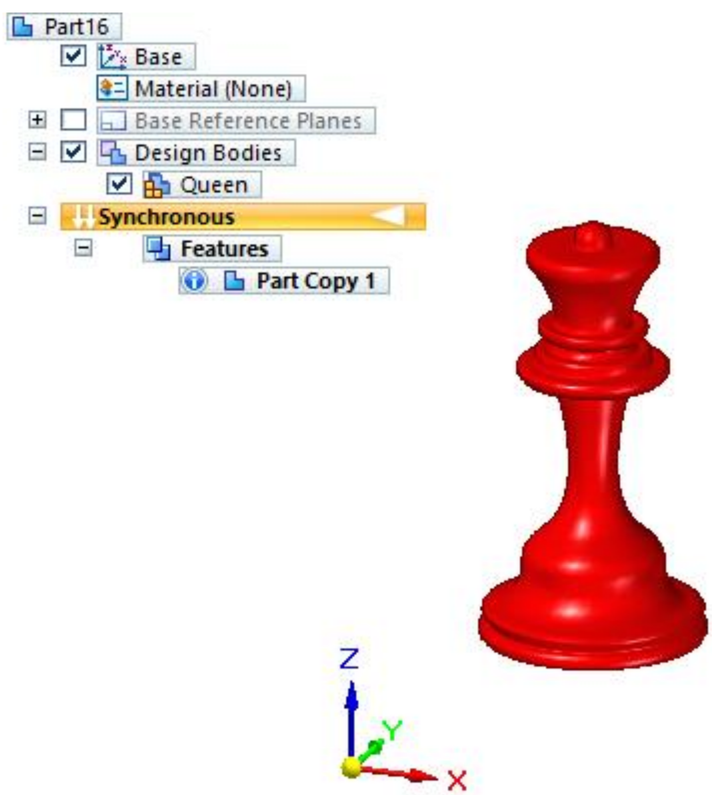


Select finish.

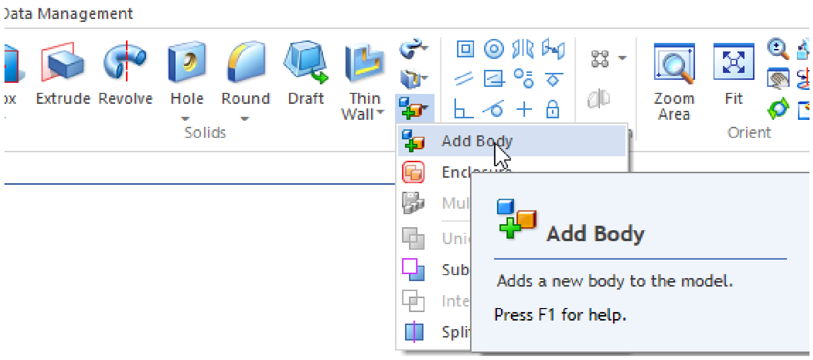
The chess piece appears on the screen and the Path Finder shows a design Body. If you right click on this you can select the option to rename the design body.



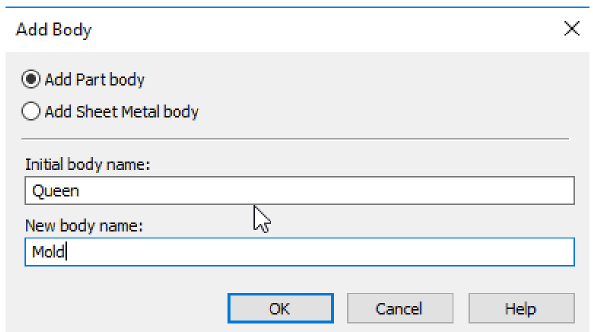
This will be easier to see and find later.



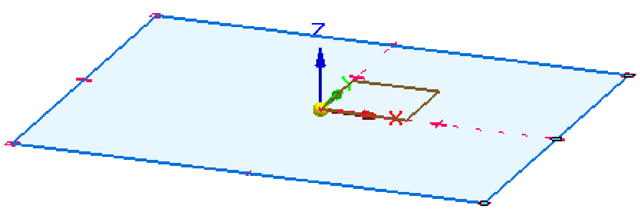
From the bodies menu in the solids section select add body.



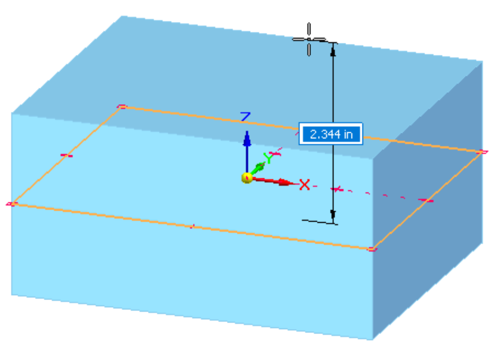
Give the new body a name. In this example Mold is used.



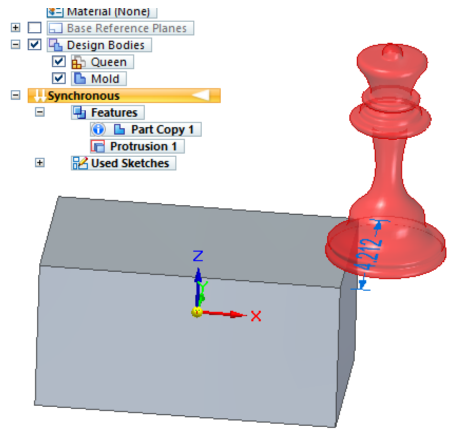
Draw a rectangle whose center is at the origin in the XY plane.



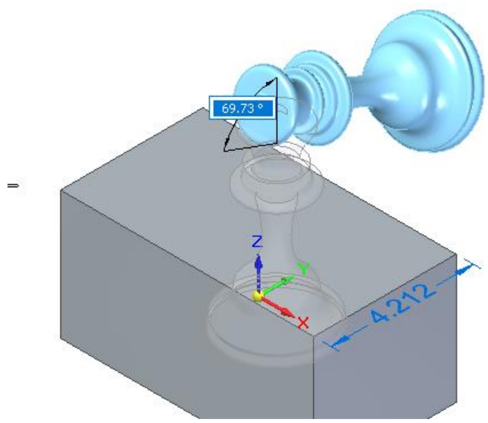
Extrude the rectangle symmetrically so the middle of the plane is on the XY plane.



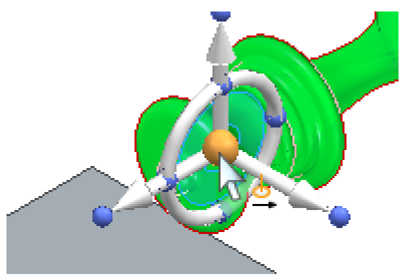
The queen and mold are now in the Path Finder.



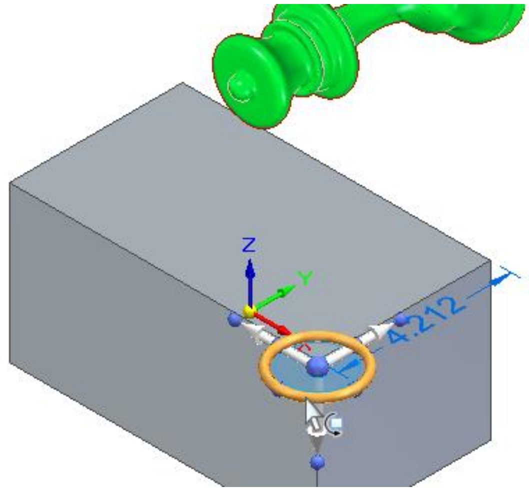
We can change the orientation and move the part to the middle of your block. Highlight the queen in the Path Finder and use the steering wheel torus and arrows to move the queen into the block. By selecting the torus on the steering wheel we can change the angular position of the piece.



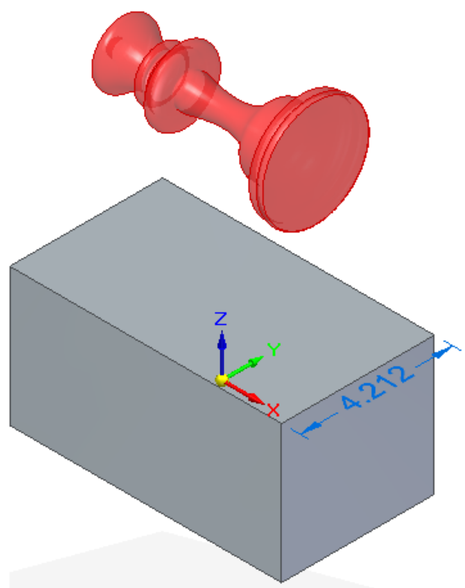
By clicking on the ball in the center of the wheel, you can control the orientation of the steering wheel by selecting other geometry.



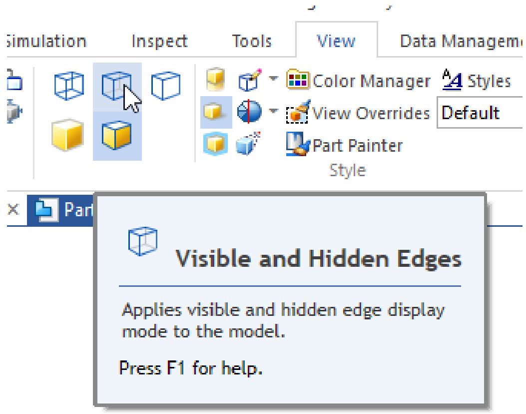
In this example a vertical line on the mold is chosen to position the steering wheel.



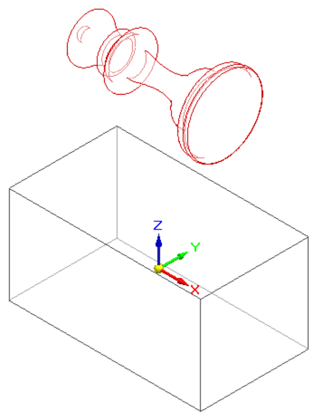
We can then use the steering wheel torus to reorient the chess piece to the mold.



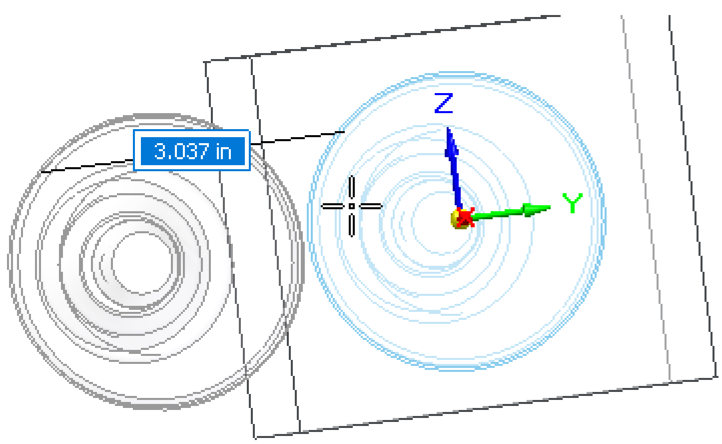
It is now possible to move your piece to the center of the mold. It may be necessary to adjust what shows on the screen to see what you are doing. Go to the View tab and select Visible and Hidden Edges.



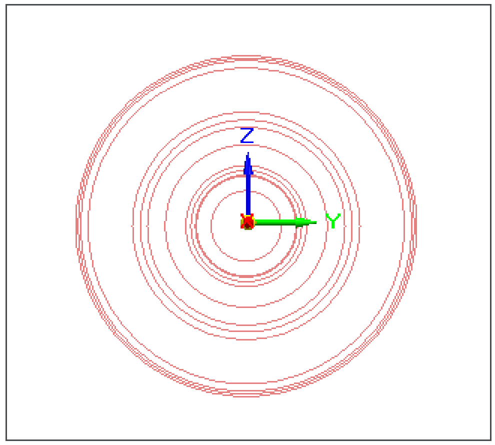
While not perfect, this might be easier.



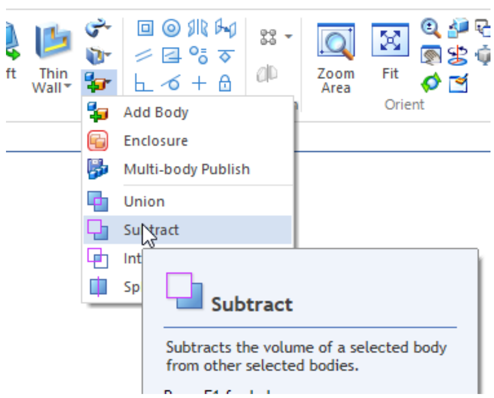
You will have to change views several times to see what is happening.



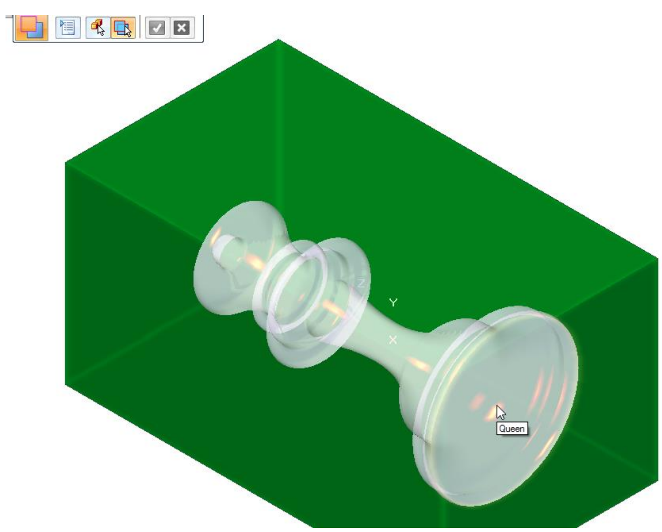
Spend time until the Queen is centered in the mold.



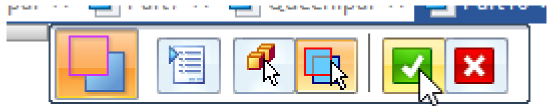
From the Bodies menu select Subtract for the Boolean option.



Select the mold for the target body. Right click and then select the queen for the tool.



Click the green check to accept.



Since we drew the mold block right on the origin we can use the origin plane to split the part.

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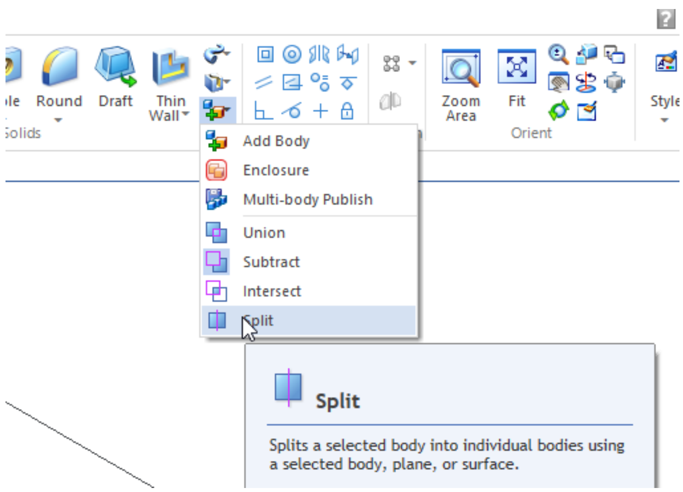
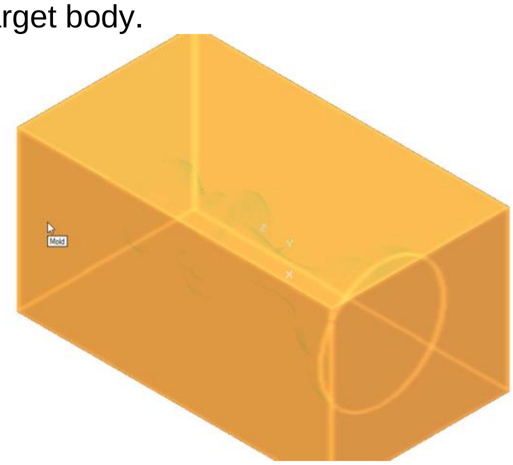
Splitting the Part

Select split from the bodies menu.

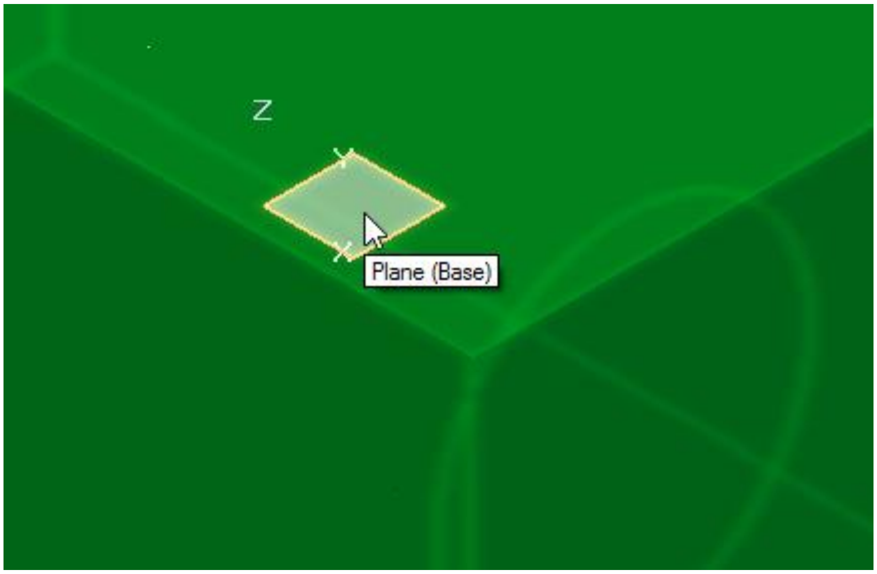


Select the mold for the target body.

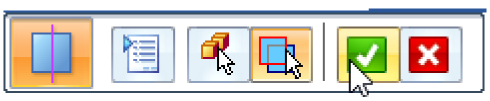


Right click to accept.

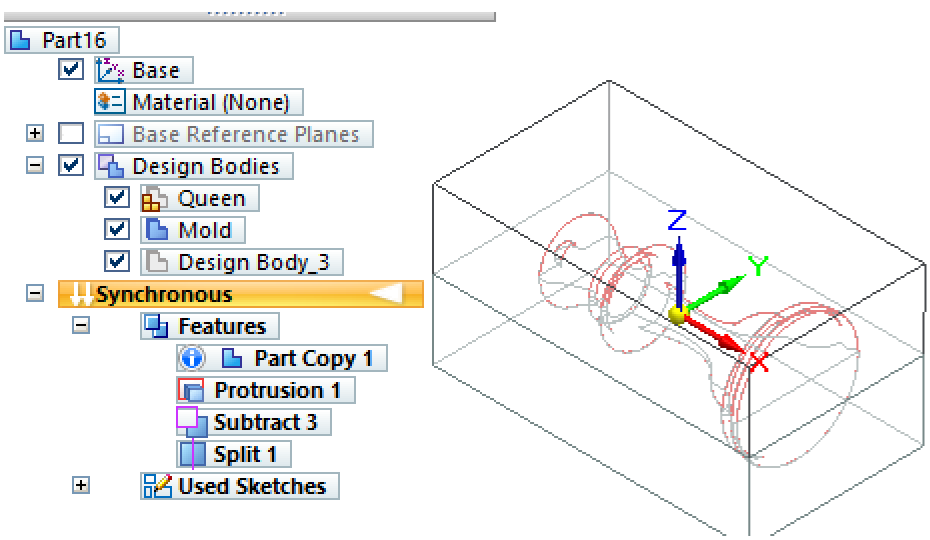
For the tool move the cursor to the origin and select the XY plane.



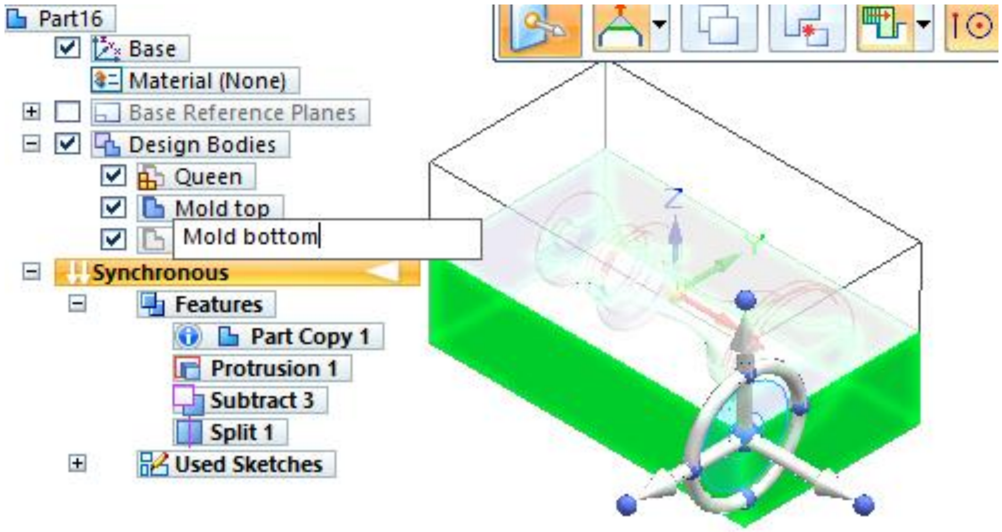
Select the green checkmark.



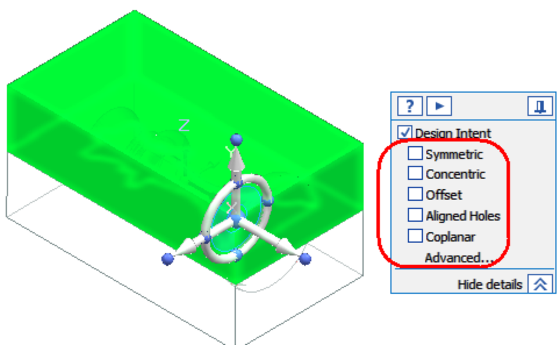
There should be a line around the mold and an additional entity in the Path Finder.



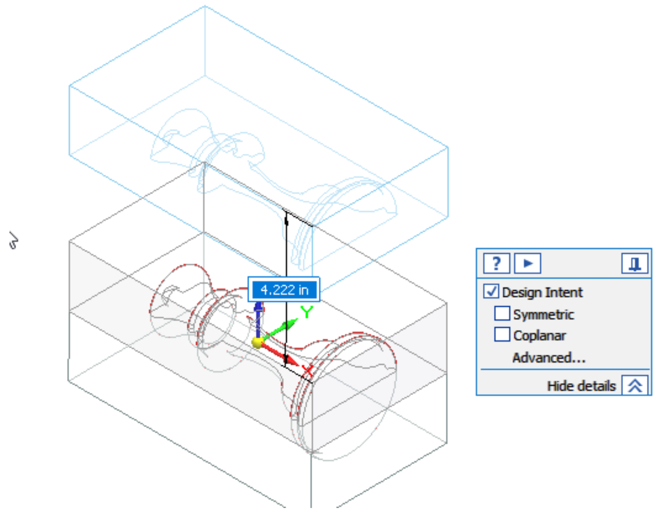
Rename the mold pieces to Mold top and Mold bottom.



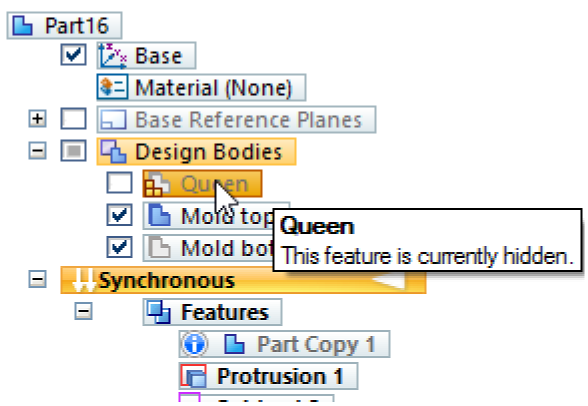
Highlight the mold top in the Path Finder. You will see the Design Intent appear. Uncheck the boxes.



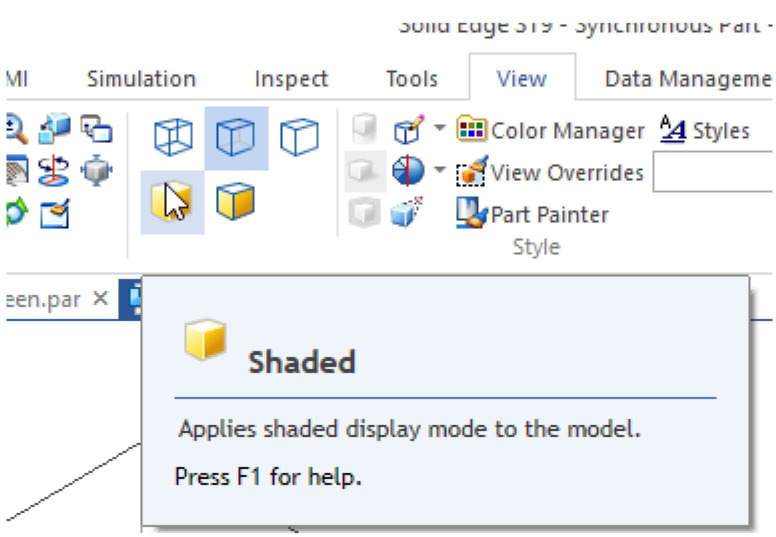
Grab the upper arrow and move the top of the mold in the upper direction.

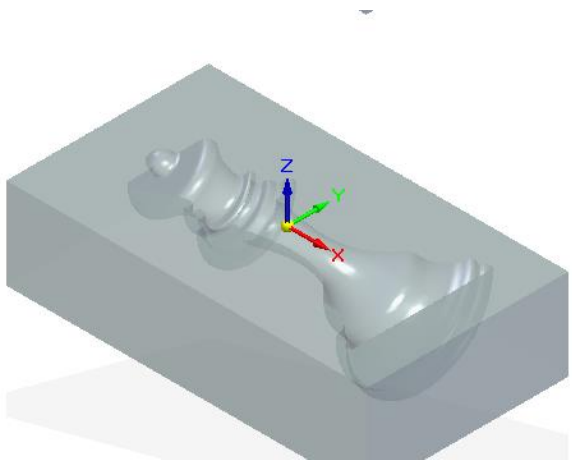


Uncheck the queen in the path finder.

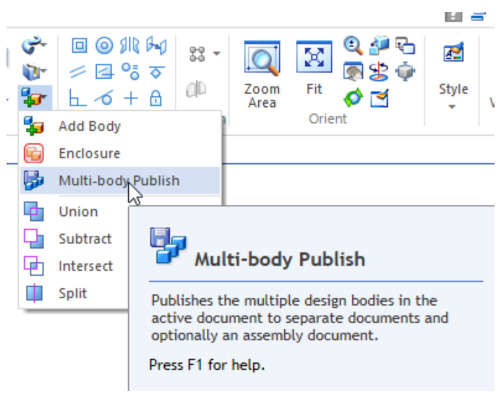


Return to the view tab and change the view back to shaded.

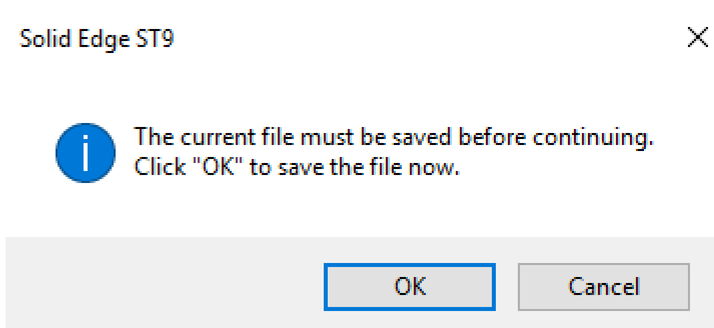




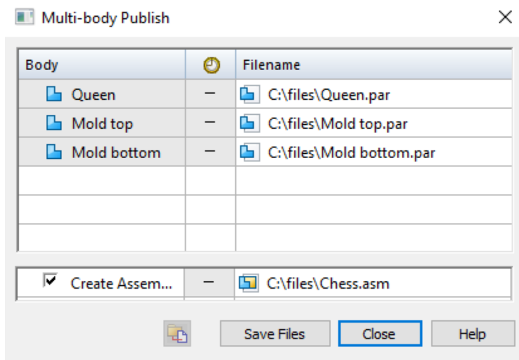
From the Bodies pull down menu, select the option for Multi-body Publish. This will save the mold pieces separately so they can be used in assemblies.



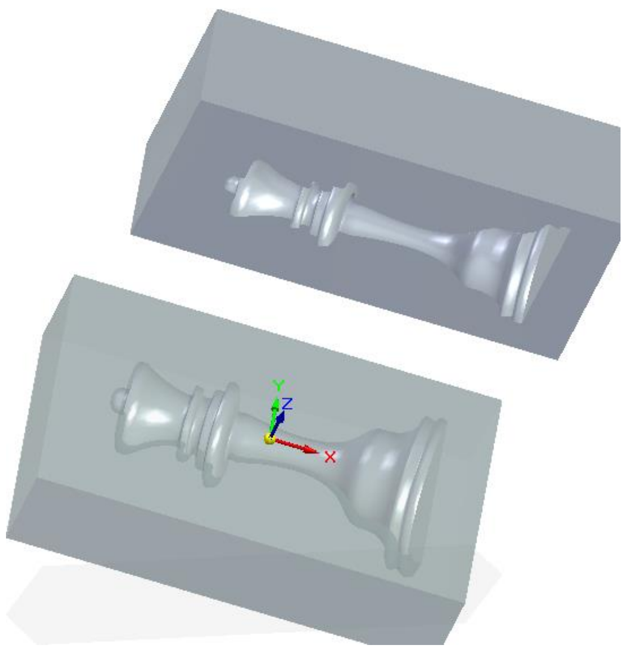
If you haven't saved the part yet you will see a warning. Select OK.



This will bring up the dialog box. Select where to save the files.



Select the save files button. Select close.



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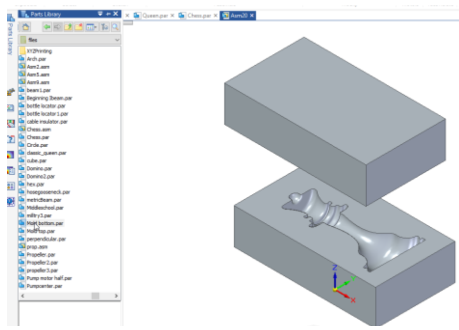
Finishing the Mold

Begin a new assembly.

From the Library, pull your mold top and mold bottom to the screen.



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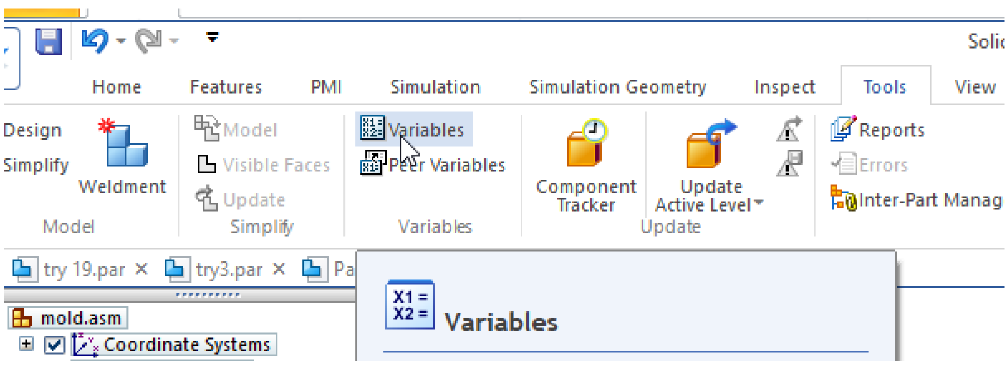
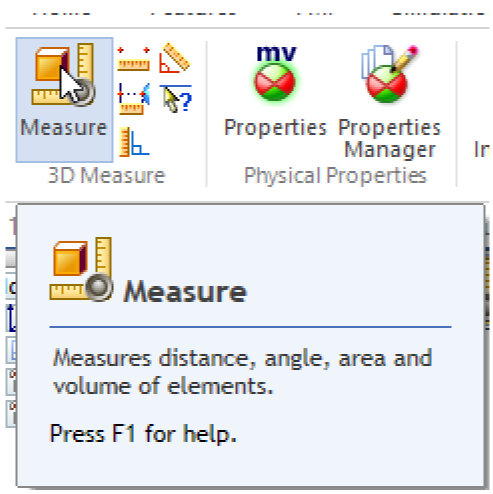
Using the Inspect Tools

You will need to know some basic information about the parts.

From the Tools menu select the Variables command. Leave the Variables window open.

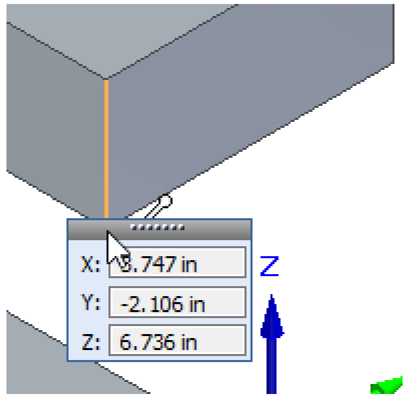


From the Inspect tab on the 3D measure section of the ribbon select Measure.

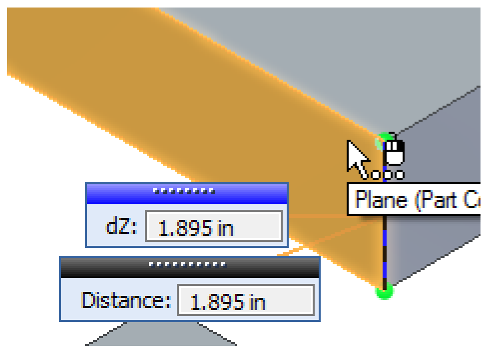


Measure the thickness of each part of the mold. Record your data in your engineering notebook.

Select the endpoint of one of the mold pieces.

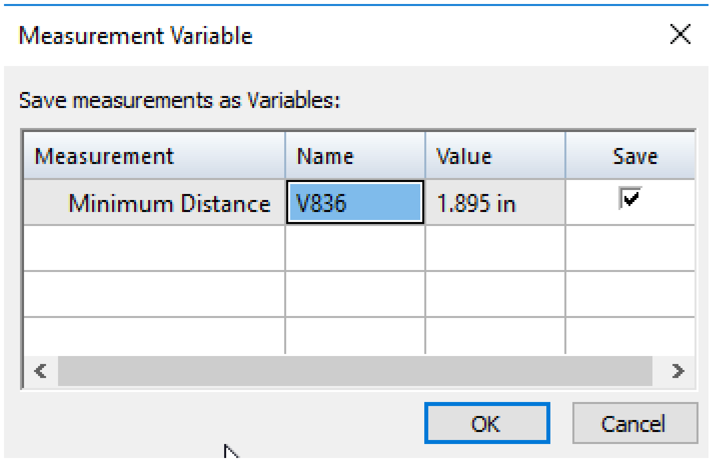


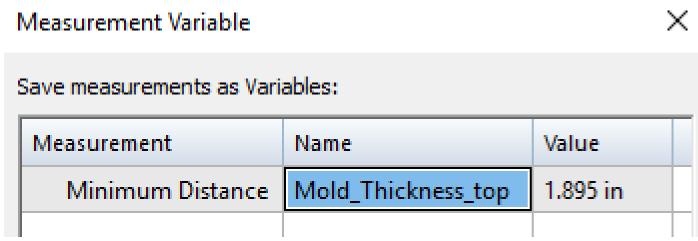
Select the point above the first.



You now know exactly the thickness.
On the measurement select the element for create a variable

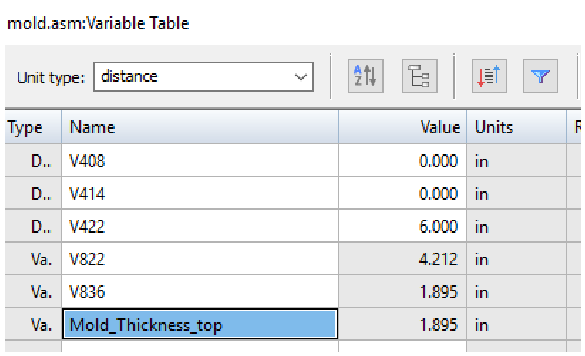
The dialog box appears. Change the name of your variable to something like mold thickness so you can find it again if you need.



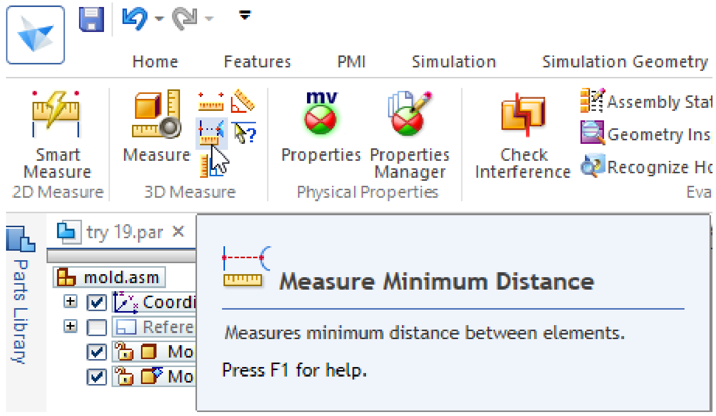


Select OK.

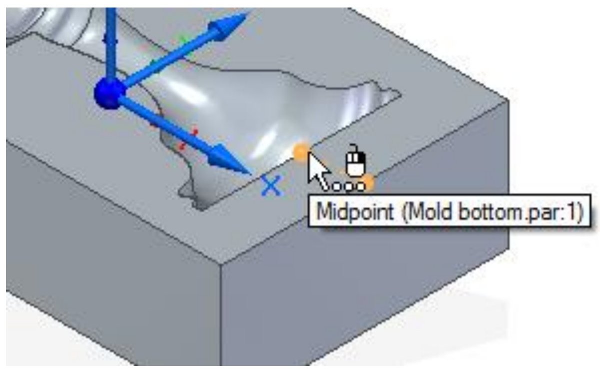
Check the Variable table to see that the measurement is there.



Check the distance from the edge of the mold to the base of your chess piece. In this case we will select Measure Minimum Distance.

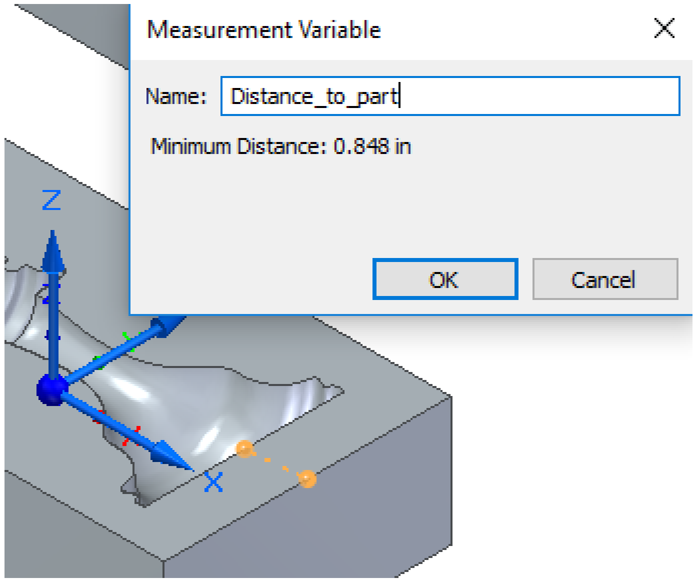


Click around the middle of the bottom line and then the middle of the chess piece line.



Once both spots appear, select the Create Variable button.

When the measurement variable box appears, rename the variable and select ok.



Again the variable table holds the information for future use if needed.

Va.	Mold_Thickness_top	1.895	in		
Va.	Distance_to_part	0.848	in		

Gather any other measurements you might need.

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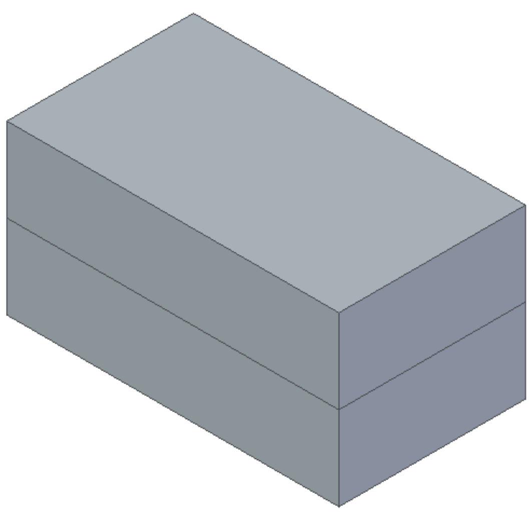
Assembling the Mold

Use Planer Align Relationship to align the mold components.

Then use a Mate relationship to put the mold together.

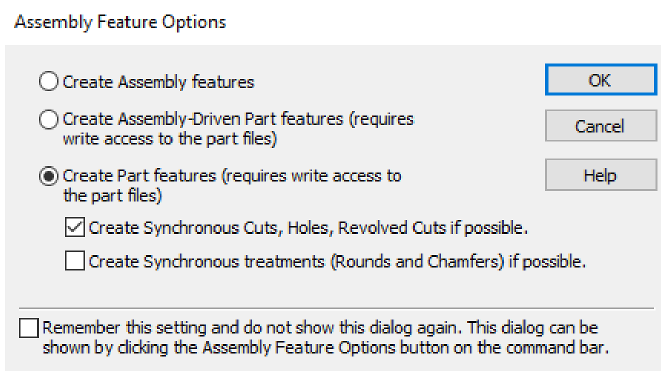


Adding Features

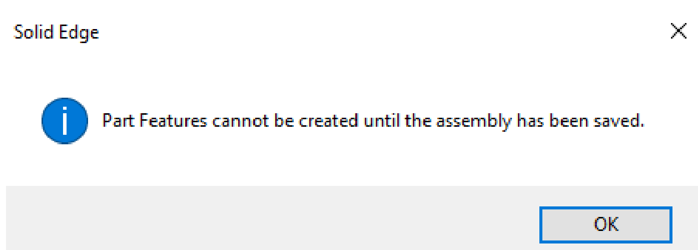
To complete the mold, it is necessary to add a way to inject the desired material into the mold.

On the features tab select Hole from the assembly features.

A dialog box appears about Assembly feature options. Check the one for Create Part features and check the box for Synchronous Cuts, Holes etc.

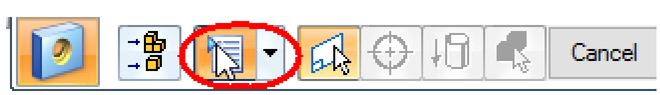


Select OK. A warning may appear stating that “part features cannot be created until the assembly has been saved”. If you see the warning, save the assembly files to a known location.

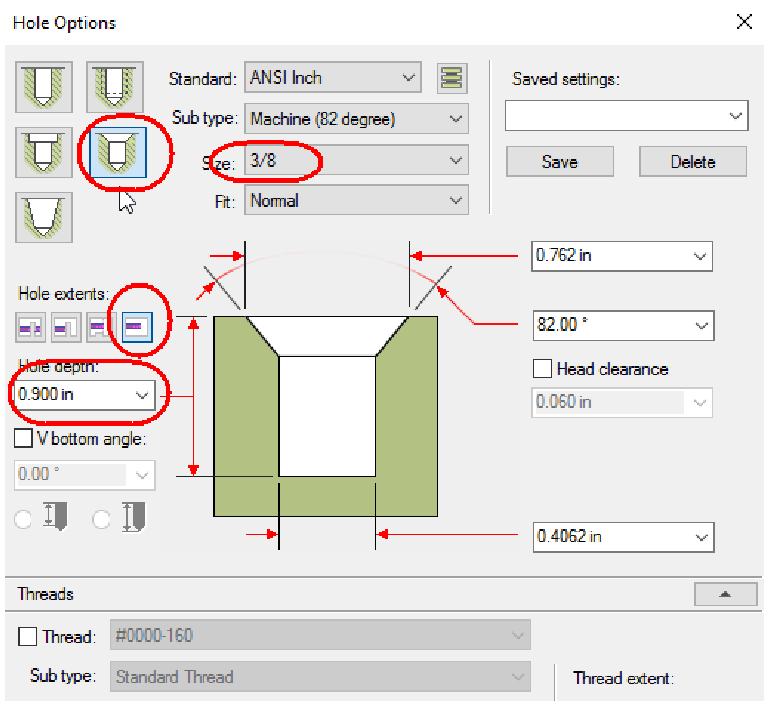


If a warning appears, save the flies and then select the Hole feature again.

Click on the Hole options link.

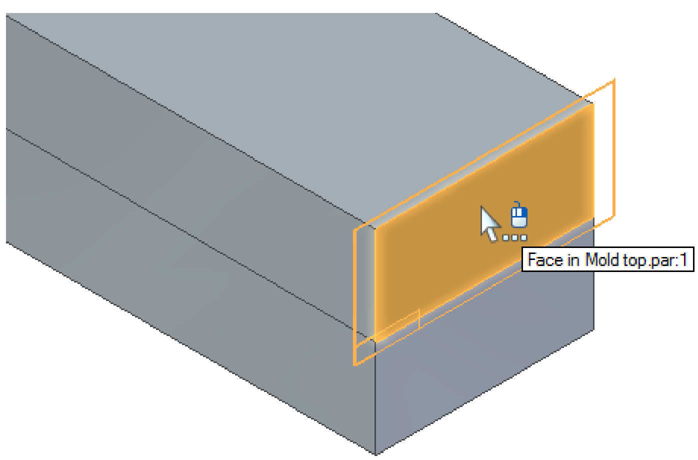


In the dialog box, select the option for Counter Sink. Set the size to 3/8. Set the depth to Finite and select a distance long enough to make it through to your mold cavity. Be sure Thread is unchecked.

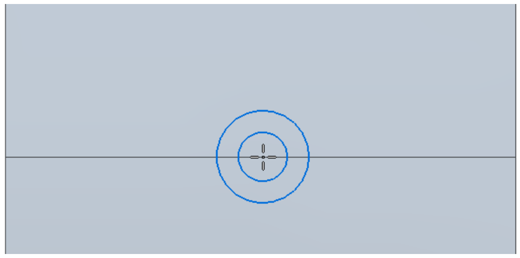


Select OK.

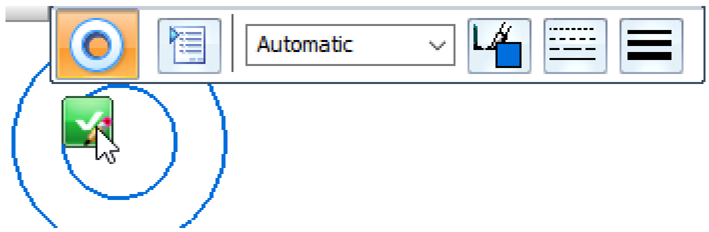
The prompt asks for a planar face for a reference plane. Select the end of the mold.



The view will change to a sketch view. Then select the center of the line between the mold halves.



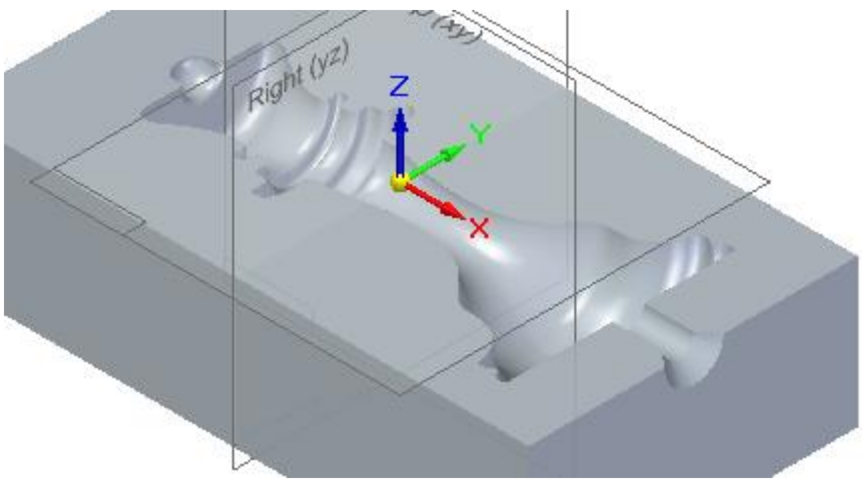
Then check the green check box.



The view returns to the original and the prompt is asking which way the hole should go. Be sure to select the inside of the mold.

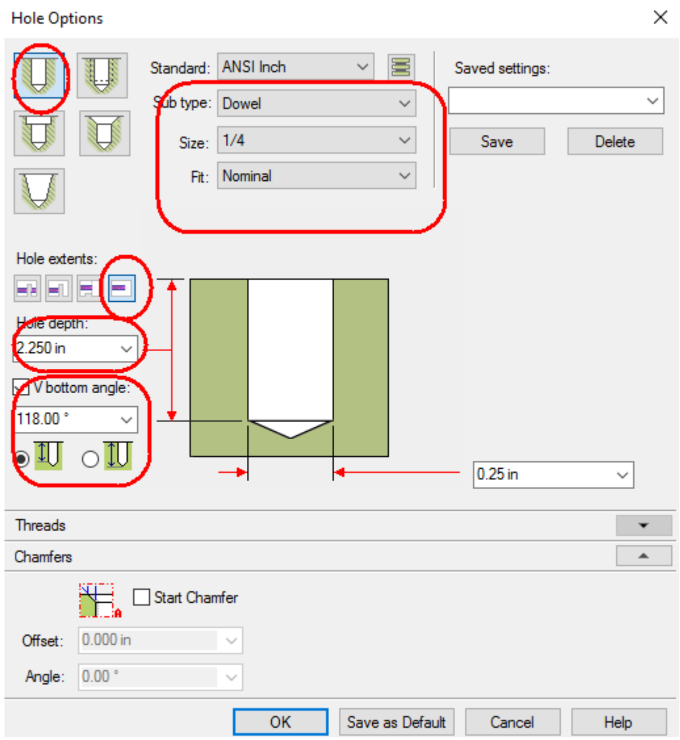
Then select the green check box on the tool. The hole will appear. Save the assembly.

Once the assembly is saved, open just the bottom half of the mold.

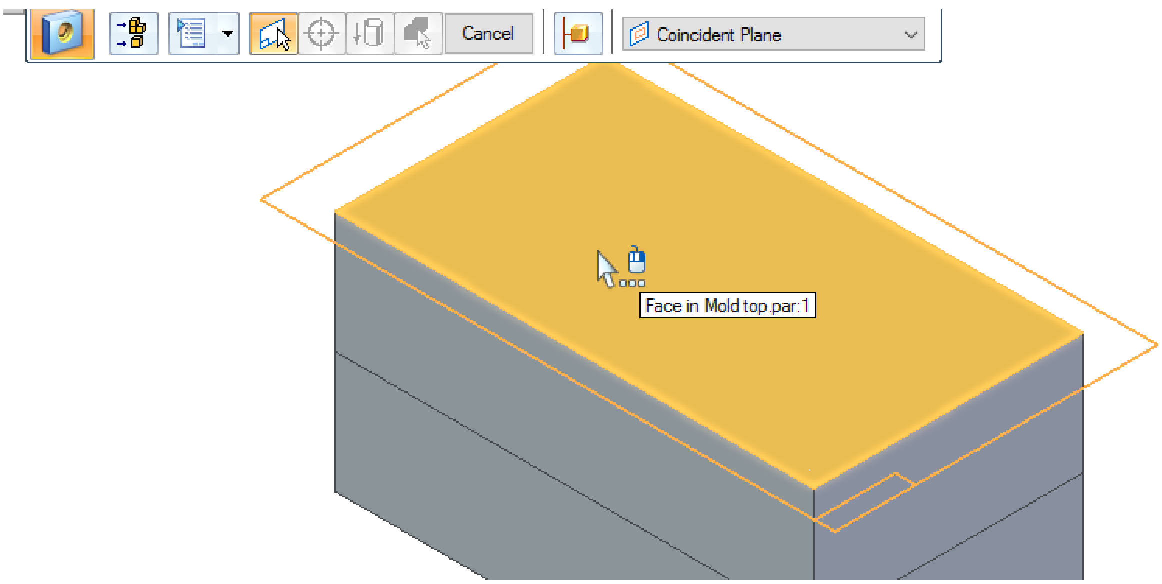


This will show that there is now a way to introduce material into the mold. Close the mold bottom and return to the assembly.

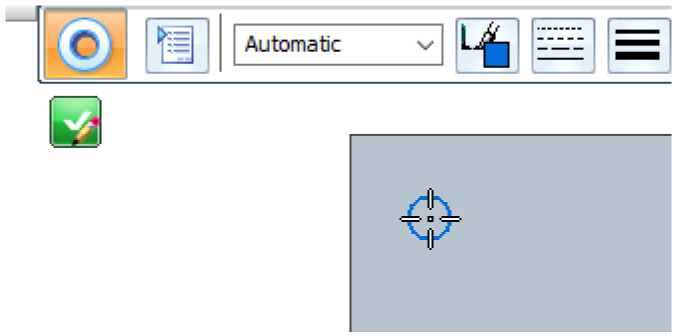
It is necessary to add locator pins to allow the halves to be perfectly aligned.
In the dialog box set the sub type to Dowel. Set the Size to ¼ and set the Fit to Normal. Set the extents to Finite, the Hole depth ¼ to ½ longer than the thickness of the mold top. Add a V bottom angle of 118°.



Select OK and then select the top of the mold to set the plane.



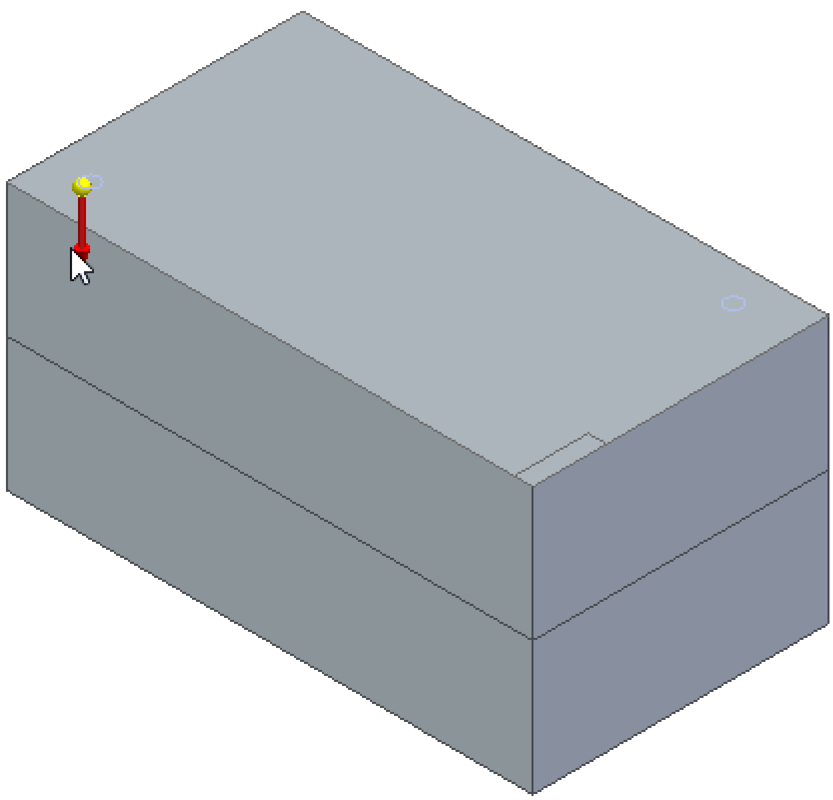
The view orientation changes and a circle appears on the cursor. Move the cursor close to a corner so it will not intersect with the chess piece cavity.



Click once in diagonally opposite corners.

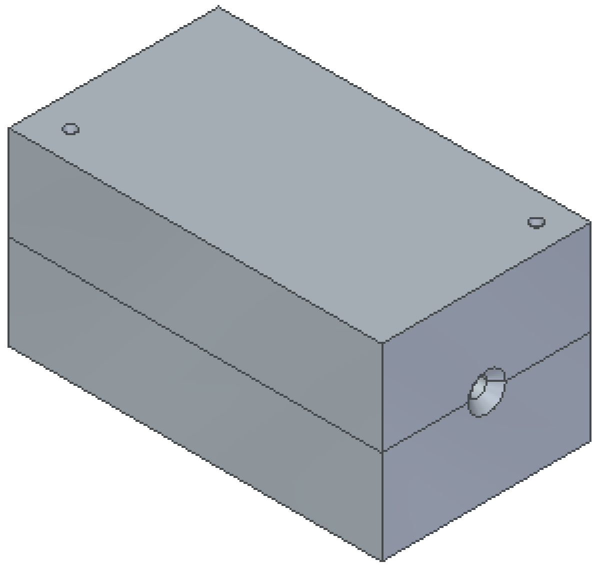
Click the green check box.

This returns the view to isometric. A prompt will require a direction.

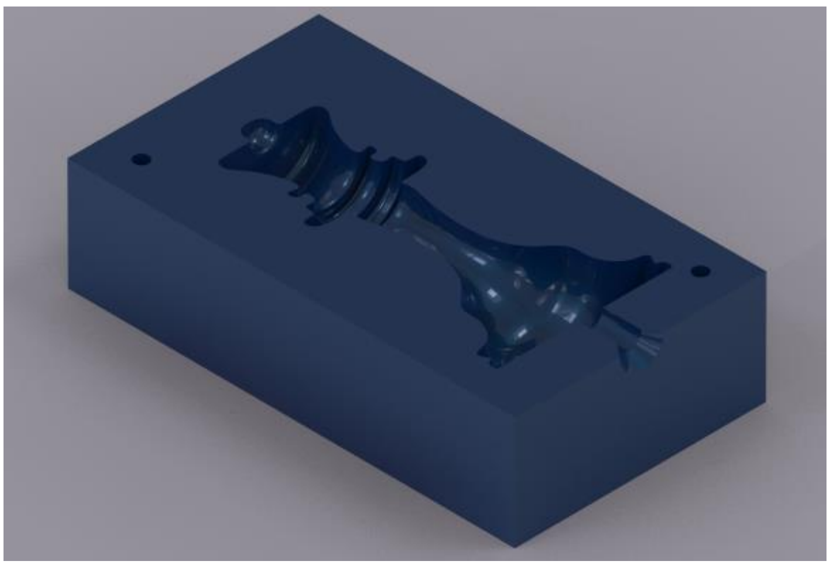


Select the down arrow. Select Finish.

Hit Esc to exit the command.



Save the assembly again. Open the mold top and the mold bottom to see what has happened to the two parts.



Design a dowel pin to fit the holes and add that to the assembly.

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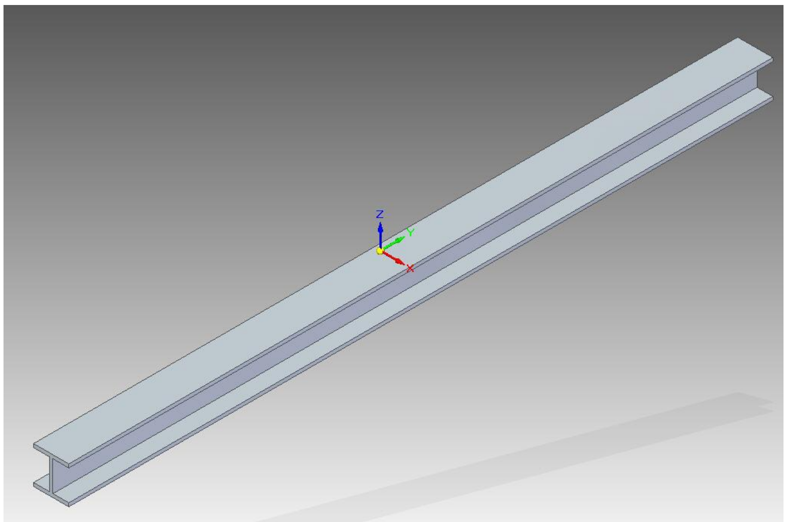
SIEMENS

Ingenuity for life

Analysis in Solid Edge



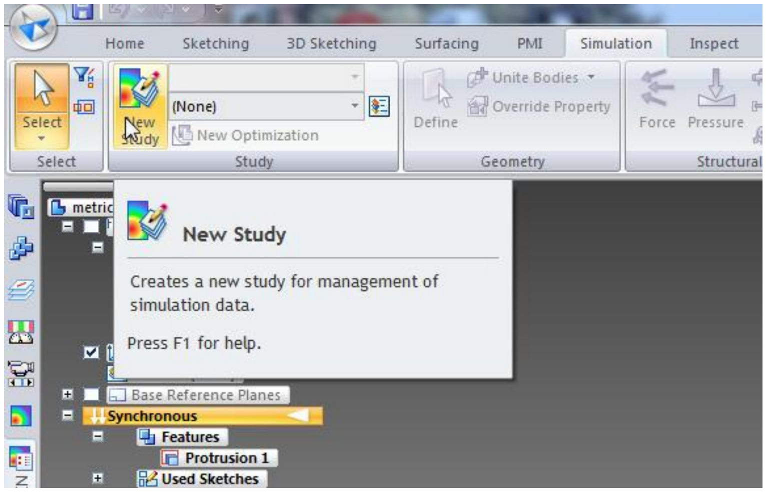
The Analysis function in Solid Edge allows us to simulate loading conditions on the model and determine its behavior or response at different locations. This information allows us to determine how our model will actually perform before we spend the time and material to create the actual structure. To perform the analysis, certain parameters must be set and the process understood.

Finite element analysis predicts behavior by breaking the solid model into small elements. If you think of the beam as made up from hundreds of mini-marshmallows you can see that each marshmallow is one element of the entire structure. As we load the structure each marshmallow interacts with the one next to it so the behavior is easy to see. To perform the analysis on the beam we will need to define how many elements to divide the structure. We create something called a mesh to define the sections. This will allow a focused look at each element and how they all interact. The program will automatically perform the numerical approximation to create the solution based on the solid model boundaries. It is also important to provide the material so the analysis will understand how it will behave. We can then export a report of the analysis to see visually how our design will perform under conditions we are likely to see.

Analysis Setup

Open the beam file designed in the beam design activity.

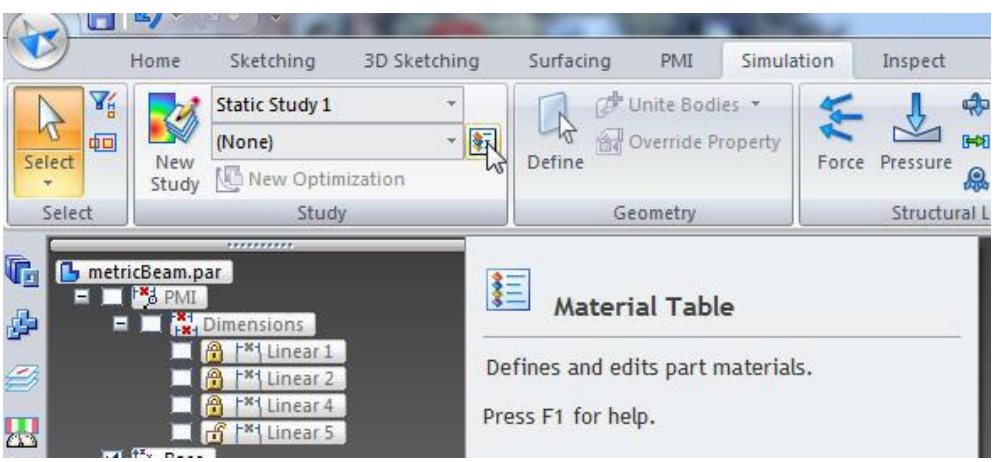
Select the Simulation section of the ribbon. When it appears, select New Study to begin the analysis setup.



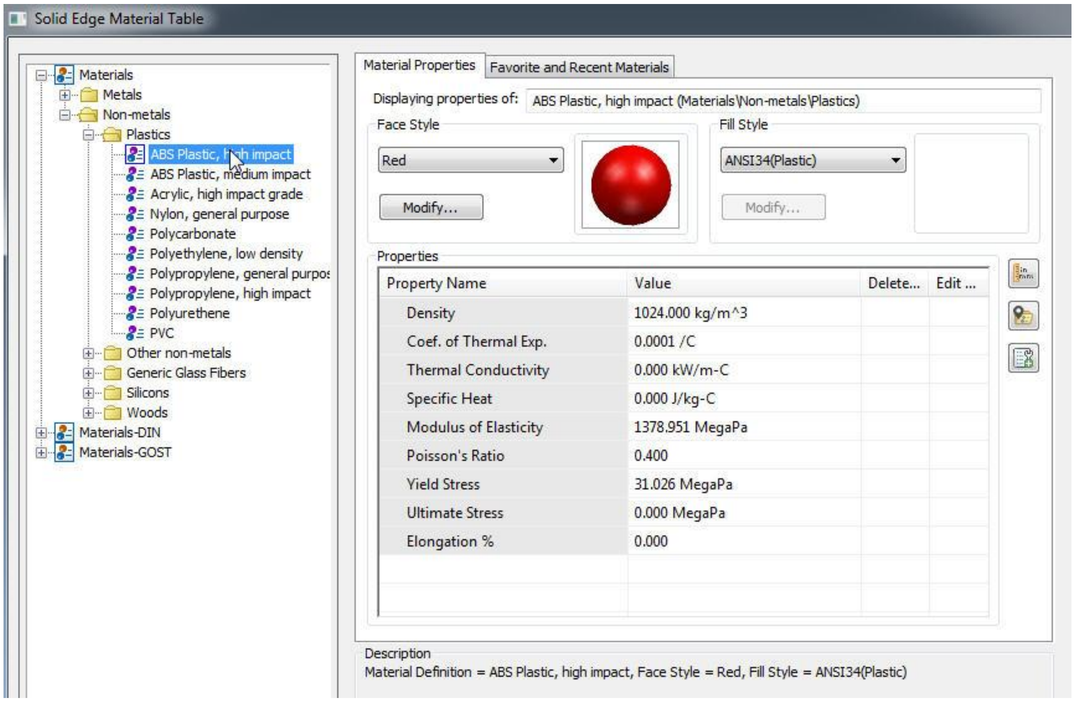
Click on New Study to see a dialog box for more details about the type of simulation available.

Select Linear Static as the study type and set the mesh type to tetrahedral. Select OK.

Next, assign a material to the beam. Select the button for the Material Table in the Study area of the ribbon.

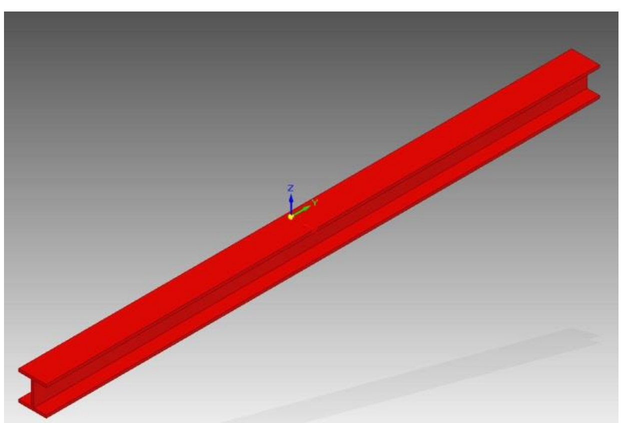


When the Material Table opens, expand the Non-Metals folder and locate the Plastics folder. This example is using the ABS Plastic as the material closest to the plastic the 3Doodler 2 printer uses. Change the color if desired. Designers can add materials based on the type of work planned. A good source for the information about materials can be found at www.matweb.com.



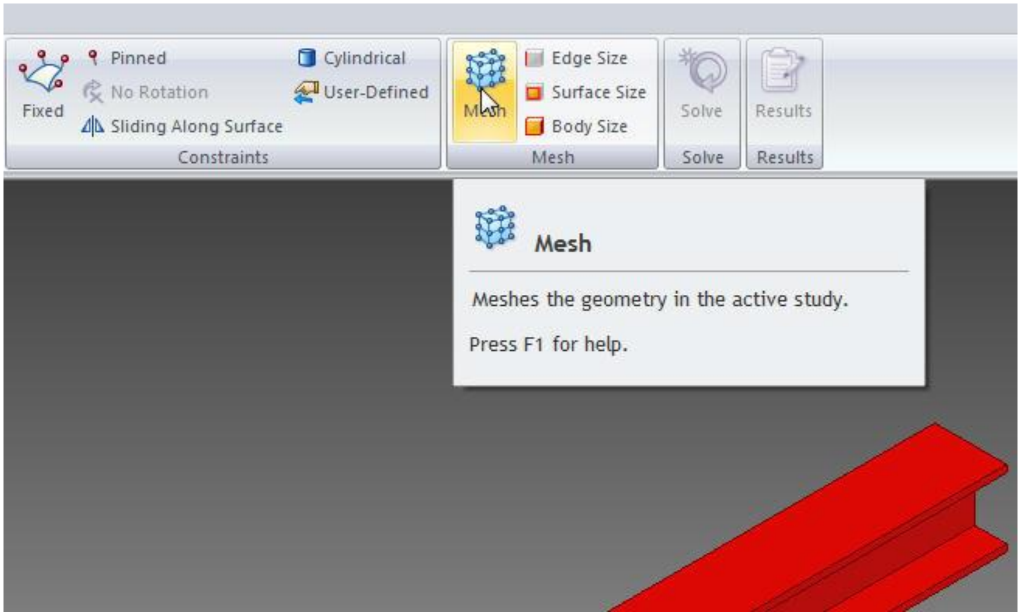
When all selections have been completed, click on the “apply to model” button at the bottom of the dialog box.

At this point, the color selected should be applied to your model. The color is a fun aspect of design work, but the parameters such as the modulus of elasticity will provide important information about how the model should behave.

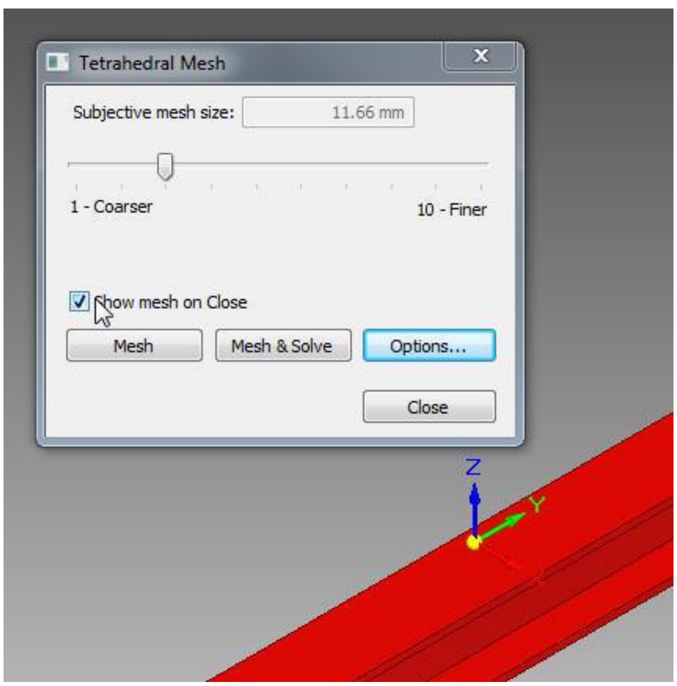


Now that the material has been applied we can set the mesh. If the mesh is too fine it will take a long time to solve. If the mesh is too large the computer will not be able to figure out how the structure will behave.

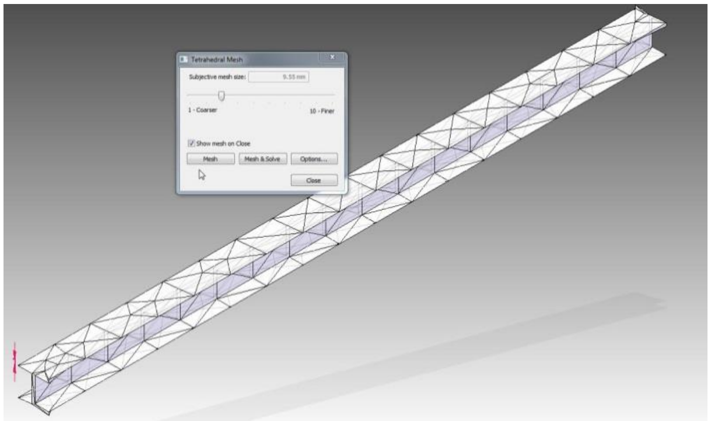
Select the Mesh icon from the Mesh section of the Ribbon.



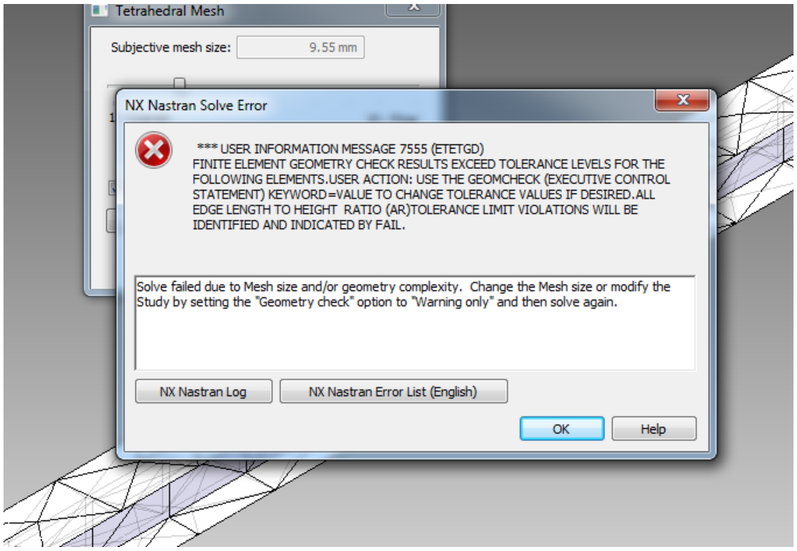
This will open the Tetrahedral Mesh dialog box. Begin by checking the box for Show mesh on Close.



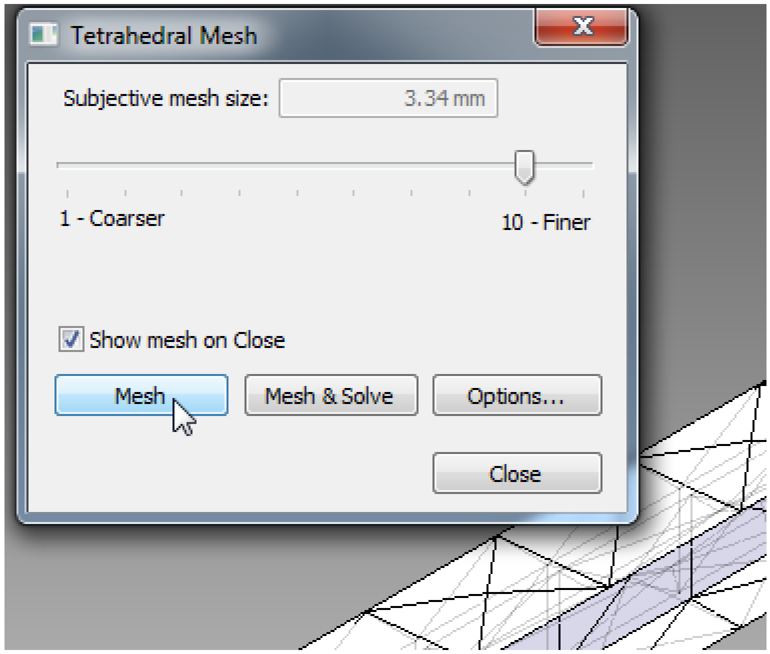
Click on the Mesh button. A mesh will be applied to your beam. The mesh should look fairly course.



Click on the Mesh and Solve button. This should indicate whether the program can actually solve the mathematics. In this case the program created a mesh that was too large.

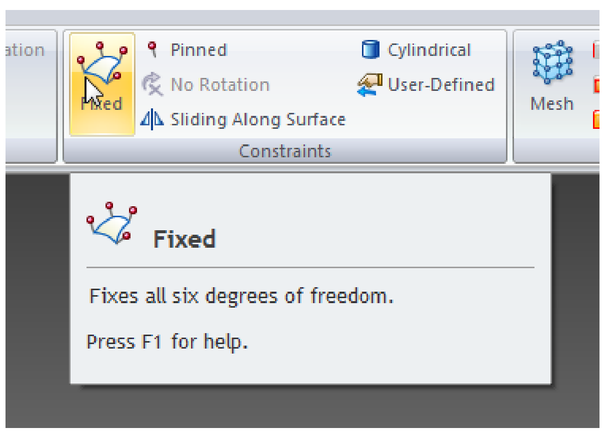


Since the error is about mesh size we can make the mesh smaller with the slider. Dismiss the error message and move the slider to make the mesh smaller.

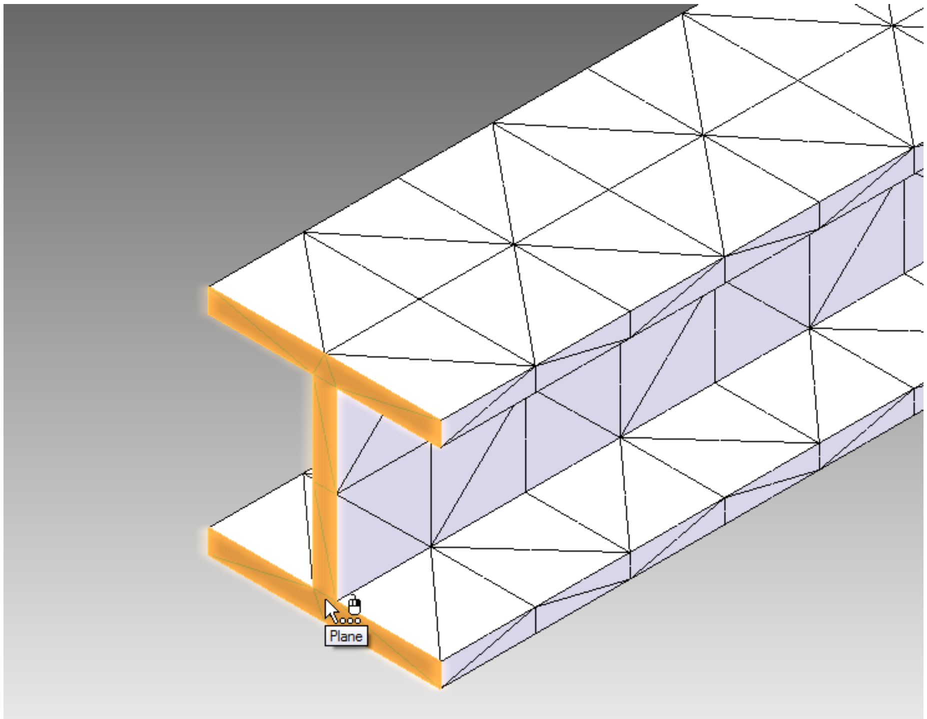


The result of clicking on mesh this time will be a much smaller mesh. Select Close.

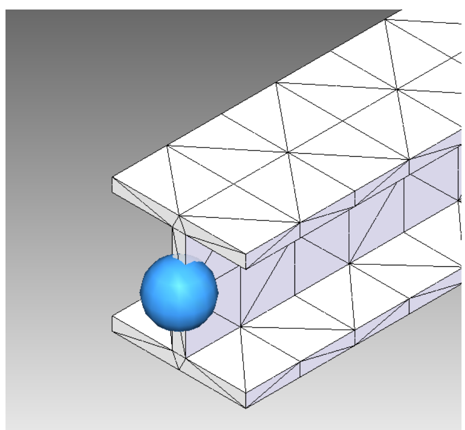
In order for the computer to solve the analysis, some constraints must be added. In the constraints section of the ribbon select the Icon for Fixed.



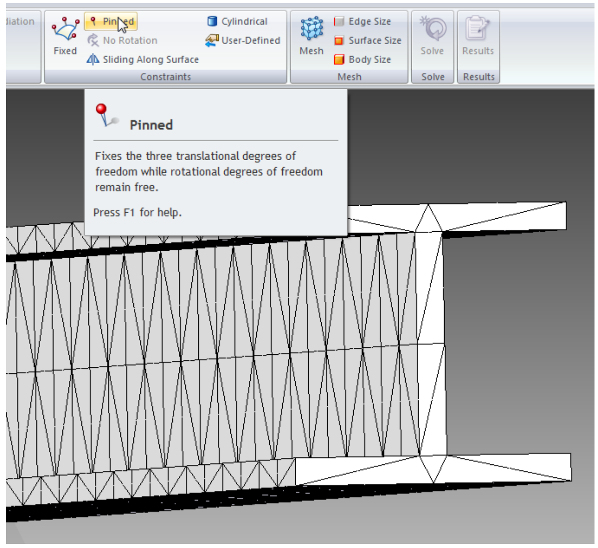
Now select the end of your beam. Wait until it highlights to ensure selection of the end plane.



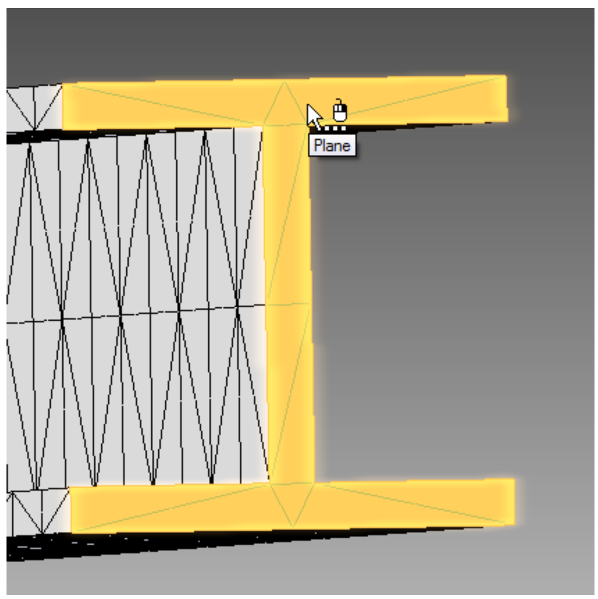
Left click to select the end and then right click to fix the end. A ball will appear to indicate that it is fixed.



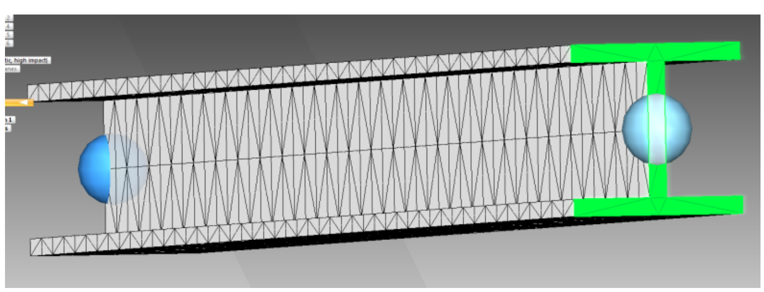
To truly see how this beam will behave it is necessary to pin the opposite end to allow it to be stationary but still allow the beam to move. Rotate the beam around to look at the opposite end. Select the Pinned Icon from the Constraints menu.



Select <u>just</u> the end. Left click to select and then right click to accept the end.

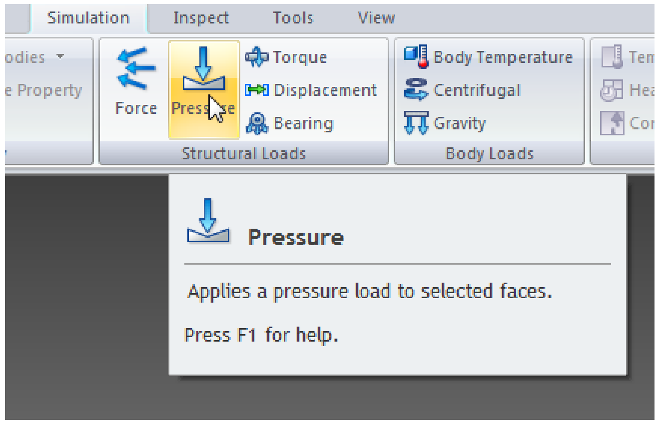


There should be a ball on each end of your beam.

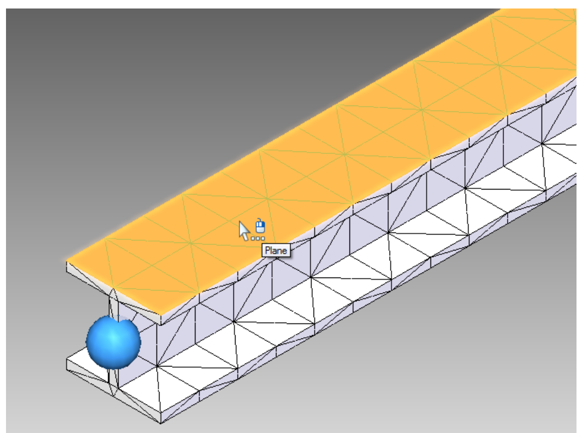


Return to the isometric view.

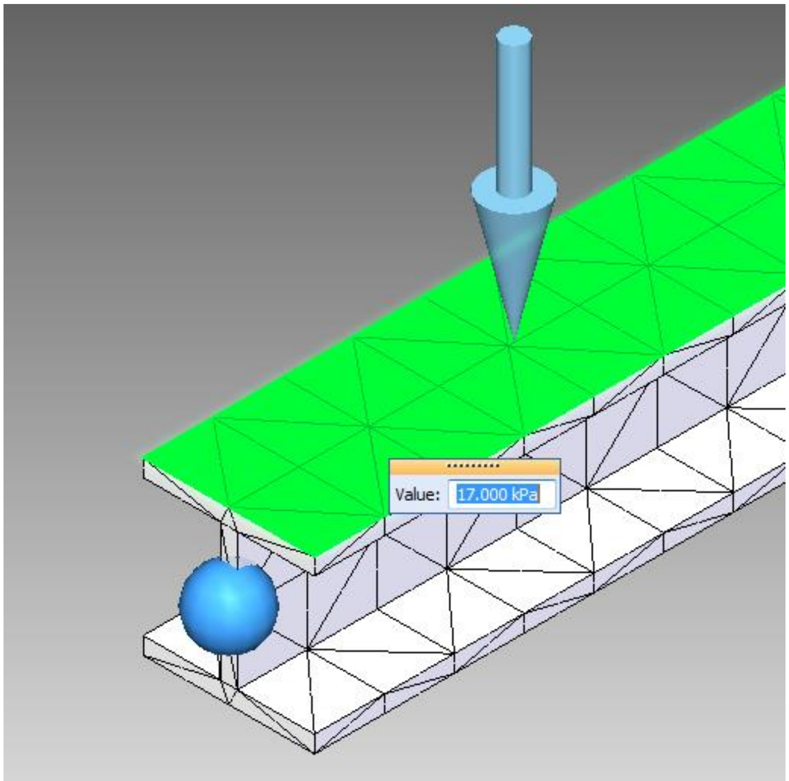
Define the load applied to the beam. From the ribbon find the Structural Loads section. Select the Pressure icon.



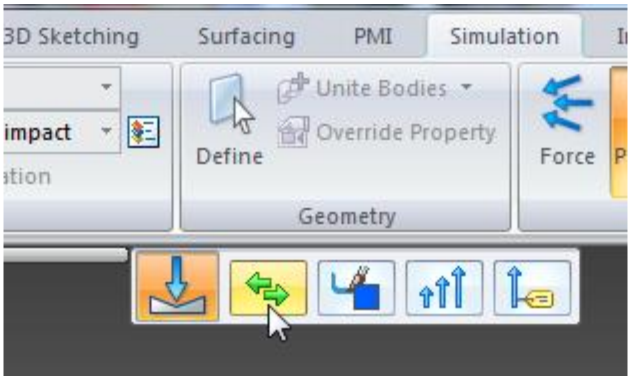
This will add a force equally along the face of the beam selected. Click on the top surface of the beam.



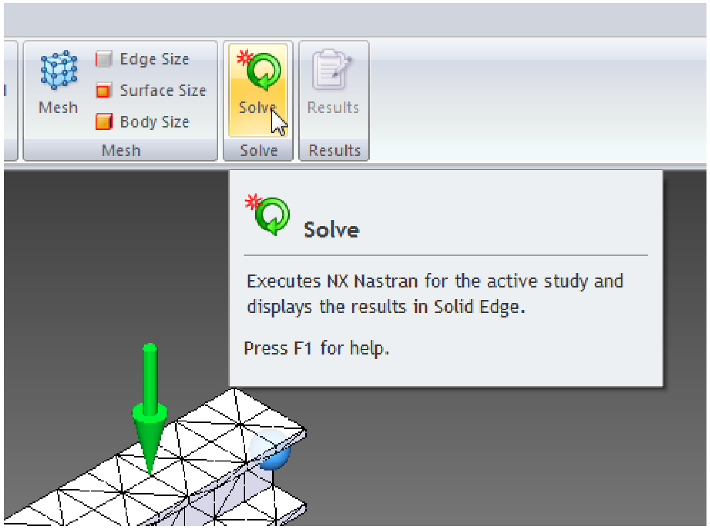
Force arrows appear. This example utilizes a force of 17 kPa in a downward direction.



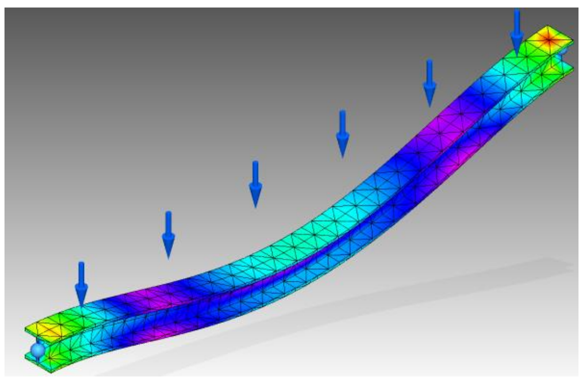
If the arrows are pointing up reverse the arrow by selecting the flip direction arrows on the tool bar or typing F to flip the direction. Right click to accept the setting.



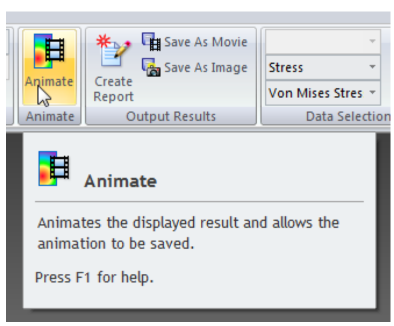
Now try to solve the analysis of the beam. Select the Solve button on the Ribbon.



After thinking for a few seconds the analysis solution appears.

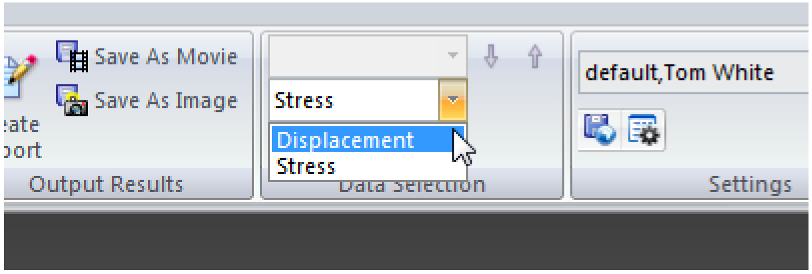


At this point it is possible to animate the force. On the ribbon select the Animate icon.

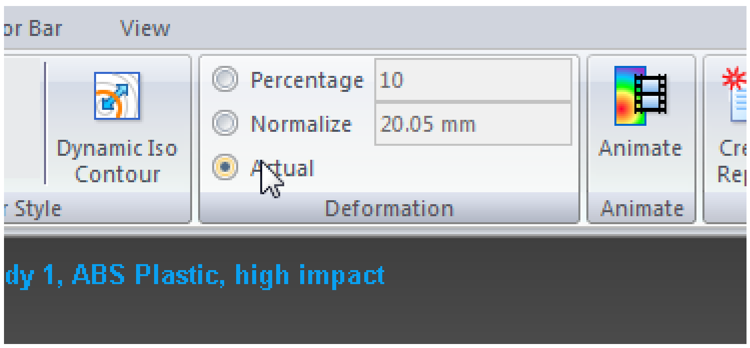


Select close on the Animation toolbar.

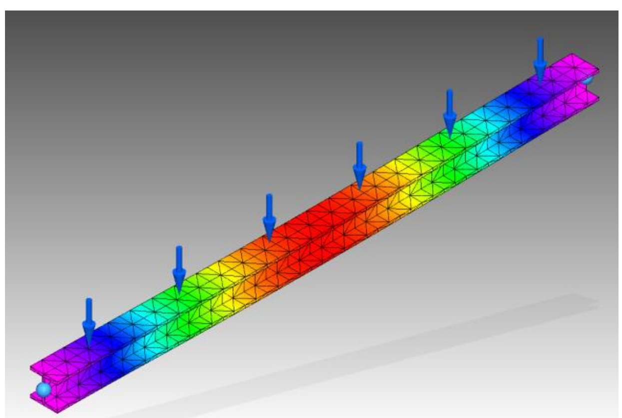
On the right of the screen see the display of the forces and the color they are assigned. Change the display to look at Deflection. From the Data Selection section of the ribbon change the selection from Stress to Displacement.



The colors associated with the deflection are visible. The computer exaggerates the image to magnify the change making the effect visible. To show the display without the distortion select Actual radio button in the Deformation section of the ribbon.



The effect will be seen immediately. Now the display is showing the displacement in proportion to the object.



Save the animation movies to play back during a report. It is also possible to print out the entire report of the simulation results. Control of these options is found in the Output results of the ribbon.

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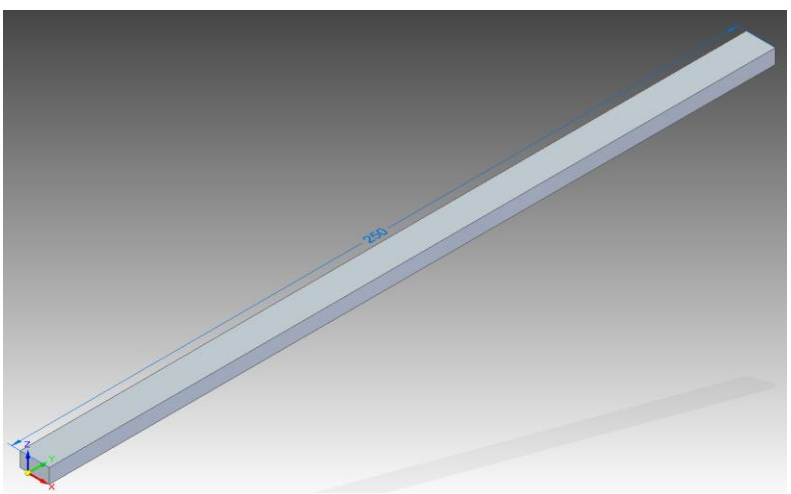
Testing Beams

When designing beams, there are numerous formulas to use to predict behavior. While engineering and design software can do much of the work for us we can also utilize some basic formulas and design a quick test to see how materials will behave.

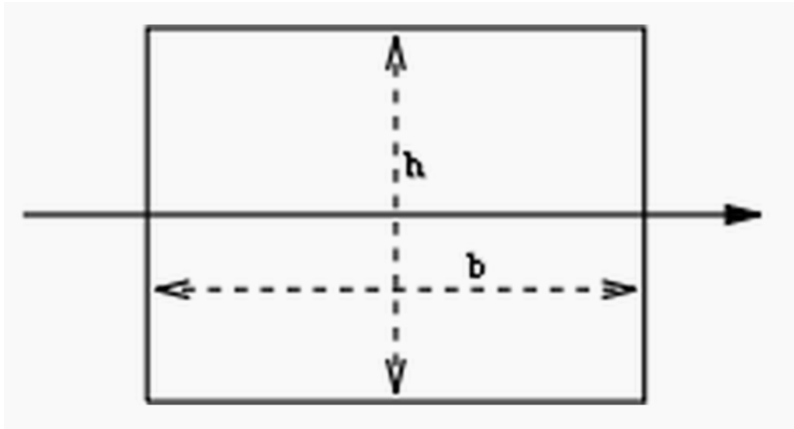
Materials needed:
Dial Caliper
Blocks or pencils
Plastic cup
Sand
String
Paper clip

Design and print a rectangular beam that is 5X10X250 mm.



To predict how this will behave we need to test this beam by applying a load and seeing how it will behave.

The area moment of inertia is a number applied to predict the strength of the shape. With a simple shape such as ours we can utilize a basic formula to calculate this value.



$$I_x = \frac{bh^3}{12}$$

Where b is the width of the base and h is the height.

This number represents the area moment of inertia.

Deflection is how much the beam will bend in the middle. We use the formula

$$Deflection \Delta = \frac{L^3 \times F}{48 \times E \times MI}$$

Where
L = Length
F = Force in Kilograms
MI = Moment of Inertia
E = Modulus of Elasticity
Δ=deflection

In our case we will be measuring the deflection. We know the moment of inertia from the calculation. We know the length of the beam and we can weigh the plastic cup and sand. Our unknown in this formula is the actual Modulus of Elasticity. There are tables where we can look up to see what the average value might be. In our case we will be using the 3Doodler to create the beam. Due to the layered nature of the plastic it will not be uniform so we test to see what kind of a value we might use in future calculations.

The formula is rearranged and the values of the base and height are used to provide us with the missing information

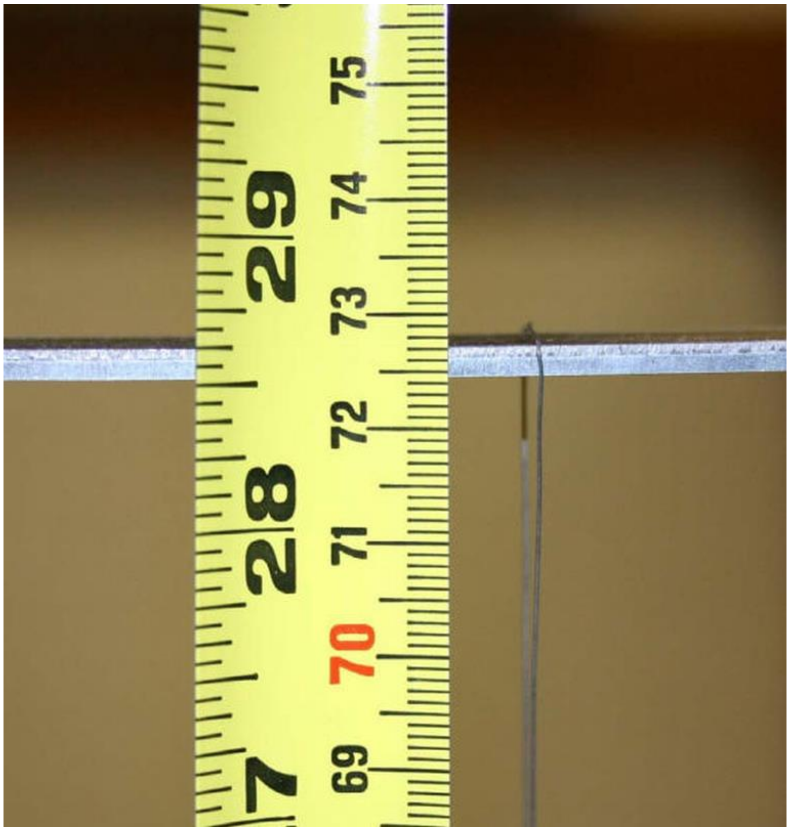
$$E = \frac{L^3 \ x \ F}{4 \ x \ \Delta \ x \ bh^3}$$

The deflection is represented by the Δ

What the formula tells us is the longer the beam, the more deflection you will have from the same force. It is a geometric relationship so the length is very important.

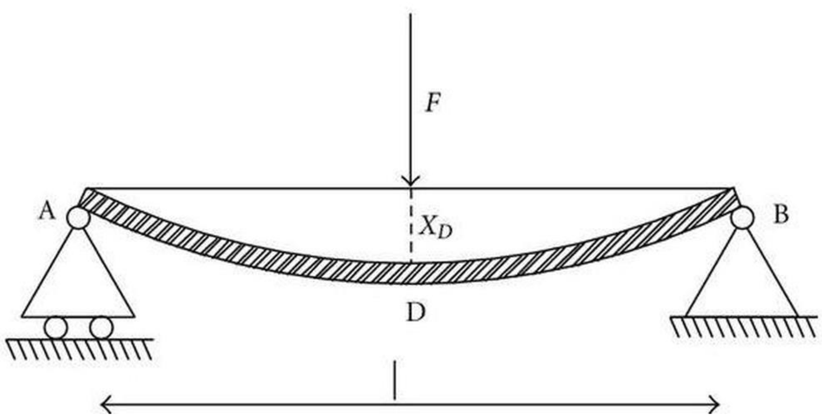
Testing

- Separate two pieces of same-height furniture (such as desks or lab stools) about 20-cm distance apart.
- Use masking tape to fix a pencil on the surface next to the edge of each.
- Measure the distance between two pencils and record this data in your engineering notebook.
- Place the sample beam on the top of two pencils so there is a known distance between the pencils and the beam is adequately supported.
- Measure and place a mark on your beam at the center of the span
- Measure the distance from the floor to the beam center mark.
- Measure the mass of plastic container with string on the triple-beam balance which will be the initial weight.
- Hang the plastic container in the center of the beam and measure how much the beam deflects. Record this in your engineering notebook.



- Add sand to your container a little at a time. The deflection will increase.
- Measure the distance to the floor. This difference between the original measurement and the new measurement is the displacement.
- Weigh the plastic container string and sand. This will give you the total weight in Kg for your force.

Use Excel to graph to display the relationships of “loading force vs. displacement” for the materials.



Testing with a torque wrench.

Normally a torque wrench is used to apply a specific torque to a fastener. They are used extensively in the assembly of all kinds of mechanisms. Assembly manuals will provide a specific torque that should be applied. In the picture below a mechanic is tightening a bolt to a specified torque.

In beams we see moments caused by the loading of the force. It creates a twisting force at the support. Eventually it will cause failure if the force is more that the structure can stand. Clamp the end of the beam in a vice so a small portion is protruding from the vice. Find a socket that fits the end of your beam. If you drew it to exact dimensions a 10mm socket will fit. Set the wrench to .1 N-m. Twist slowly until you hear the click. This is the same amount of torque that you would find if you placed the one kilogram weight in the center of the beam during testing.

Design your own beam shapes

Using the Solid Edge you can create beams of different shapes and test them the same way. Create the different shapes you want to try and then apply weight and torque to see how they behave.

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Fits and Tolerance:

How should parts fit together?
How is friction addressed?
How are Dimension Tolerances communicated?

Think about a child puzzle like this one:

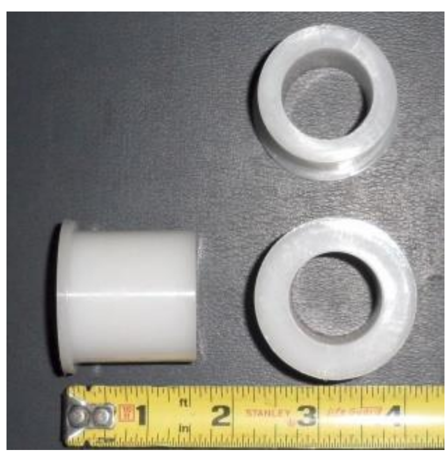
If you were the designer of this puzzle it would be important to consider a space between the outer edges of the puzzle pieces and the cut out openings. This space should allow for the pieces to fit in their respective openings "comfortably"- not too tight but also not too loose. This is an example of tolerance. In this case, the tolerance might be a space between each piece and the opening of .031 inches which is the decimal equivalent of 1/16 inch.

Designers need to be mindful of the physical sizes of components of a product assembly. Here is an example of a product that has an assembly of parts:

We have all used one of these or perhaps a motorized version of this manual can opener. Regardless of the type, the proper operation of the can opener is very much dependent on a number of factors none more important than the fit tolerances in the assembled parts.

Sometimes parts move within a product. Some movements can cause a buildup of heat due to friction. When there is friction it needs to be addressed.

Sometimes a special material such nylon can be used to address friction. Nylon is a very tough material with great thermal and chemical resistance. One great application of nylon is using a nylon sleeve or bearing that separates a wheel hub from the axial shaft. The picture below is one example of a nylon sleeve/bearing. The hole in the wheel hub is a little bigger in diameter than the outside diameter of the nylon sleeve, perhaps .002 inches, enabling a close fit. The hole in the nylon sleeve is a little bigger than the shaft diameter, perhaps .002 inches, enabling a close fit.



Nylon, as in this application, is good for modest rotating speeds and applications that are light in weight such as toys, gas grills, grocery carts, and the like.

When higher rotating speeds are present, the use of antifriction bearings are needed such as the ball bearing in a bicycle wheel, as shown below:

The blue material in the picture is a lubricant called bearing grease. All antifriction bearings need lubrication either from grease or oil.

The three pictures below are antifriction bearings. The one on the left is a ball bearing and the one in the middle is a roller bearing. Roller bearings can carry more weight such as a car wheel bearing.

The antifriction bearings pictured below have specific applications and come in many sizes. Generally speaking, ball bearings are for lighter uses while roller bearings are for heavier applications. Ball bearings are used on bicycles, lawn mowers, small electrical motors, etc. Roller bearings are used on car and truck wheels, heavy industrial equipment, etc. Thrust bearings (on the right) are used with heavy rotating products where the force is downward, such as a merry-go-round.

Ball Bearing Roller Bearing Thrust Bearing

When designing products with rotating parts requiring the use of antifriction bearings, designers must make the parts that will house the bearings according to the bearing manufacturer's tolerances. The bearing will be placed into an opening where the diameter of the bearing housing may be slightly smaller in diameter than the outside diameter of the bearing, perhaps .001 inches smaller. This will require the bearing to be placed in the housing by force pressing it in place or heating the bearing housing slightly to make the opening larger temporarily so the bearing can be installed and then to allow the housing to cool holding the bearing tightly in place. This tolerance is called negative clearance, meaning that the bearing diameter is bigger than the bearing housing. Using this procedure will prevent the bearing outer raceway from spinning.

The same is true for the shaft supported by the bearing. The inside diameter of the bearing inner raceway is slightly smaller than the diameter of the shaft. This results in a negative clearance between the bearing inner raceway and the shaft. This will make the bearing inner raceway and the shaft rotate together.

With the bearing held tightly in the bearing housing and the shaft held tightly to the bearing inner raceway, the balls or the rollers in the bearing will eliminate friction. The picture below shows an antifriction bearing being held in what is called a pillow block bearing housing. Please note the grease fitting near the top of the bearing housing. The shaft that goes in the bearing is not shown.

Some design applications require the use of plain bearing. Here is a picture of a plain bearing:

A plain bearing is different from an antifriction bearing. There are no balls or rollers moving to eliminate friction. Plain bearings use a different material, such as bronze - a nonferrous metal, to support a rotating shaft on a thin film of oil. Designers specify a positive clearance between the inside diameter of the plain bearing and the outside diameter of the shaft, perhaps .001 inches. This positive space permits the use of oil as a lubricant and if the oil is always present, the shaft will be supported by a thin film of oil and the result is virtually no friction. Very heavy industrial machinery uses plain bearings.

When designing mechanisms with multiple parts, it is important to define how each part will relate/interact with other parts. For example if a shaft is to fit into a plain bearing and needs a positive clearance for the oil film to eliminate friction, the bearing manufacturer will specify the exact tolerance, perhaps between .001 to .003 inches for the space between the shaft and the plain bearing. This tolerance is based on the viscosity of the recommended oil. Less or more than the .001 to .003 tolerance will cause wear in the plain bearing and eventual bearing failure. Tolerances are critical to the successful performance of products and especially their longevity in the marketplace. Successful companies strive for excellence in the manufacture of their products. Their future depends on it.

It is important to know that machine tools have some limitations in producing and repeating accuracy. Some machine tools are more accurate than others. Designers understand these realities and need to be mindful of the acceptable tolerances. Generally speaking, holding closer tolerances is more expensive.

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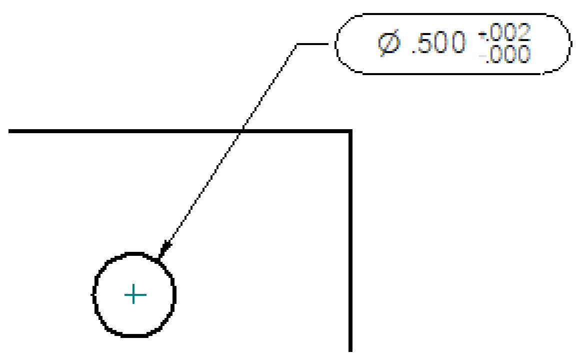
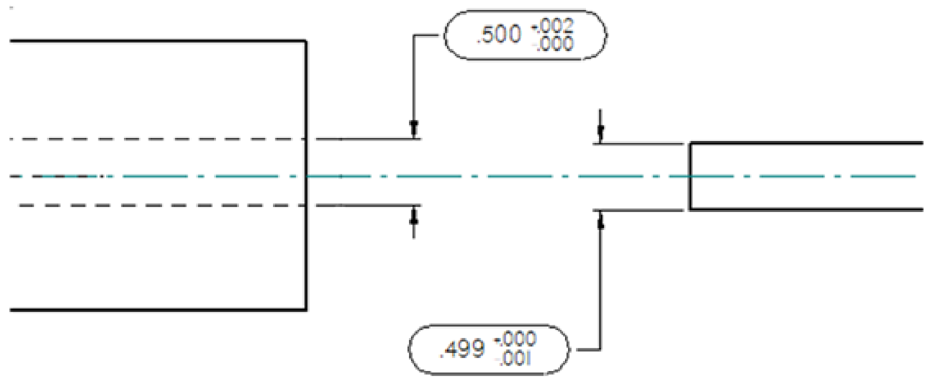
Geometric Dimensioning and Tolerancing

When communicating the size, shape, and location of a component part, it is also necessary to add in an allowable difference from the stated size. In the example below, a hole measuring .500 inches is required. In the picture below we are specifying that the hole be 500 thousands inches at a minimum but it can be up to .502 inches.



The specified dimension is shown and the limits are applied to that dimension. The upper limit is added to the specified dimension. In this case the largest the hole can be is .500 + .002 or .502. The lower limit is subtracted from the specified dimension. The tolerance markings show that the largest the hole can be is .502 and the smallest should be .500. The limits indicate whether the tolerance is bilateral, the same amount above and below or in this case unilateral where the deviation is all on one side.

The picture below demonstrates the two parts to be assembled.



The specified dimension of the shaft is .499. Again this is a unilateral tolerance. The largest the shaft can be is .499 and can be as small as .498. Taken together the smallest clearance is $.500 - .499 = .001$. The largest clearance could be $.502 - .498 = .004$. This range is called the allowance.

Fits

For many applications designers have already defined the ranges and allowable size differences we may use. These are categorized as Fits. There are several classes of fits in broad categories. The two broad categories are clearance fits and interference fits. A clearance fit specifies the size of the parts to ensure there is always a space or positive clearance between the joining parts. This will allow shafts to rotate, parts to be located with some ease of assembly, or to allow the parts to slide.

An interference fit is when two parts do not slide together easily. An example of an interference fit might be a pulley on a shaft, a bearing forced on a shaft, or locational fits that should not change once assembled. Sometimes called a shrink fit, one part might be heated so the parts can be assembled without a lot of force. As the part cools, it shrinks around the shaft, permanently joining the parts. In these cases there is a negative clearance between the joining parts.

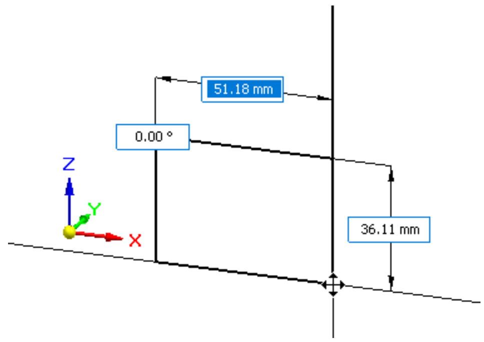
Fits tables

Tables describing all the different classes of fits are available for both Metric and English systems. They are available in the *Machinery Handbook* or on line. These tables provide guidance for acceptable sizes of materials across many types of fits.

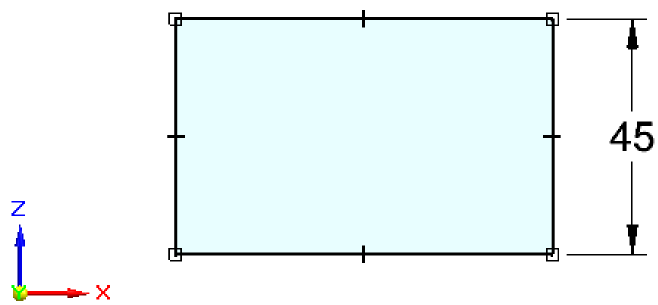
The exercises below will help you in specifying tolerance and fits in the work you are doing.

Specifying Tolerance

Begin a new part file in the unit of your choice. The actual size will be adjusted in the next steps.

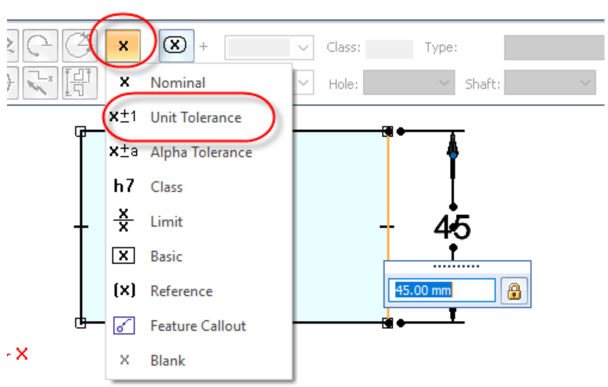


In this example the height dimension is set to 45 mm using the smart dimension tool.

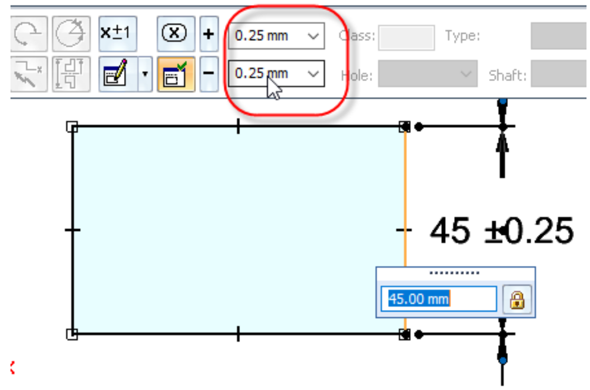


If this part is manufactured we need to communicate the range of sizes that are acceptable. This example assumes an acceptable limit of within a quarter of a mm.

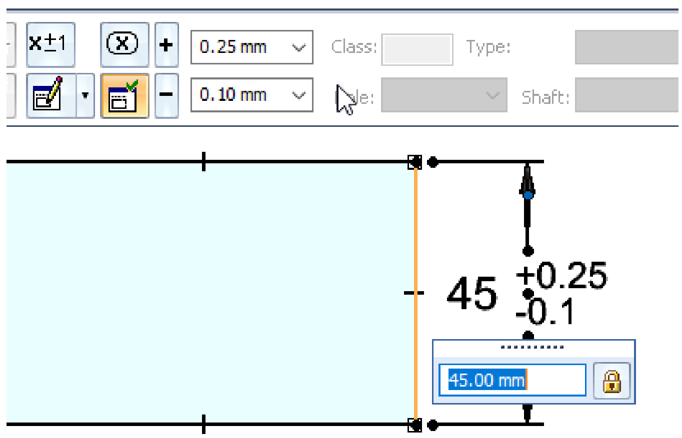
Left click on the dimension on the screen to bring up the edit box. In the dimension edit box, look for the Modify Dimension tool. It might default to Nominal represented by an X. Select the option for Unit Tolerance.



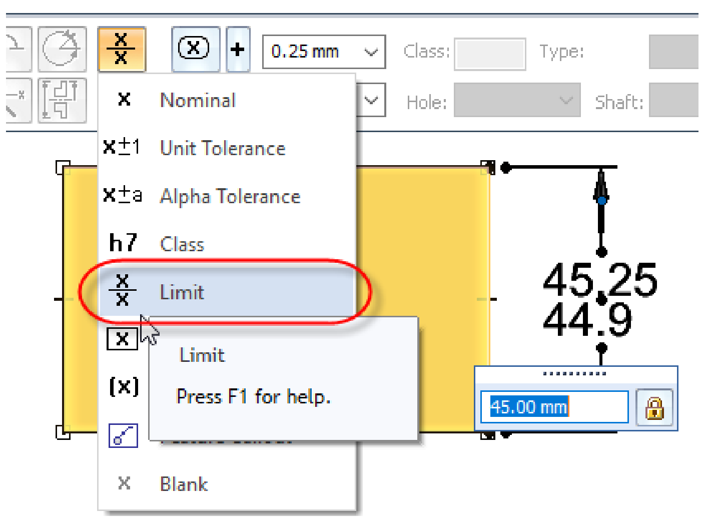
Enter the .25 mm acceptable limit in the boxes and it will appear on the screen.



Edit the dimension again. This time, change the lower limit to .10 mm.

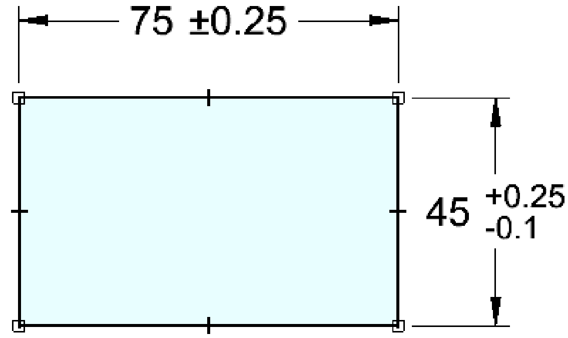


This changes the dimension. Another way to look at the dimension is to set the dimensional limits. Click on the dimension again and select the option for Limit.

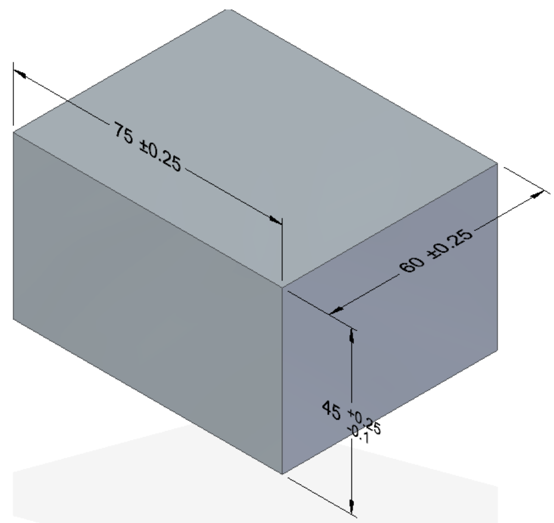


This will change the dimension display to show the largest and smallest dimensions you have set.

Dimension the width of the rectangle to 75mm ± .25.



Extrude the sketch a distance of 60 ± .25.



Using the ANSI table for a close running fit for a 20 mm hole and shaft combination the hole should be between 20.000 and 20.033 and the shaft between19.959 and 19.993mm

Basic Size[a]		Loose Running Hole H11	Loose Running Shaft c11	Loose Running Fit[b]	Free Running Hole H9	Free Running Shaft d9	Free Running Fit[b]	Close Running Hole H8	Close Running Shaft f7	Close Running Fit[b]	Hole H7
1	Max	1.060	0.940	0.180	1.025	0.980	0.070	1.014	0.994	0.030	1.01
	Min	1.000	0.880	0.060	1.000	0.995	0.020	1.000	0.984	0.006	1.00
1.2	Max	1.260	1.140	0.180	1.225	1.180	0.070	1.214	1.194	0.030	1.21
	Min	1.200	1.080	0.060	1.200	1.155	0.020	1.200	1.184	0.006	1.20
1.6	Max	1.660	1.540	0.180	1.625	1.580	0.070	1.614	1.594	0.030	1.61
	Min	1.600	1.480	0.060	1.600	1.555	0.020	1.600	1.584	0.006	1.60
2	Max	2.060	1.940	0.180	2.025	1.980	0.070	2.014	1.994	0.030	2.01
	Min	2.000	1.880	0.060	2.000	1.955	0.020	2.000	1.984	0.006	2.00
2.5	Max	2.560	2.440	0.180	2.525	2.480	0.070	2.514	2.494	0.030	2.51
	Min	2.500	2.380	0.060	2.500	2.455	0.020	2.500	2.484	0.006	2.50
3	Max	3.060	2.940	0.180	3.025	2.980	0.070	3.014	2.994	0.030	3.01
	Min	3.000	2.880	0.060	3.000	2.955	0.020	3.000	2.984	0.006	3.00
4	Max	4.075	3.930	0.220	4.030	3.970	0.090	4.018	3.990	0.040	4.01
	Min	4.000	3.855	0.070	4.000	3.940	0.030	4.000	3.978	0.010	4.00
5	Max	5.075	4.930	0.220	5.030	4.970	0.090	5.018	4.990	0.040	5.01
	Min	5.000	4.855	0.070	5.000	4.940	0.030	5.000	4.978	0.010	5.00
6	Max	6.075	5.930	0.220	6.030	5.970	0.090	6.018	5.990	0.040	6.01
	Min	6.000	5.855	0.070	6.000	5.940	0.030	6.000	5.978	0.010	6.00
8	Max	8.090	7.920	0.260	8.036	7.960	0.112	8.022	7.987	0.050	8.01
	Min	8.000	7.830	0.080	8.000	7.924	0.040	8.000	7.972	0.013	8.00
10	Max	10.090	9.920	0.260	10.036	9.960	0.112	10.022	9.987	0.050	10.01
	Min	10.000	9.830	0.080	10.000	9.924	0.040	10.000	9.972	0.013	10.00
12	Max	12.110	11.905	0.315	12.043	11.956	0.136	12.027	11.984	0.061	12.01
	Min	12.000	11.795	0.095	12.000	11.907	0.050	12.000	11.966	0.016	12.00
16	Max	16.110	15.905	0.315	16.043	15.950	0.136	16.027	15.984	0.061	16.01
	Min	16.000	15.795	0.095	16.000	15.907	0.050	16.000	15.966	0.016	16.00
20	Max	20.130	19.890	0.370	20.052	19.935	0.169	20.033	19.980	0.074	20.021
	Min	20.000	19.760	0.110	20.000	19.883	0.065	20.000	19.959	0.020	20.00
	Max	25.130	24.890	0.370	25.052	24.935	0.169	25.033	24.980	0.074	25.021

This page can be found by a search for ANSI B4.2. Similar tables can be found for customary measurements by searching for ANSI B4.1. A close running fit is used for accurate machine motion. This is a clearance fit that will allow room for lubrication between the parts.

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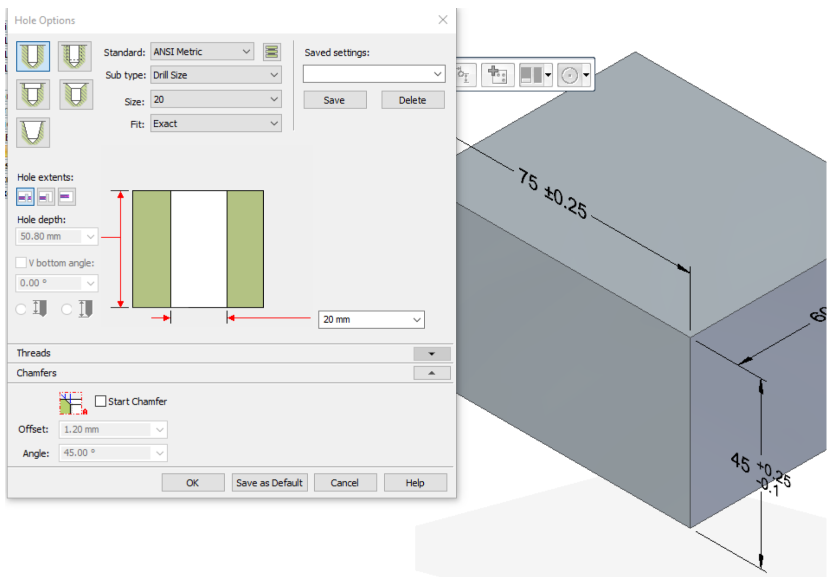
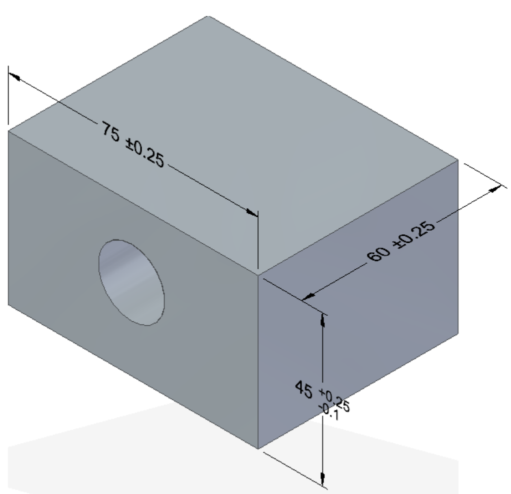
Tolerance for Holes

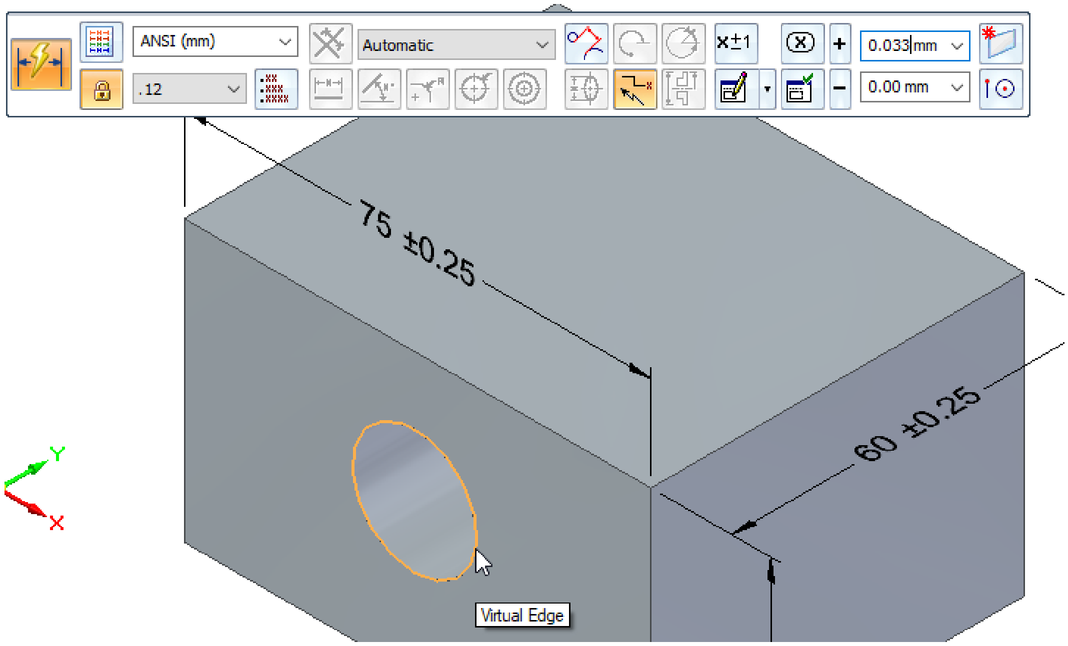
Use the Hole Command to place a hole on the face of the block. This example uses a 20 mm through hole as the nominal size.



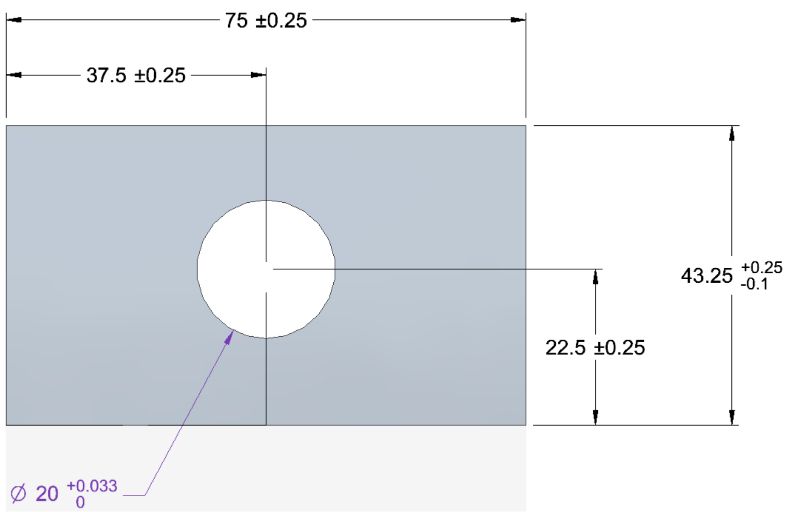
The hole is placed on the block.



Use the Smart Dimension tool and with the unit tolerance option and use the settings from the close running fit table to control the tolerance of the hole.

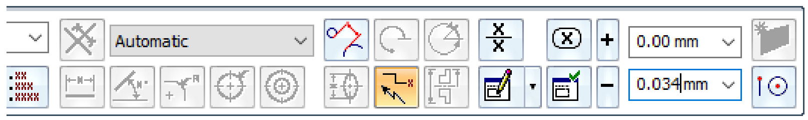


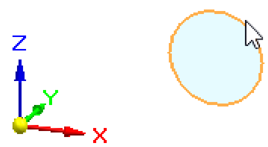
Once the tolerance is set for the hole, you can dimension the center to be where you need it.



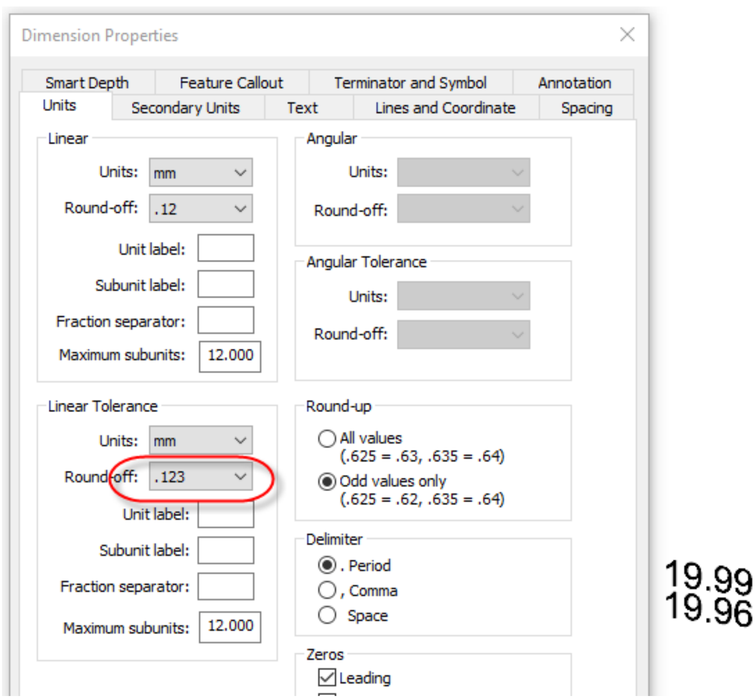
Save the part.

Open a new part and create the shaft. Begin with a circle and use the smart dimension tool to add the necessary dimension and tolerance. Use the Limit setting of the dimension tool. Set the initial dimension to 19.993.

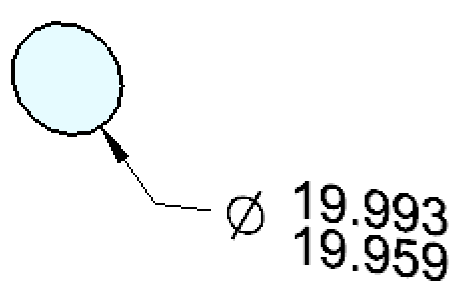




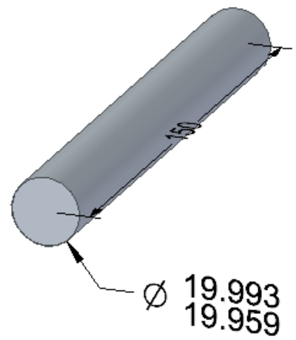
If you only see two decimal places, right click on the dimension and select Properties from the options menu. In the dimension properties dialog box, adjust the round off to three decimal places on the Linear Tolerance.



Once you select OK, the third decimal place appear.



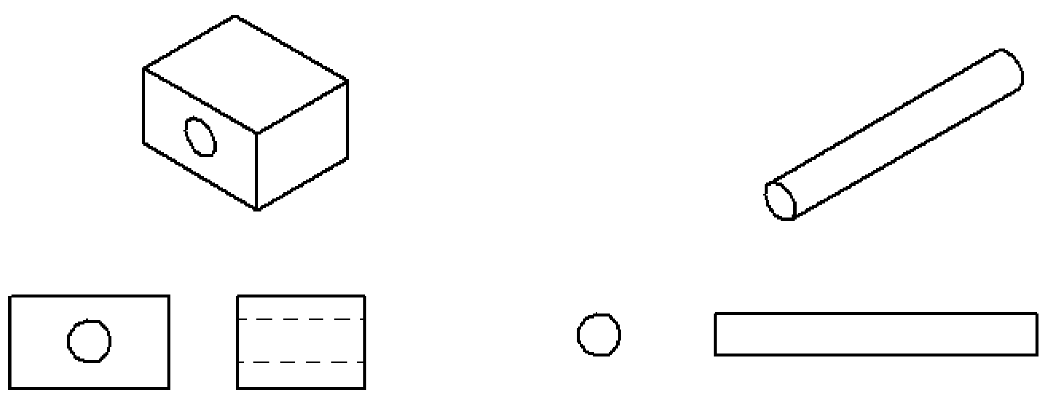
Extrude the shaft 150 mm.



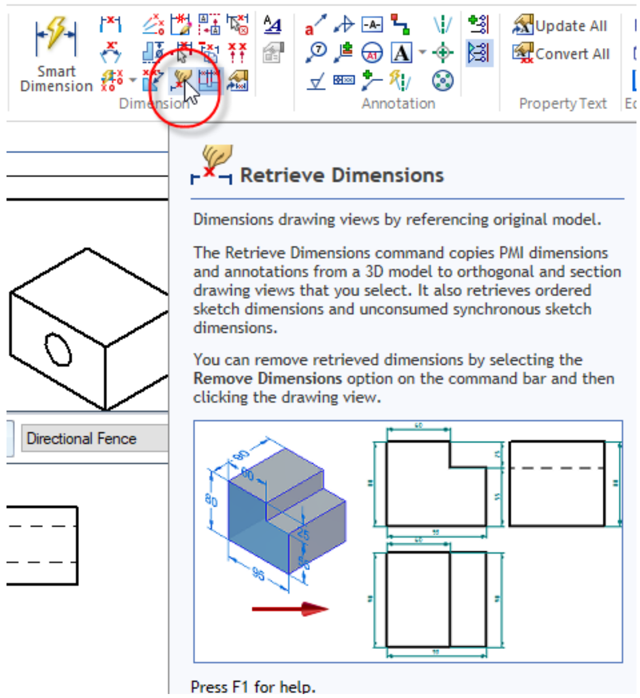
Save the part.

Creating the Drawing

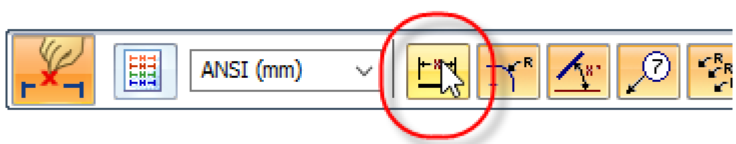
Create a new drawing. To have the tolerance appear on the working drawings place the parts from the library on a sheet.



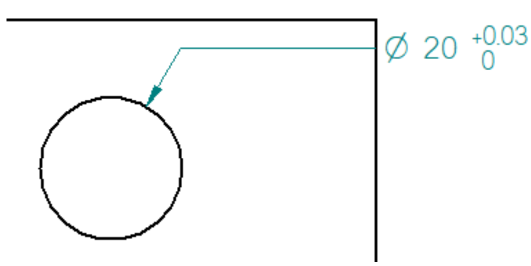
Use the Retrieve Dimensions option from the dimension area.



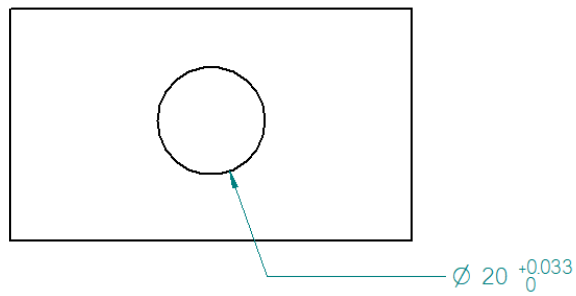
This will allow access to the dimensions you placed earlier. Select the option for linear dimensions.



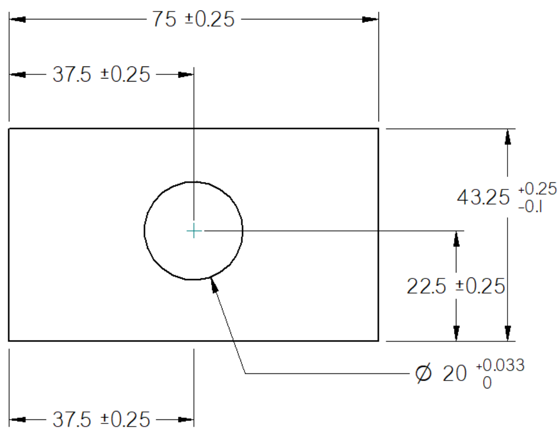
Select the hole. The dimension will appear. Use the escape key to exit the command.



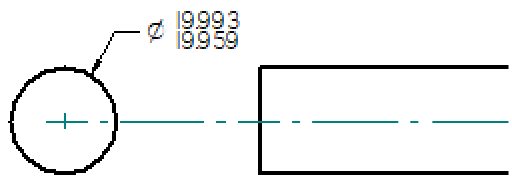
Change the dimension tolerance round off to three places.



Use the retrieve dimension tool again. Select linear as the option and select a line on the drawing.



Repeat the process for the shaft.



Save your work.

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Generative Design

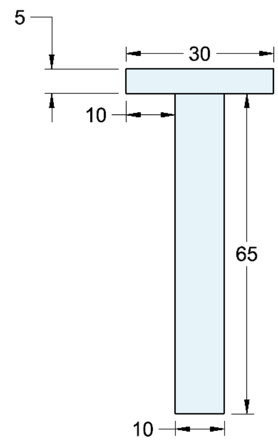
Generative design is a relatively new concept in computer aided engineering. It applies computing power to develop and analyze thousands of solutions to one engineering problem and then suggests a solution. These solutions come from the basic parameters inputted by the designer. Things such as material, basic size, important area, forces applied, and untouchable regions define the parts of the design that must be retained. The process resembles the natural world in that the parts adapt to their environments. Many of the parts resemble organic shapes rather than traditional machine parts.

Generative design is particularly useful in the green design sphere. One of the main goals is to eliminate unnecessary material. Combined with 3D printing, this technology allows designers to create and print exceedingly strong and light weight objects. It also saves time for the designer to spend on other areas of design.

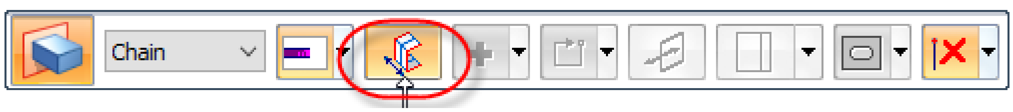
This activity will introduce you to the process of this style of design. It will allow you to create designs that would take weeks otherwise.

Begin a new metric part.

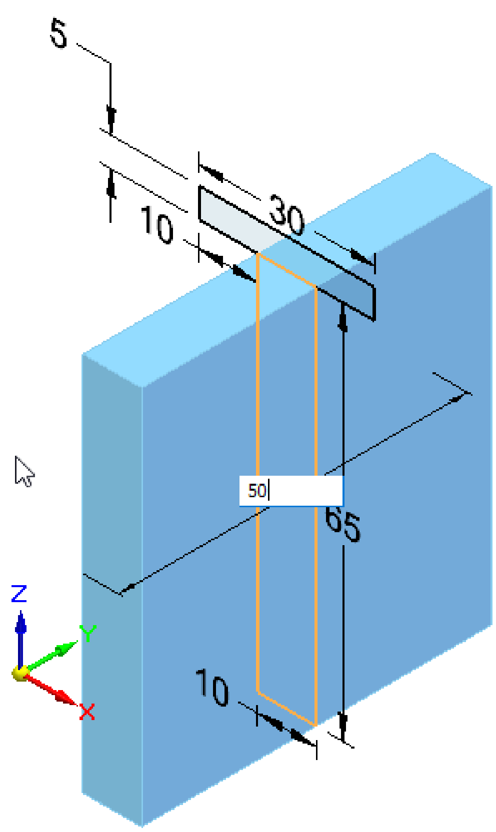
Create the following sketch on the ZX plane.



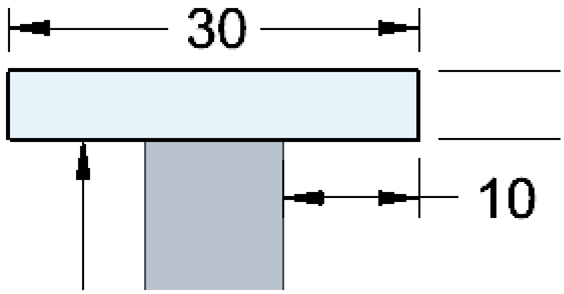
Extrude the bottom sketch 50mm using Symmetric as the option for Extrusion and Chain as the method to select the lines that make up the bottom rectangle.



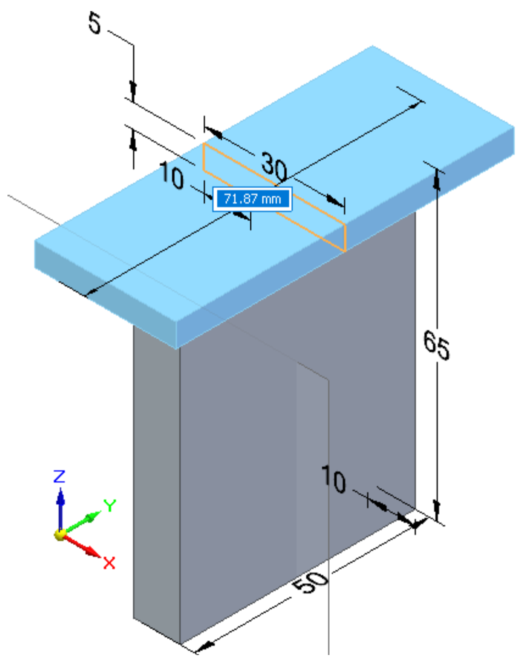
This should leave the sketch at the top.



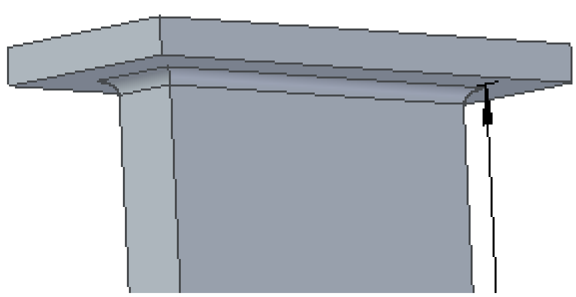
It will be necessary to draw a line between the ends to complete the sketch.



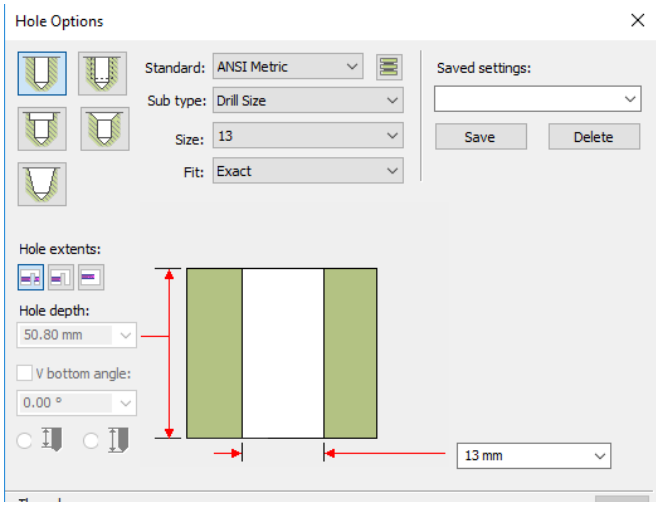
Use symmetric as the choice again and this time use 70 for the extrusion extents. This should leave 10mm overhang from each end.



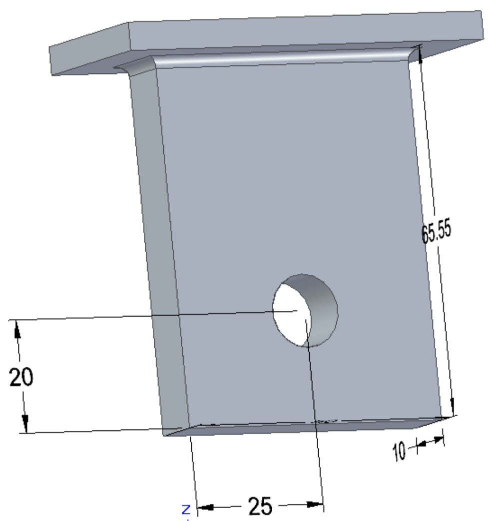
Place a 2mm round at the junction of the two parts.



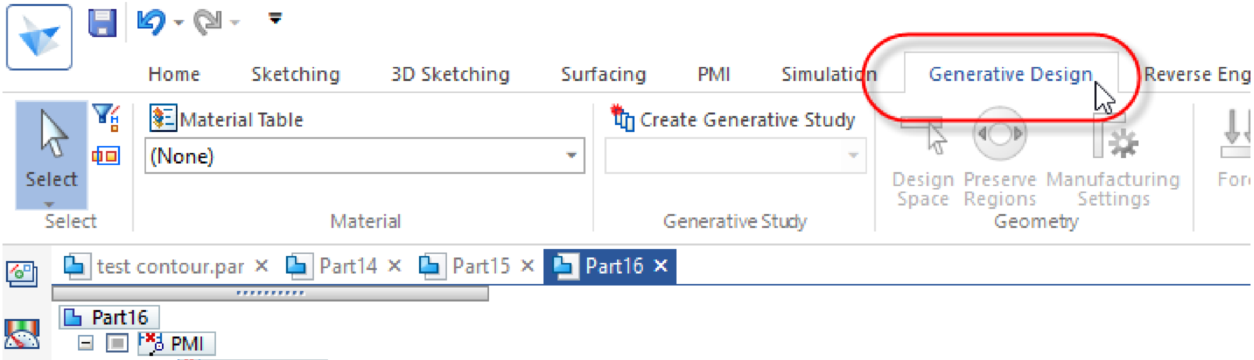
Place a 13 mm hole on the face of the part.



Place the hole 20mm up from the bottom and 25mm from the side which will center the hole in the middle of the part.

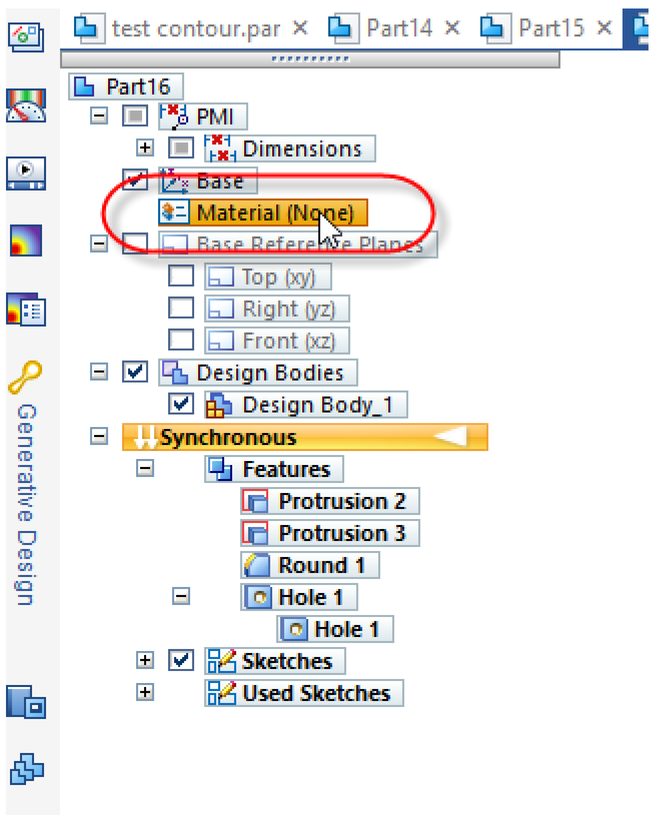


We can now add some parameters to allow the computer to finish our design.
Select the Generative Design ribbon.



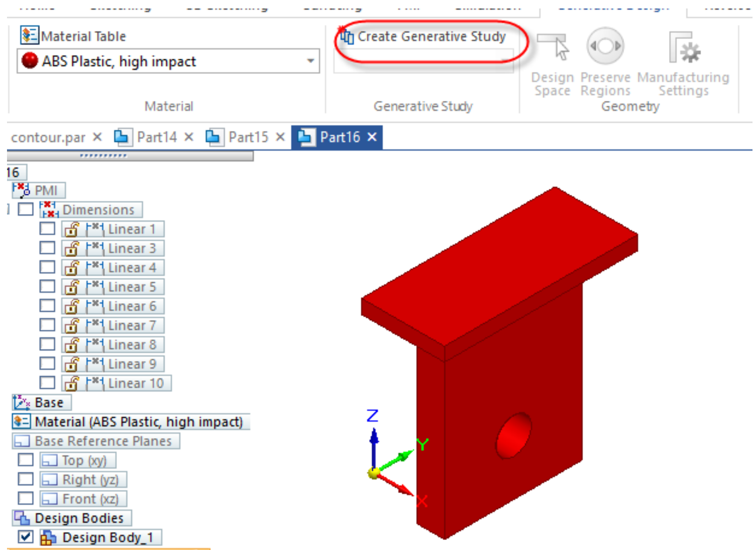
This will provide the tools necessary for creating a generative design from the initial part. The first step is to define the material to be used. This is one of the parameters used by the computer in fabrication of the part. Each material will define the build differently.

In this case we will be 3D printing the part. Select the Material from the part finder.



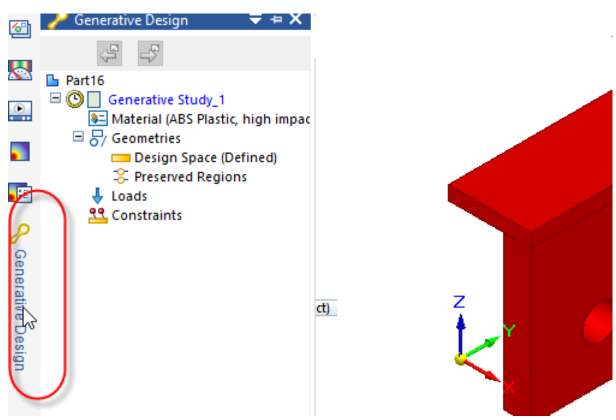
In the dialog box, expand the Plastics and select ABS high impact from the options. Apply this to the model.

The model will take on the color assigned to the material and the material will show up as selected in the Material Table. Next to the material is a button for Create Generative Study.

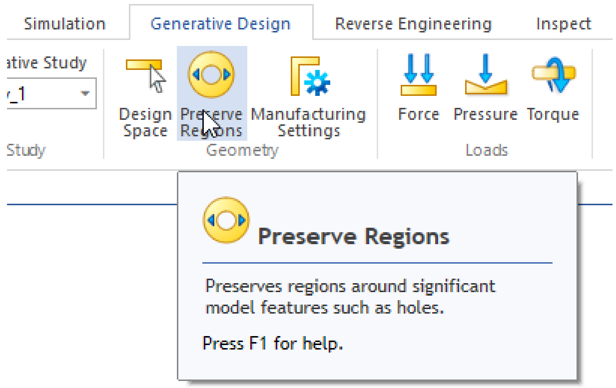


Click the button and Generative Study_1 is identified.

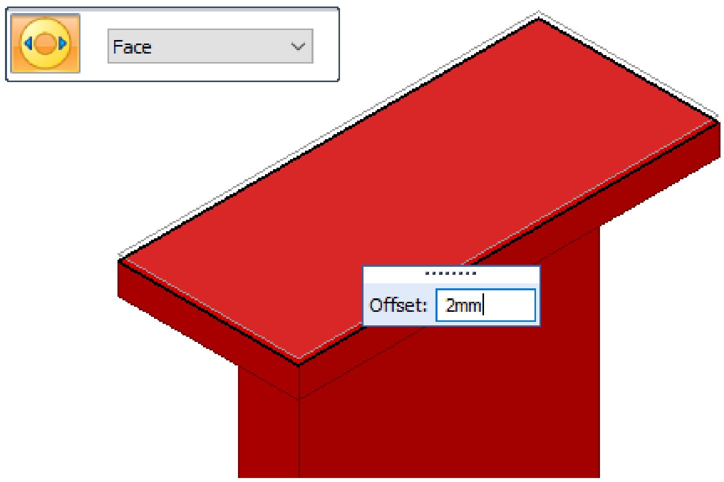
Select Generative design at the side of the Path Finder to bring up information about the generative design.



From the Generative Design select Preserve Regions to allow the definition of important components of the design.

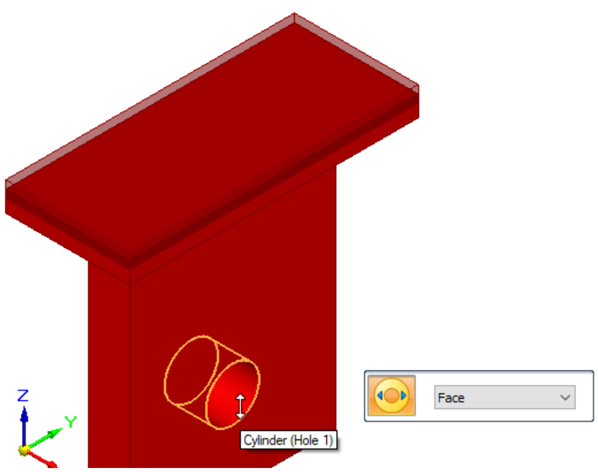


Select the top of the part and set the offset to 2mm.

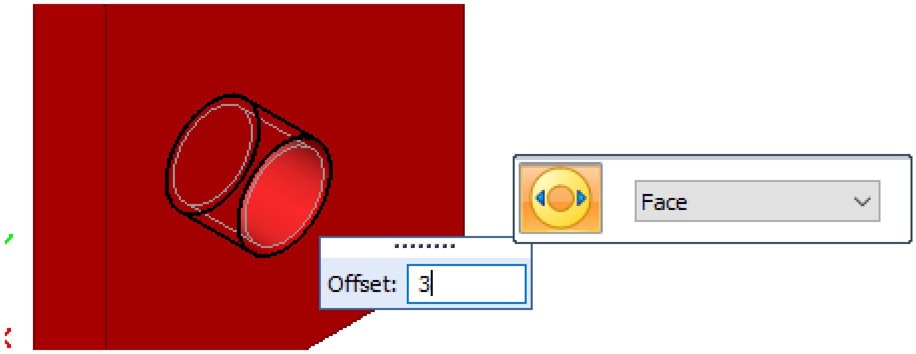


Select the enter key to accept this choice.

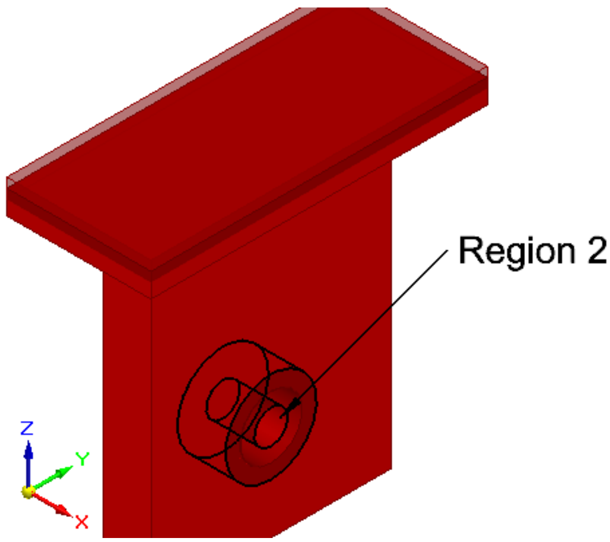
Select the preserve regions again and this time select the hole in the part.



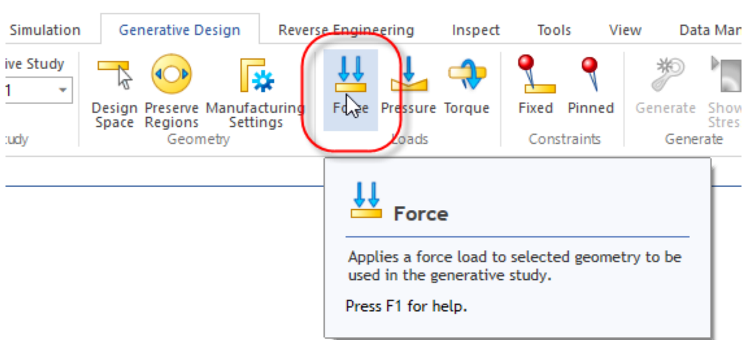
Set the offset to 3mm.



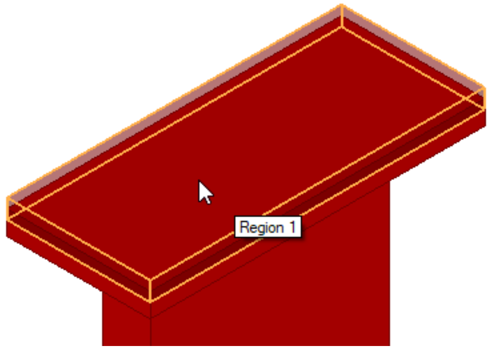
Now that the region is defined select Enter.



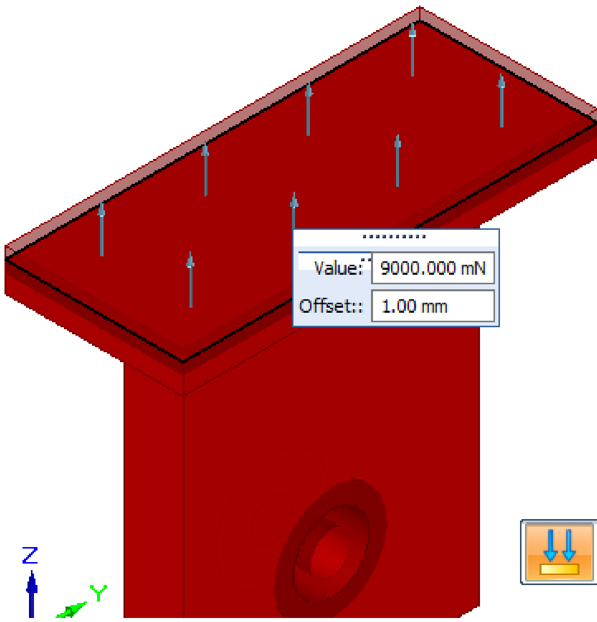
We can now apply forces and pressures to indicate how the part will behave. Select Force from the Generative design ribbon.



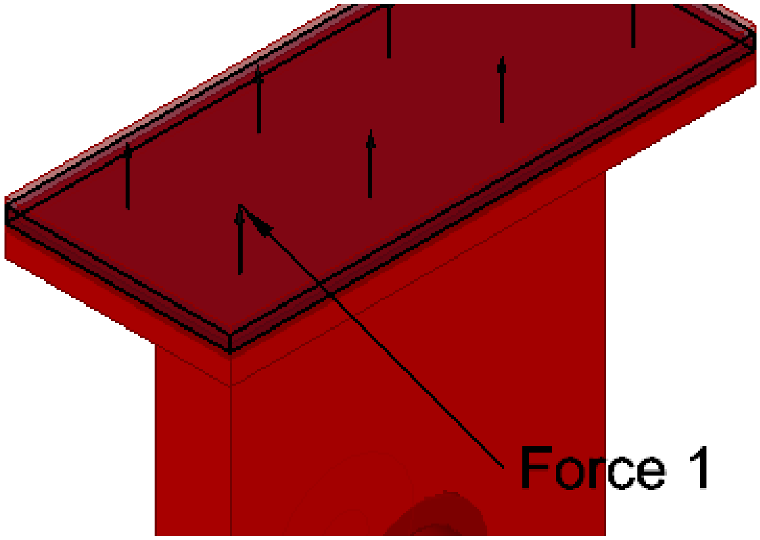
Select the top of the part. This indicates it is Region 1 which is one of the preserved regions.



This example provides 9000mN of force or the amount of force cause by 1kG.

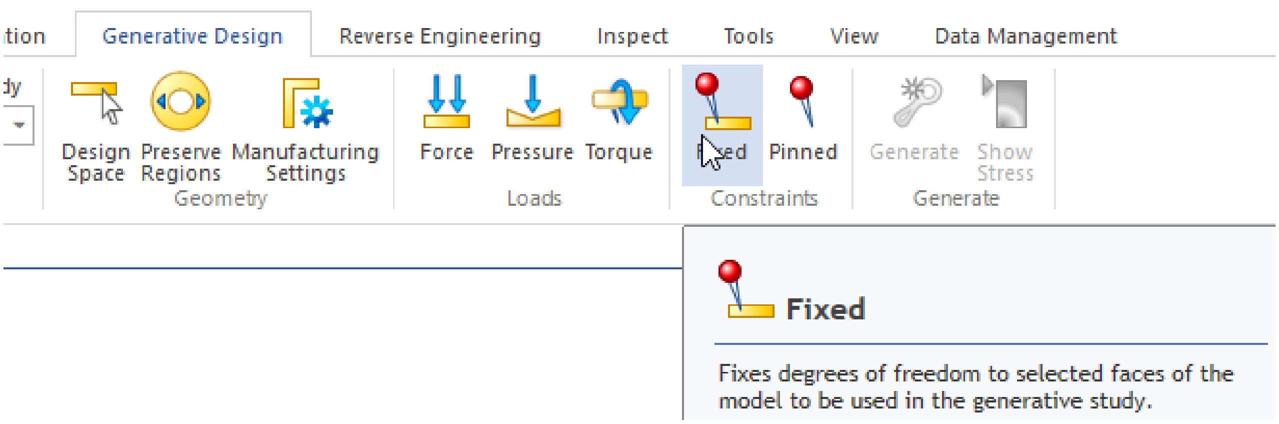


Select enter and force 1 is applied.



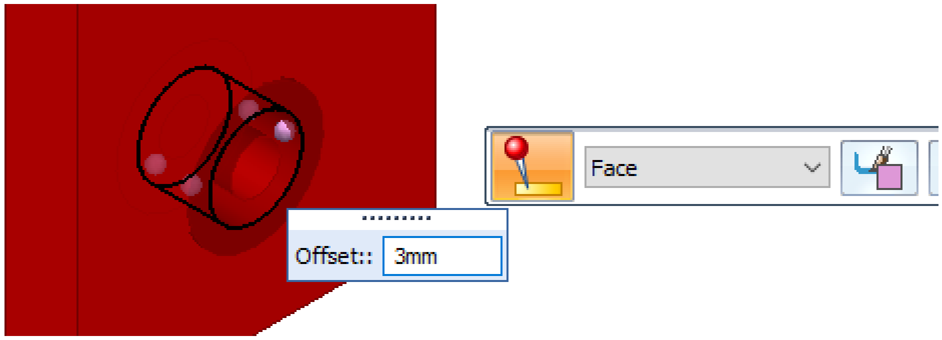
The shaft or bar that will slide through the hole is now trying to stretch the hole because of the force applied.

To let the program know that we don't want it to move we will fix the hole. Select Fixed from the constraints section of the Generative Design ribbon.



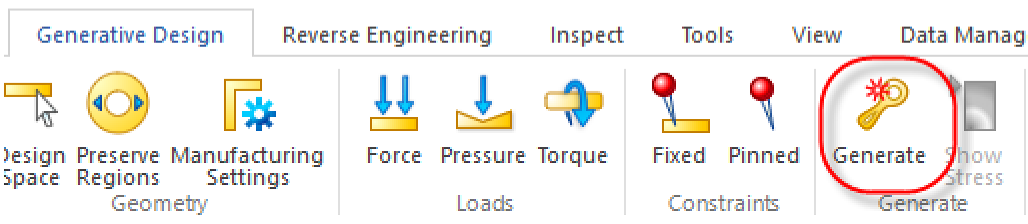
Select the hole.

Set the offset to 3mm which we defined before.



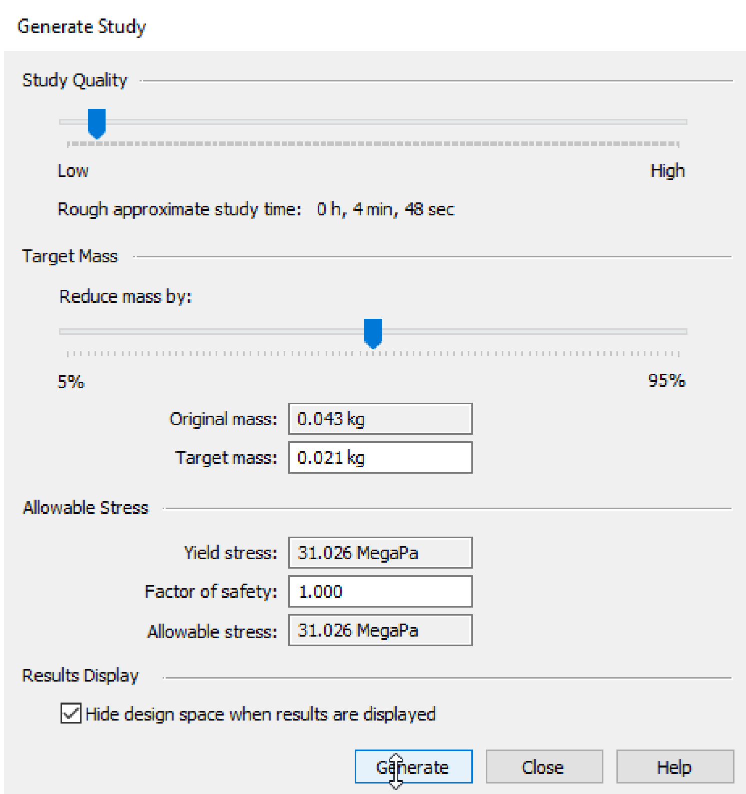
Select enter to apply.

The Generate option should now be available for selection.

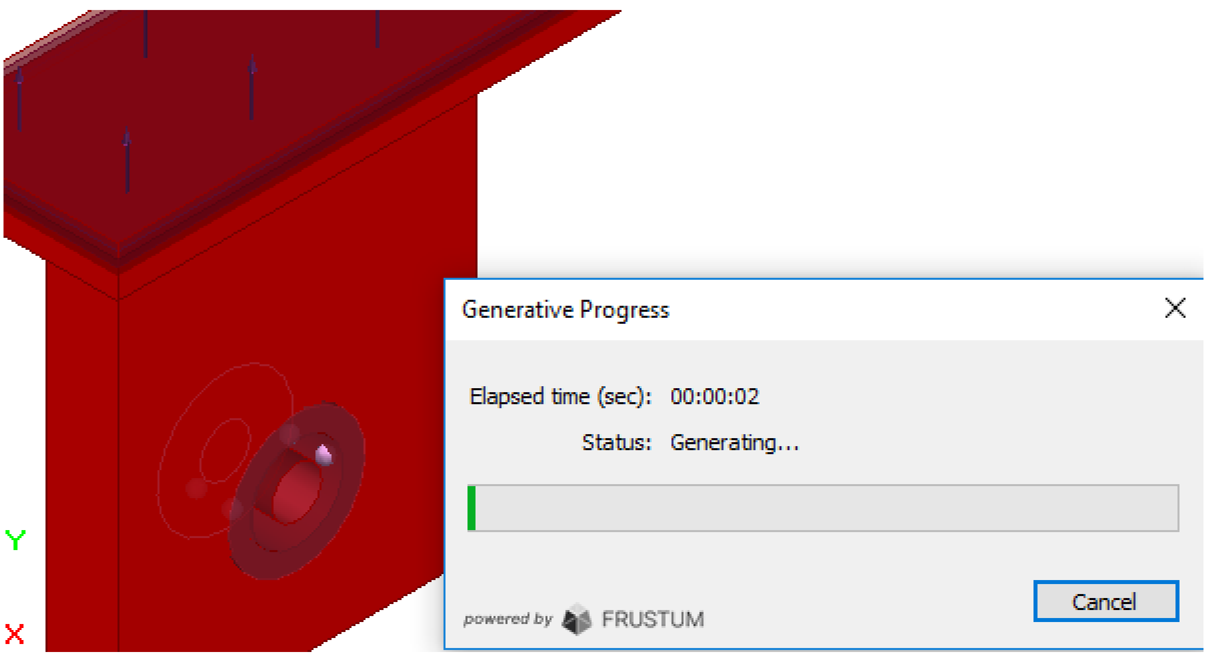


Click on the Generate icon.

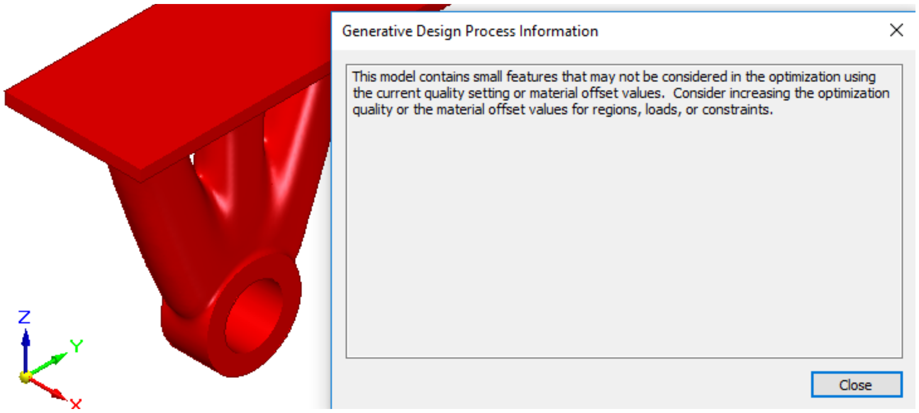
In the options box there will be many options available. The first time through keeping the options simple will speed up the processing time. Later you can extend the settings and see if you can reduce more mass. Set the study quality to 15 to help speed up the process. This example sets the target mass to reduce 50%.



Select Generate and allow the computer time to finish.



When the program is done a warning might be displayed.



In this case the program is looking at the small round we created between the components. It is forcing it to create things it doesn't need.

At this point you can increase the quality setting, eliminate the rounds, or increase the offsets.

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Learning G-Code

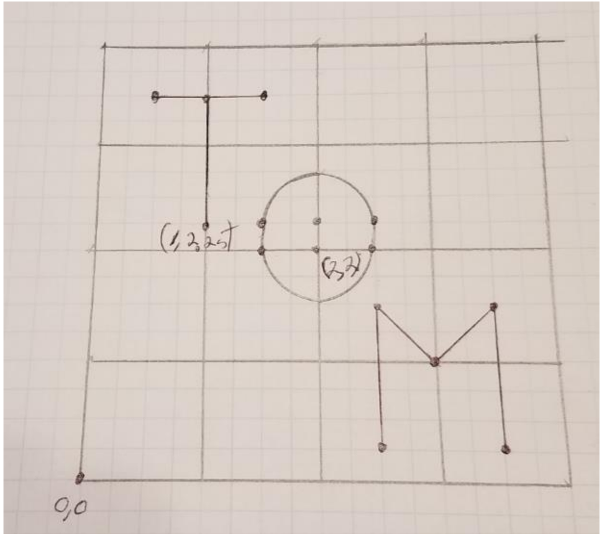
Explore internet to find sites and videos that introduce G&M codes for milling. Some common search terms to find videos and tutorials are:

G&M codes introduction
Basic CNC programming
Beginners guide to CNC programming
G code circular interpolation
CNC tutorial
How to program a CNC machine
Introduction to CNC mill

Once you are somewhat familiar with G codes begin by creating a simple code by hand to create your initials or graphic outline. Be sure you know how to create the following g-codes.

Rapid move
Linear interpolation
Circular interpolation (clockwise and counter clockwise)
Turn the motor on and off
Set the speed of the motor
Set the feed of the machine
Set the tool necessary

Utilize a piece of graph paper with ¼ inch squares. Layout a 4” x 4” square and center (locate) your initials in the 4X4. You should establish all the important points including centers similar to the picture below.

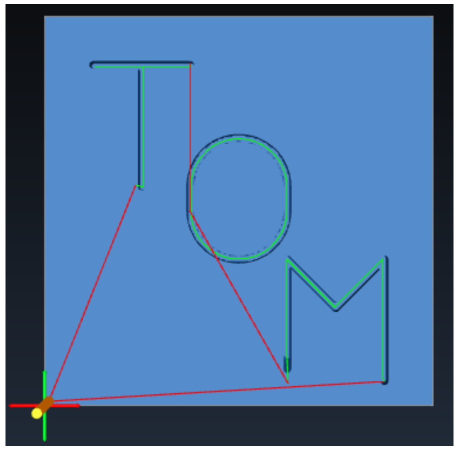


Develop code to create the desired toolpath one line or arc at a time. The semicolon is used to place comments on each program step. It is a good habit to document all steps. Begin by creating a new text document by right clicking on the desktop and selecting New and selecting Text document from the options.

File Edit Format View Help

```
G90                      ;Absolute coordinates
G20                      ;Measurements in inches
G00 X 0.5 Y 0.5 Z 2.0    ;Rapid to tool change position
M06 T1                   ;Tool change tool 1 end mill
M03 S2500                ;Sets the spindle to clockwise and the speed t
G00 X1 Y2.25 Z.5         ;Rapid to point above the first point
G01 X1 Y2.25 Z -0.1 F15  ;Linear motion into the part at feed of 15
```

Your code should be saved when completed. You will enter your code into a simulator to be sure it works. This example uses CAMotics (www.camotics.org), an open source software which will simulate the results of the coding. Become familiar with a simple simulator for verification. The manual for CAMotics is available from https://camotics.org/manual.html. The manual is short but provides a good overview of the process. The cutting tool will have to be defined to match the tool specified in their code. This will allow students to find mistakes before going to the milling machine.



Once the code is tested, you will be introduced to the mill in small groups. Your teacher will review the safety rules and aspects of using a milling machine and cutting tools.. Proper eye protection is a must and you will be required to wear safety glasses. You should view basic setup videos for their mill and be familiar with how to set the Point Reference Zero (PRZ).

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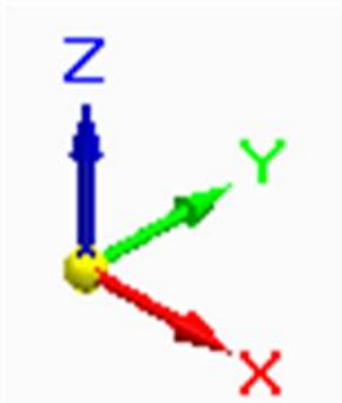
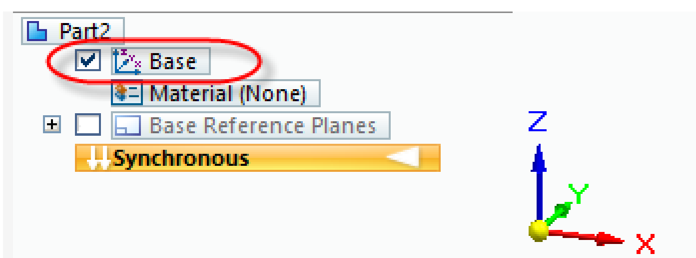
Learning CNC

Coordinate systems



This symbol on the screen should be familiar to students when using Solid Edge for design work. This represents the three axes and the planes created when using them. In Solid Edge they are called the Base.



When beginning to design for CNC milling machines, each axis represents a movement of the machine. The X axis represents the left and right motion of the table on the machine. The Y Axis represents movement from front to back and the Z axis represents the up and down motion of the machine.

The mathematician Descartes described a method of establishing any point on a plane with just two numbers one for X and one for Y. There is a story of Descartes lying in bed watching a fly crawl on the ceiling and deciding he could pinpoint the location of the fly by identifying the distance from each wall. If you add a third dimension you can position the fly anywhere in the room with just 3 points.

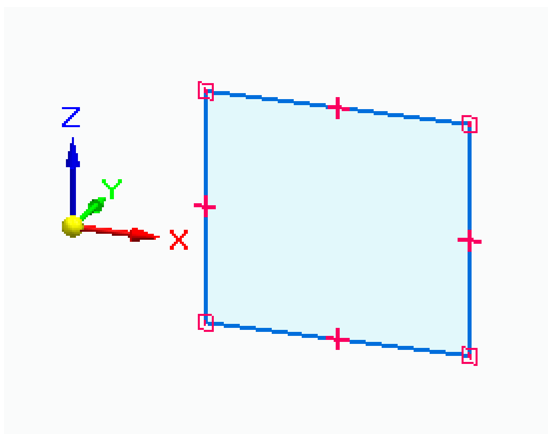
To control a machine we need to establish a reference point for X, Y & Z. In the first few exercises we will be using the corner of the block to provide the origin or point reference zero (PRZ) for the part.

Locating a Sketch

Begin a new part file.

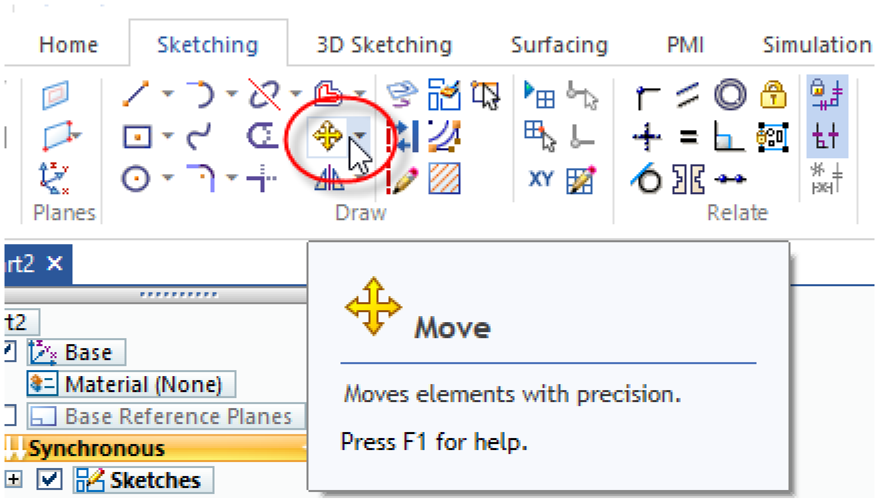
Moving Sketches

There are times when you want to move a sketch in Solid Edge. After fifteen minutes working on the sketch and getting it just right, it may not line up with the Base coordinates. Moving the sketch to locate the coordinates so 0, 0, 0 is located to provide the top left hand corner of your block will make this process easier. Begin a new part and sketch a rectangle.

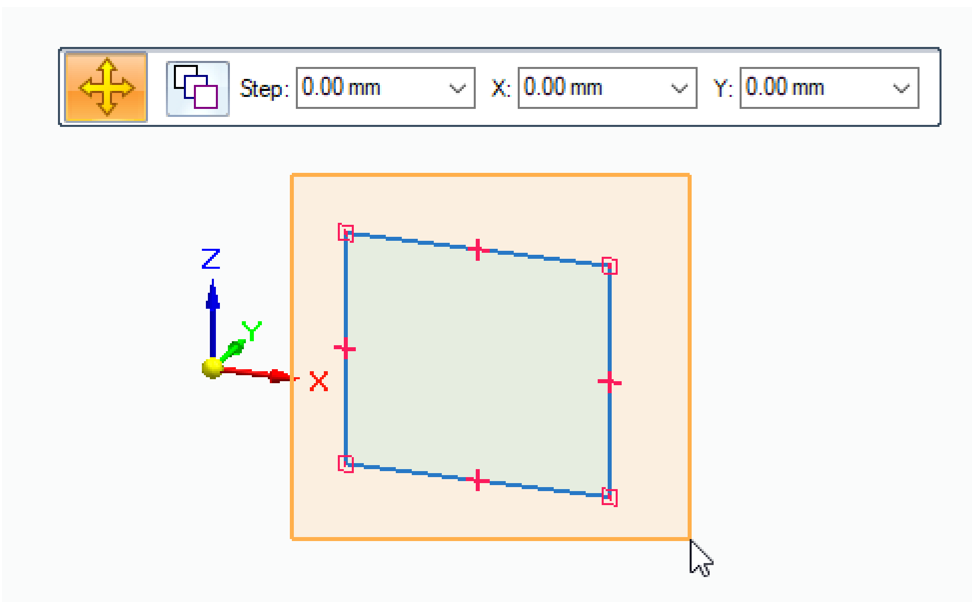


Use the ESC key to exit the rectangle command.

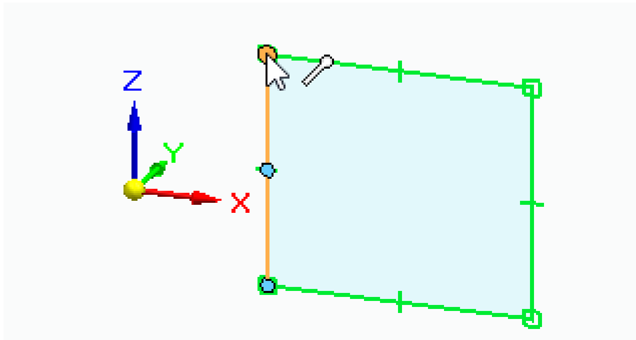
Select the Move command from the Draw section of the Sketching ribbon.



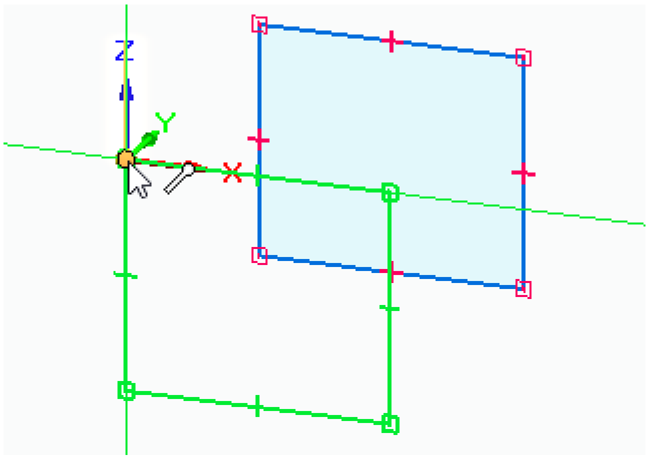
When the Move dialog box appears, highlight the rectangle by dragging a pick box around it.



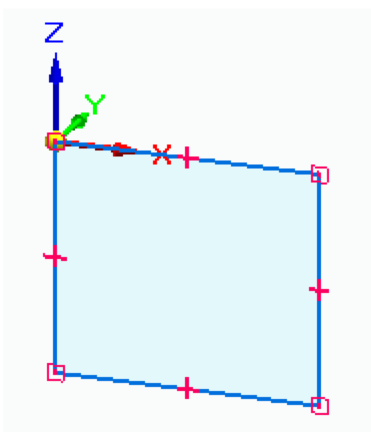
Select the corner of the sketch desired for the 0, 0 coordinate of the current plane. Look for the end point symbol.



After you select the corner to be 0, 0 it will follow the mouse cursor around. Select the yellow junction of the base.



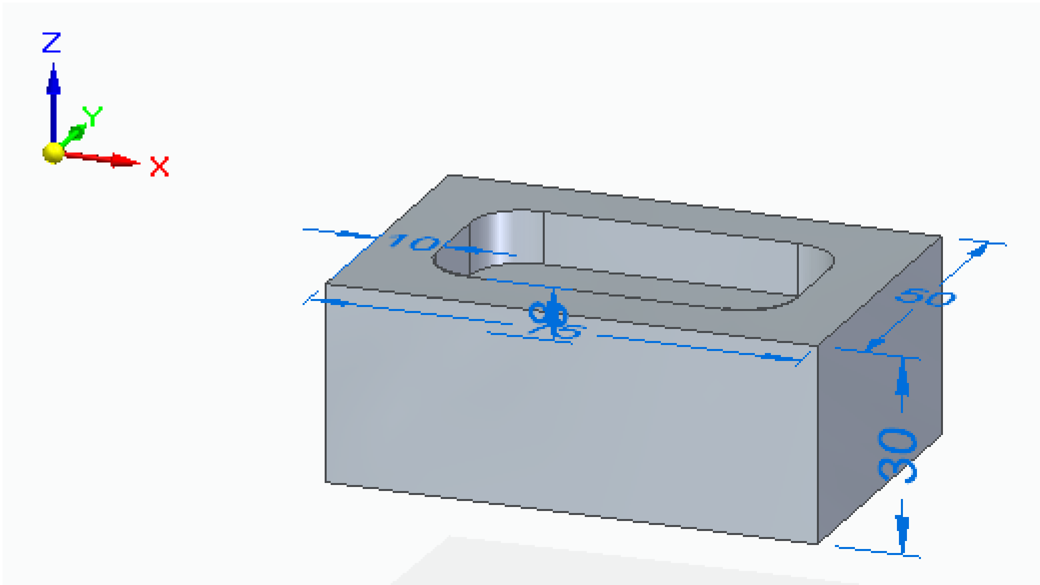
The corner of the sketch is now at 0, 0 on the plane.



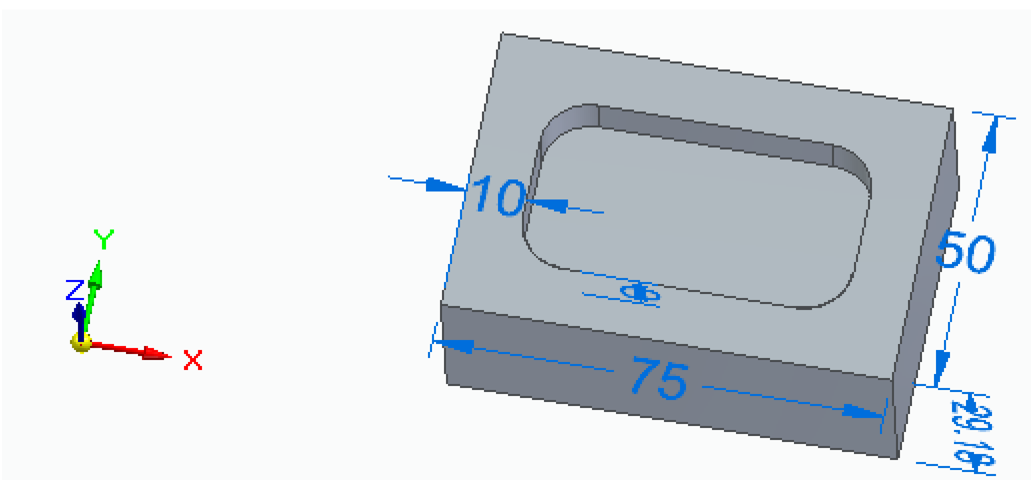
Moving Objects

There are times when the entire part is already in existence but at the wrong location to bring in and have the top left hand corner be in the 0, 0, 0 position.

Start a new part. Draw something similar to the following part.



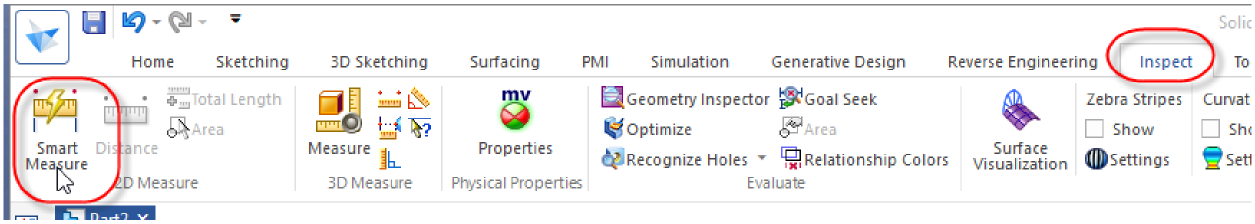
To move the component into the correct position move the top, front left hand corner to the yellow ball indicating the 0, 0, 0 position. Move the view until the block is in the orientation needed.



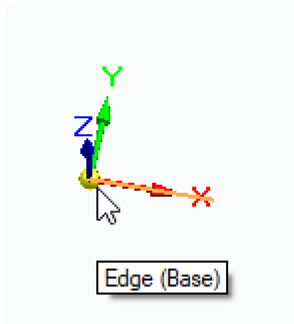
To maneuver the component to the correct position, it is necessary to know how far to move the object.

Inspect-Smart Measure

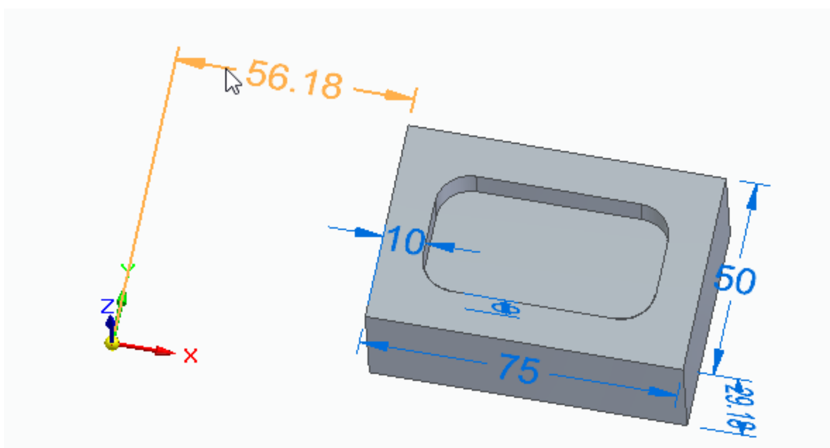
Select Smart Measure from the Inspect ribbon.



First select the yellow ball representing the X-base leg.



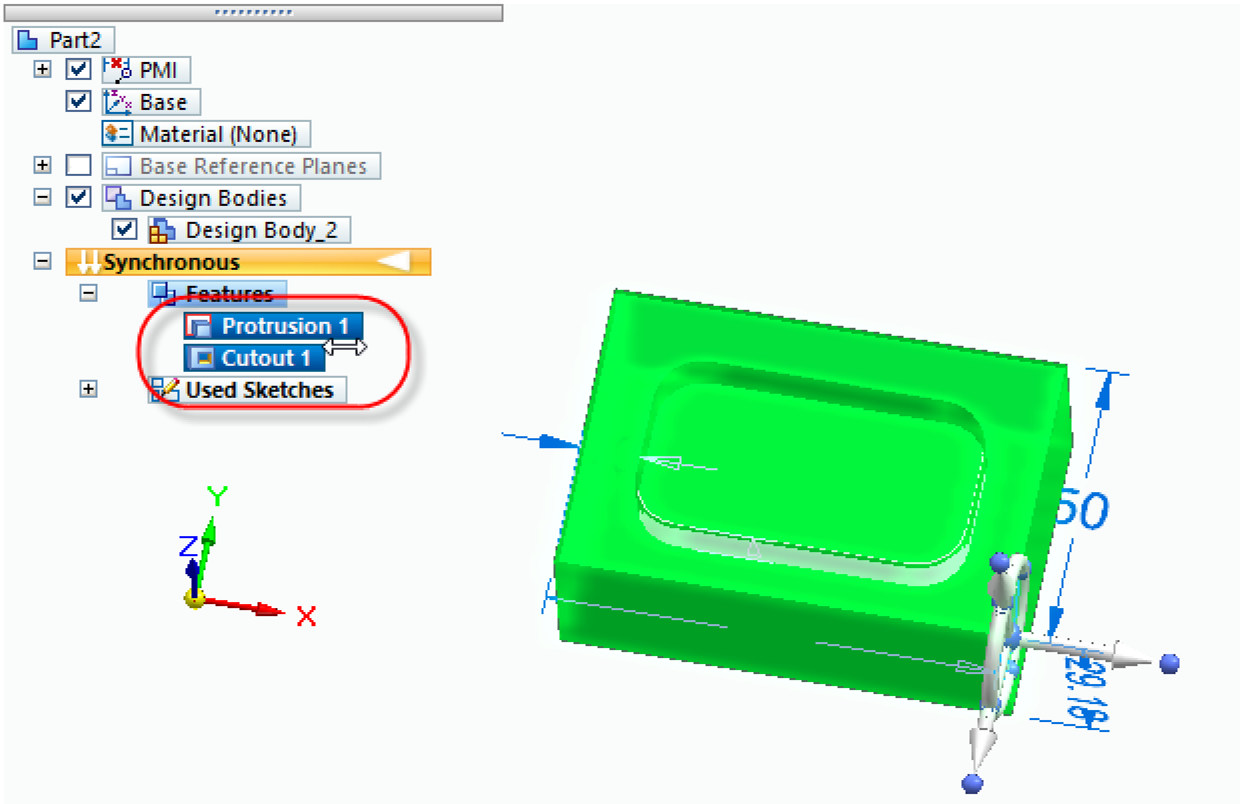
Then select the side of the block to provide the exact distance to the base.



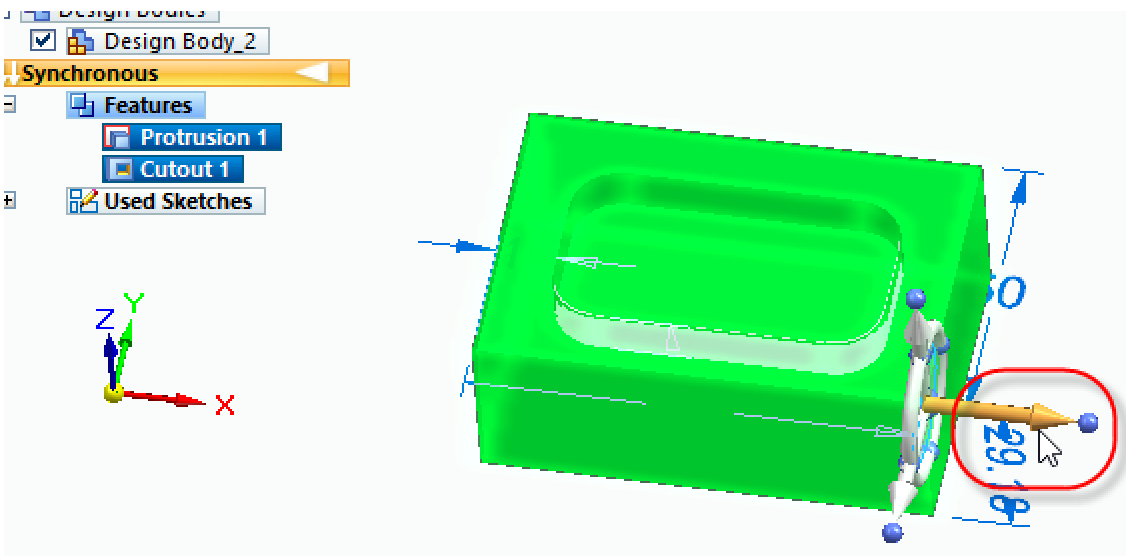
This information will determine how far to move in the X direction.

Selecting the Part

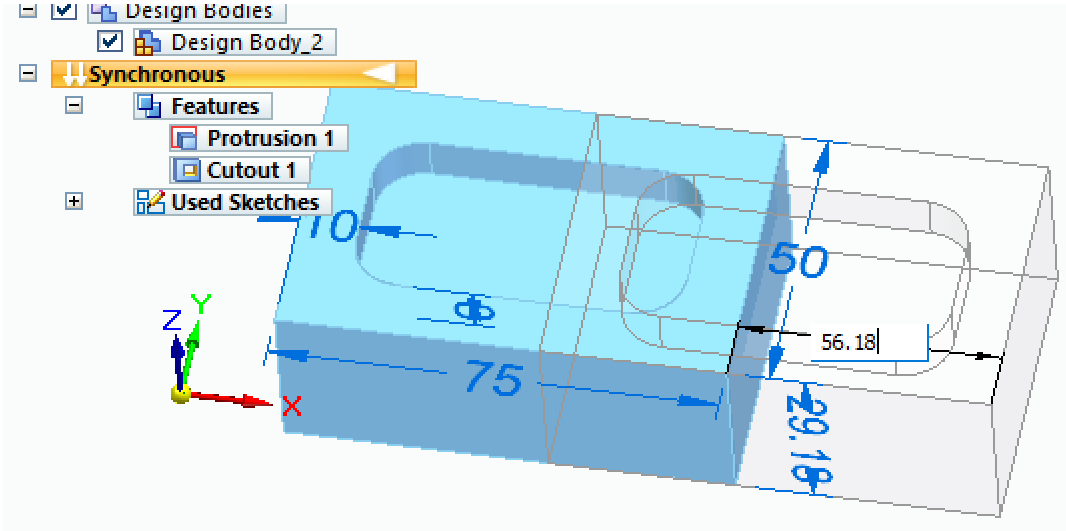
In the Part finder highlight all features of the part. See them highlight and then see the part.



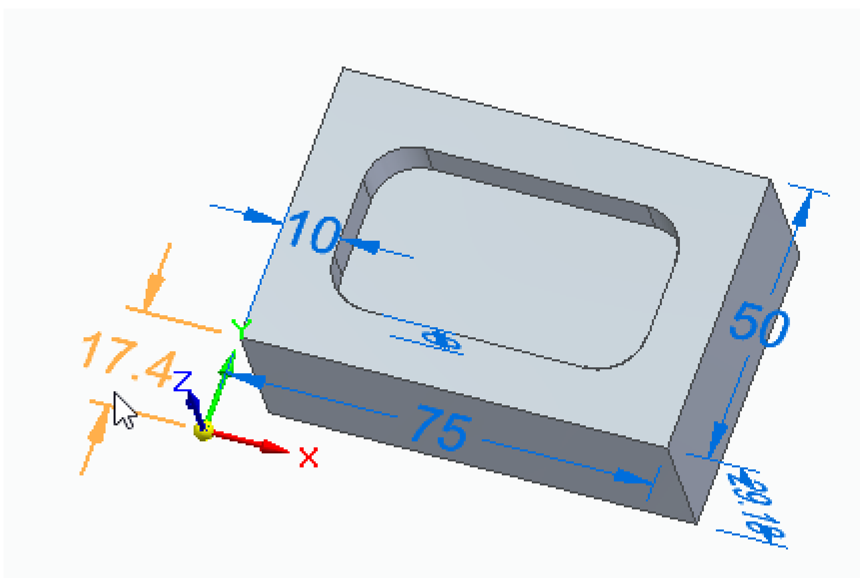
Once it is highlighted the steering wheel will be visible. Select the arrow representing the X axis and begin to drag toward the base.



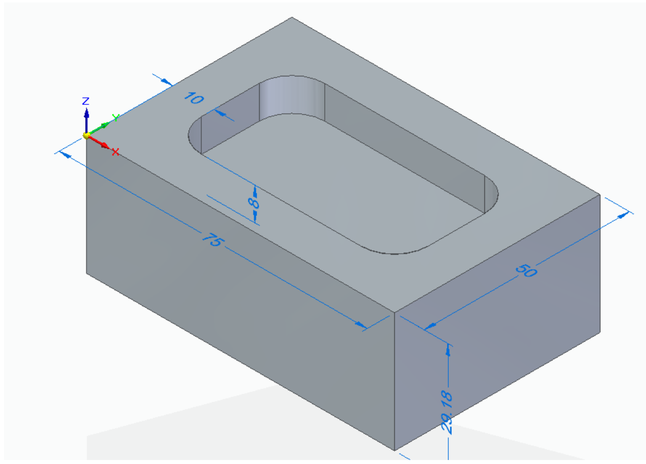
The window will appear to be able to enter the value from the smart measurement created earlier.



Hitting the enter key will move the block in the correct direction and be aligned with the base axis. Repeat as necessary to move the block into the exact position.



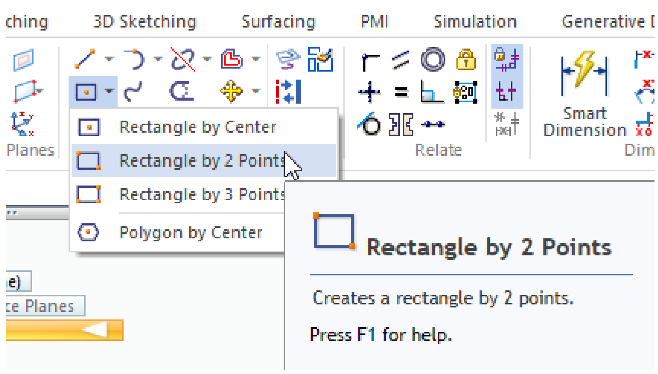
The Base should now be on the top, left hand front corner of the block.



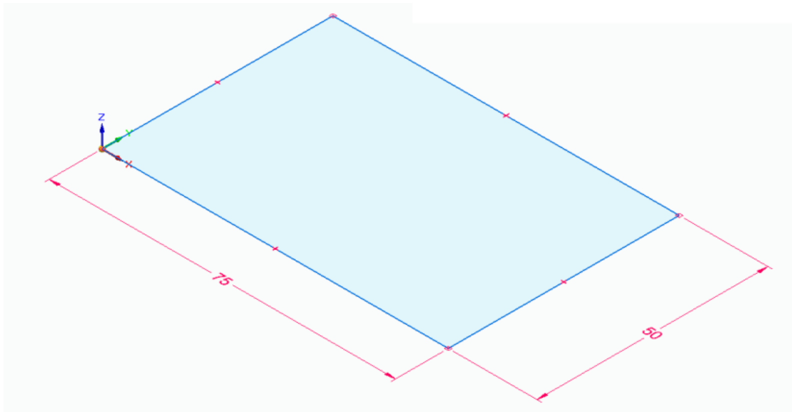
Creating the First Part

Create the first part with the appropriate corner at 0, 0, 0. This will assure, once introduced to the CAM tool, the part is in the proper orientation and position, greatly simplify the students' first attempt. With more experience, students will learn to set the coordinate system for the part.

Begin a new metric part in Solid Edge. Use the rectangle by two corners to create a rectangle on the XY plane.

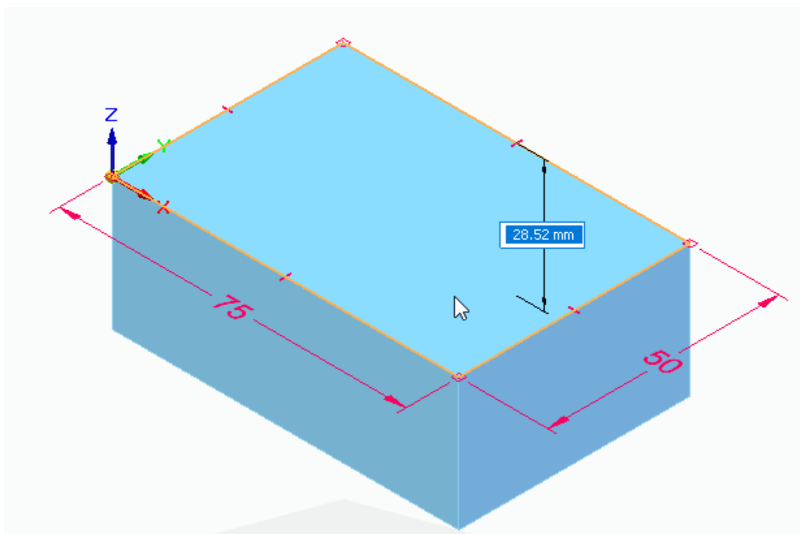


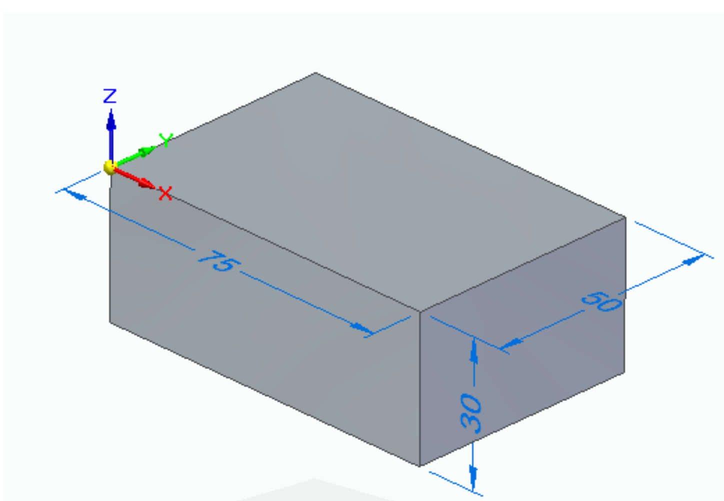
Select the base as the first point. Size the rectangle so it is 75 mm in the X direction and 50mm in the Y.



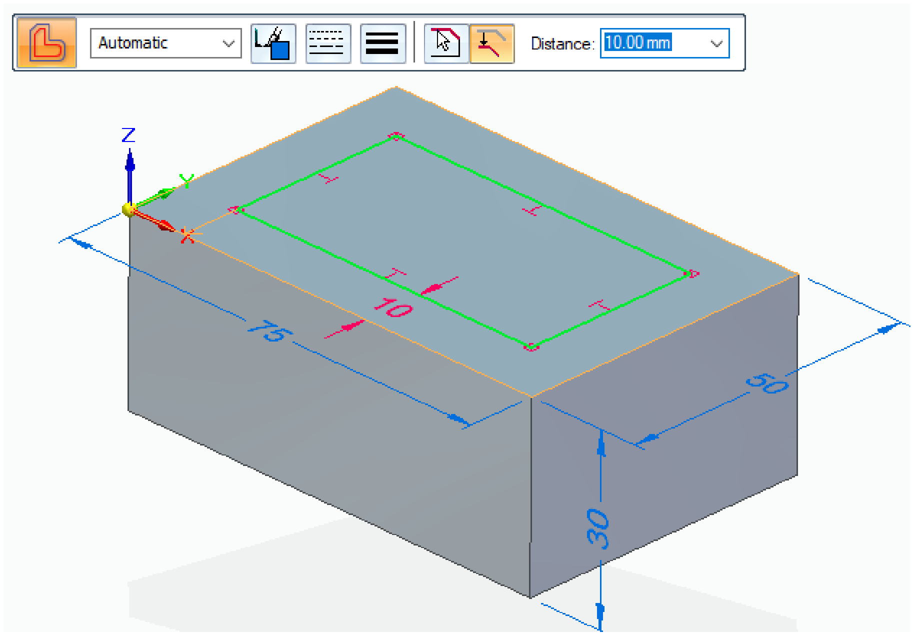
Be sure the initial corner is on the Base.

Extrude the block down 30 mm.

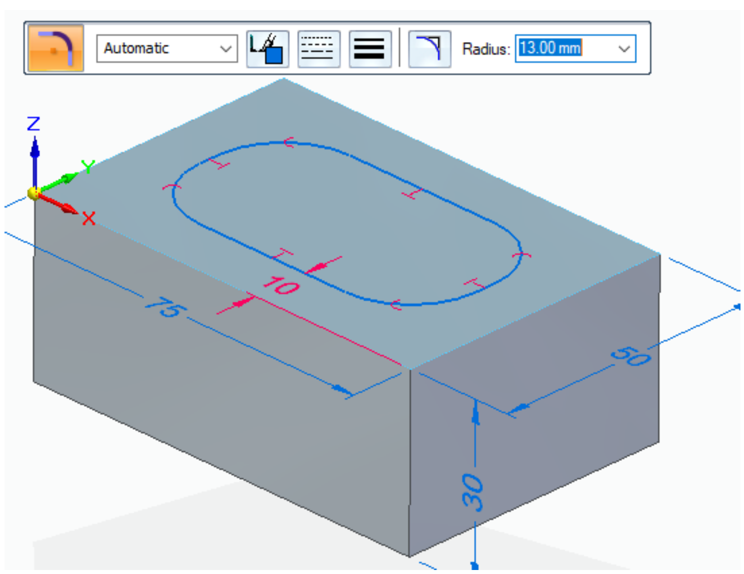




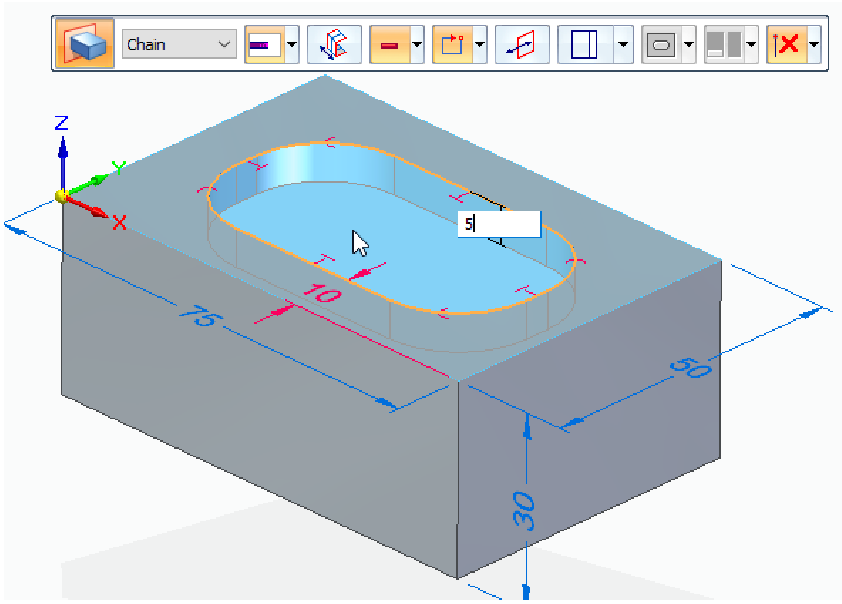
Place the sketch on the top of the block. Space the rectangle 10 mm from the sides of the block.



Use the Fillet tool from the Solids section of the home menu to round the corners of the rectangle. Use 13mm for the radius.



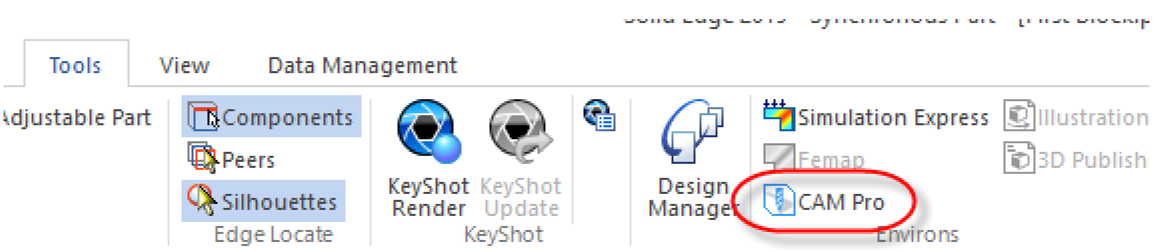
Use the Extrude/cut function to create a pocket 5 mm deep on the top.



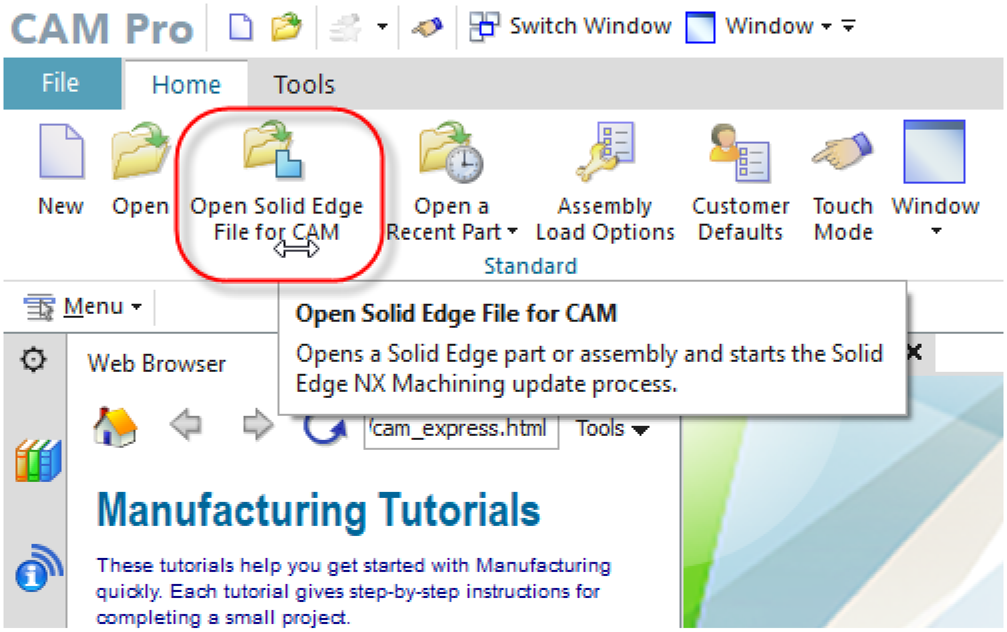
Save the part to a directory accessible with a recognizable name. In this example the file was named “first block”.

Importing a Part

There are a number of ways to open the file in CAM Pro. The first way is to use the tool in Solid Edge. On the Tools ribbon in the Environs section, select the CAM Pro icon.

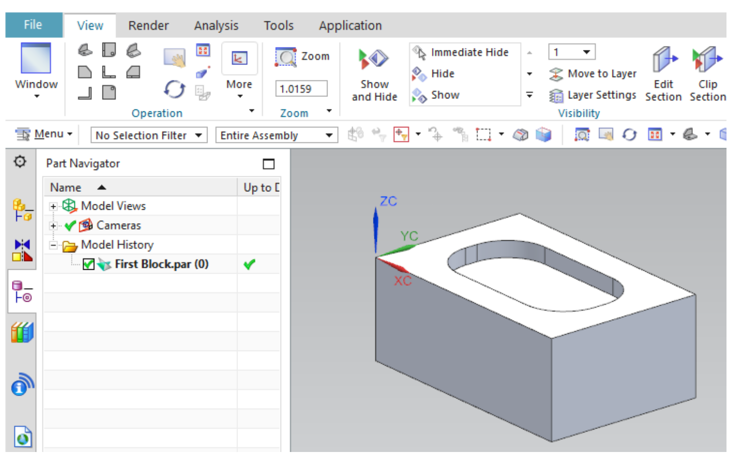


Another option is to open Solid Edge CAM Pro and use the icon on the Home ribbon and select the Open Solid Edge File for CAM option.

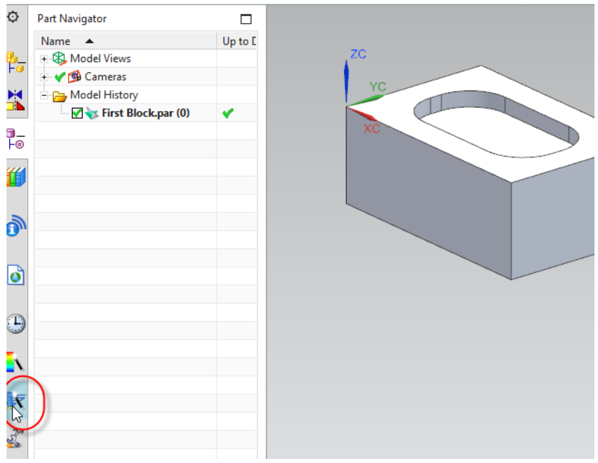


You can also go to the file pull down menu and select open.

Either way you select will open the block in Cam Pro.

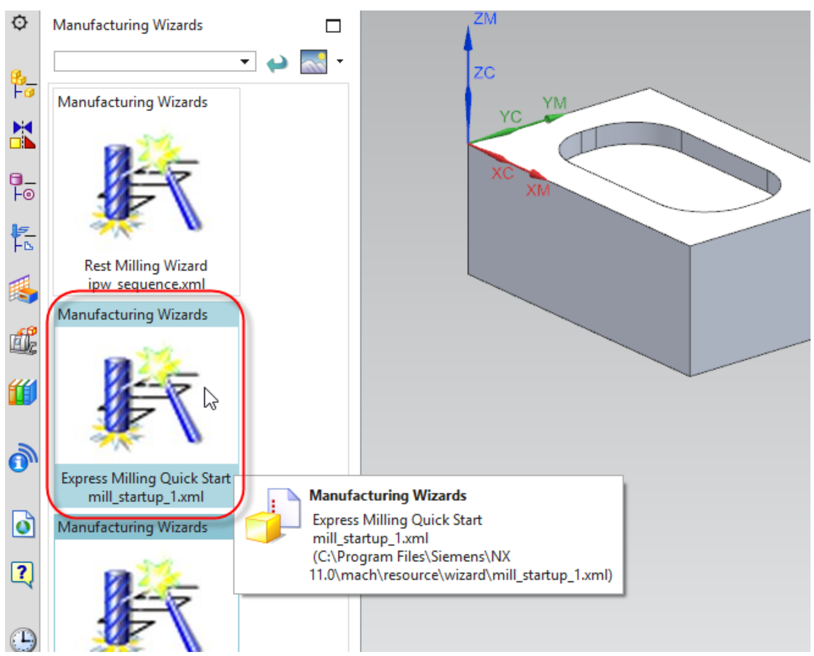


In this example, the block opens and the Part Navigator is visible on the left hand side. This section keeps track of all the operations you use. The fastest way to generate code is to use the Manufacturing Wizards. The link is found on the resource bar on the left side of the screen.

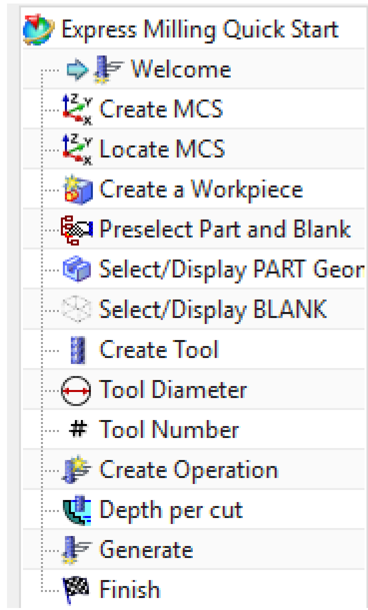


The icon resembles a tool with a magic wand.

Select the wizard for Express Milling Quick Start.

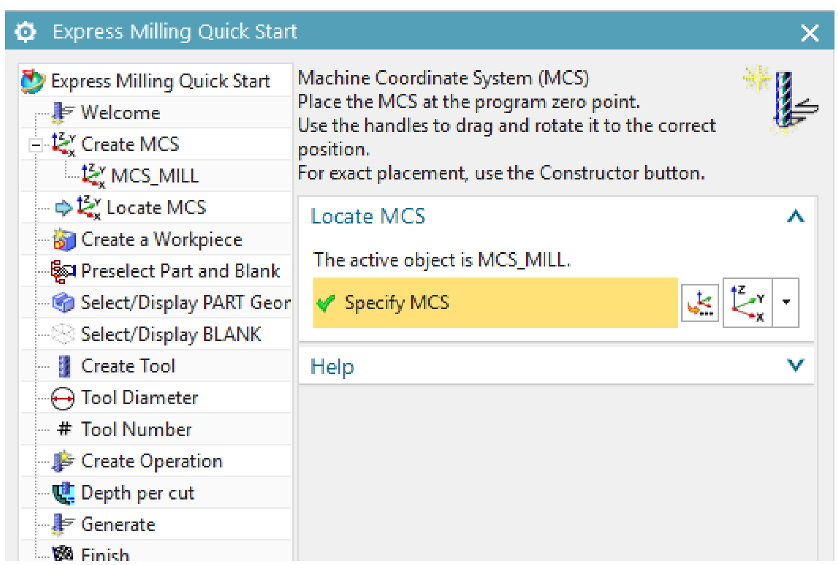


These express setups will provide the user with guidance while working through setting up the creation of tool paths the first few times. The flow of steps needed from the top to bottom of the list in the dialog box will be shown. When one step is finished select Next to be automatically taken to the next step.

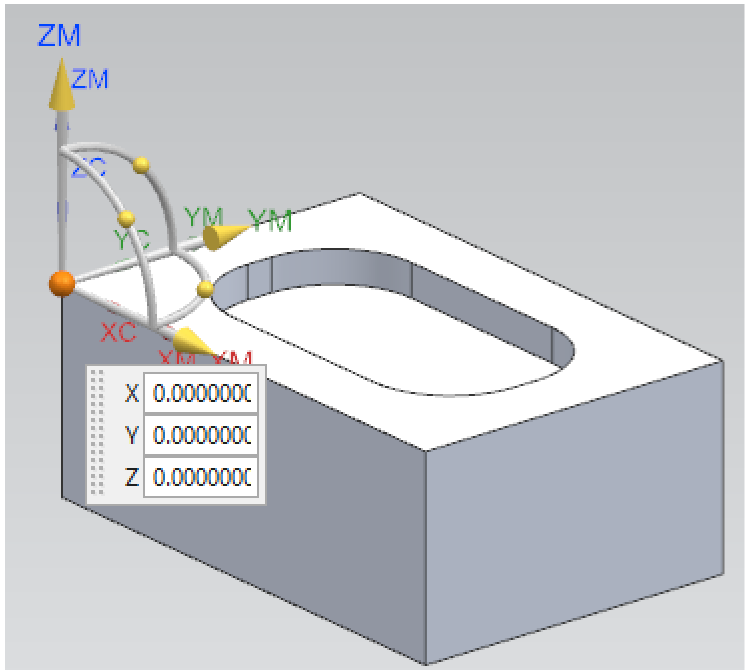


This exercise serves to explain the process, meaning, and the background for each step. Later when working through some tutorials, the basic vocabulary will be familiar making various processes easier to understand.

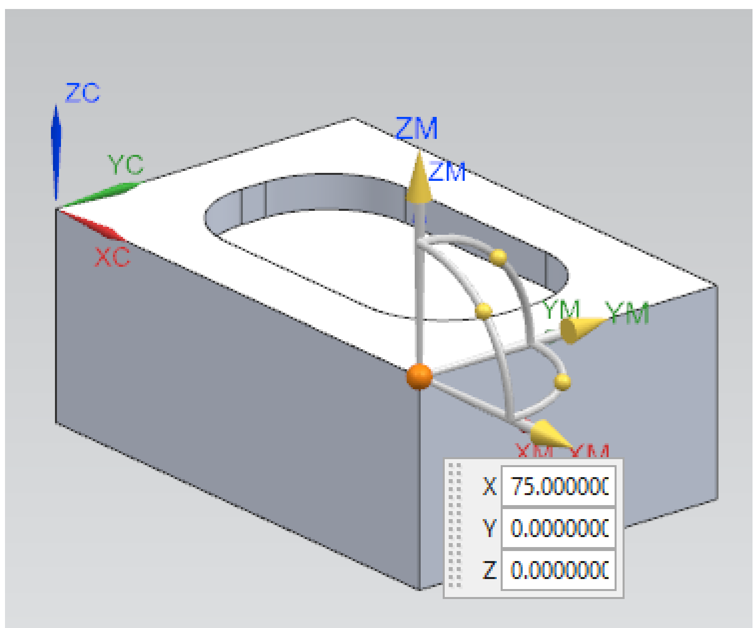
Select the next button to proceed to the Create MCS step.



This step allows the location of the point on the block at the zero point. This point represents 0, 0, 0 in the machine coordinate system If you observe the screen notice it has found the 0, 0, 0 point because the block as imported had the 0, 0, 0, located in the correct spot. If your block is not in the correct location you can specify it with a series of points, planes and/or lines.

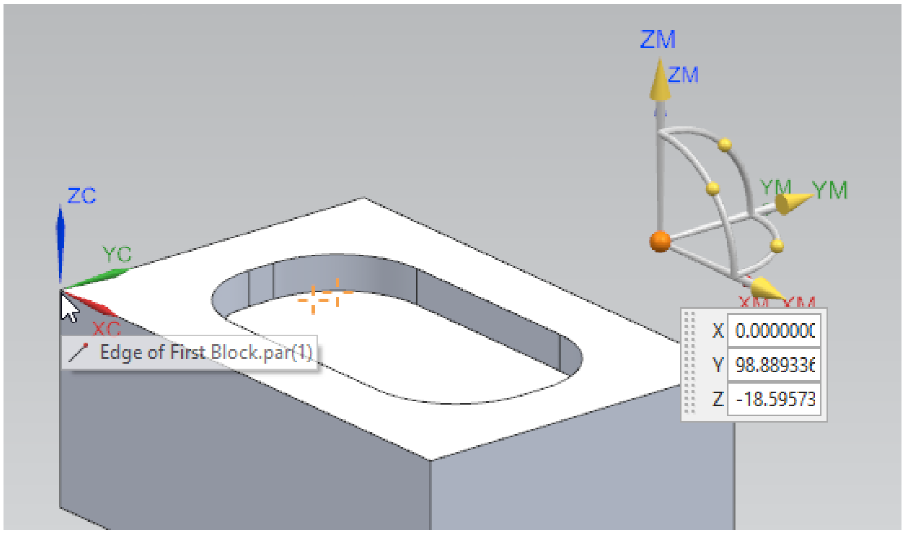


Try changing the X value to 75mm which is the length of the block in the X direction.



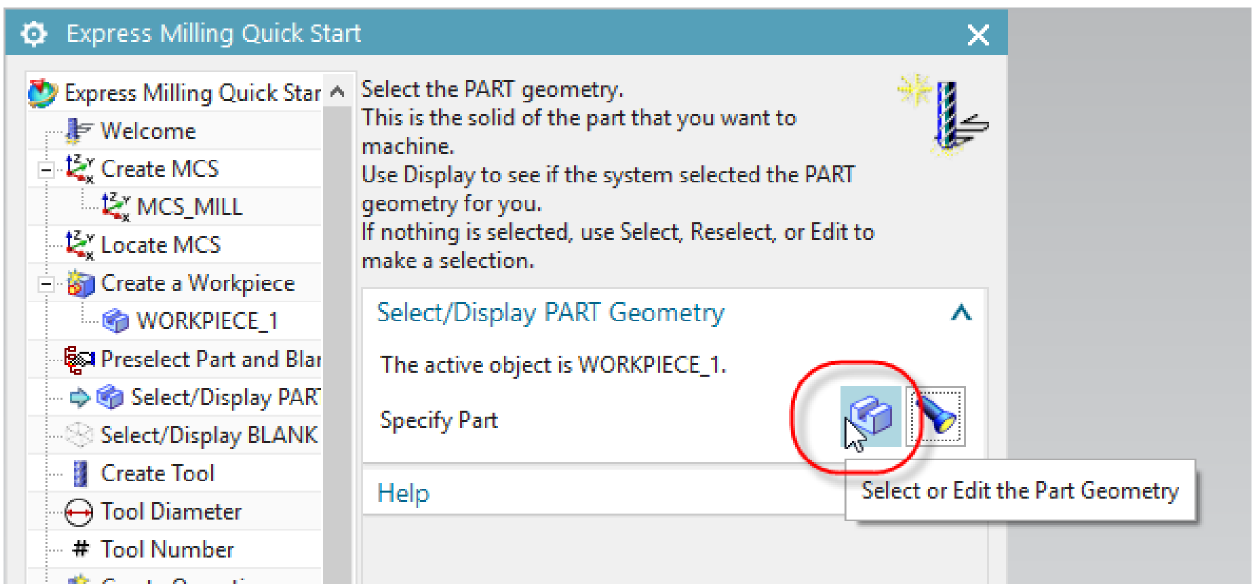
Try other dimensions and see what happens.

Try clicking on the block after seeing the endpoint symbol. This will cause the Machine Coordinate System (MCS) to locate back at the corner without having to type it in.

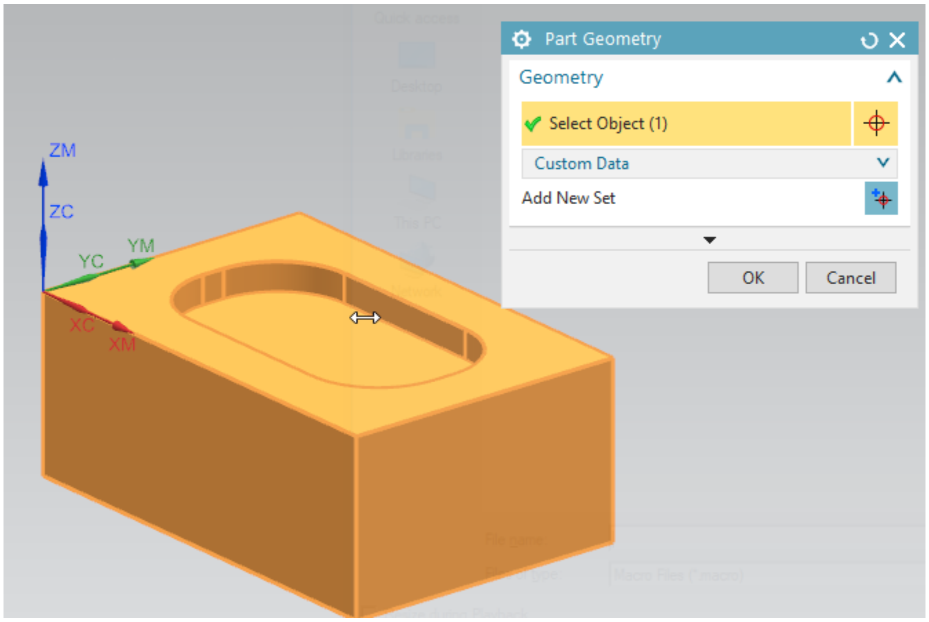


Be sure it is at the top left hand front corner before clicking on the next button.

The wizard located the MCS and is now concerned with the part geometry. In this section we are identifying the components that make up the part we are interested in. Select the icon for selecting or editing the part geometry. In our example the geometry is very simple.

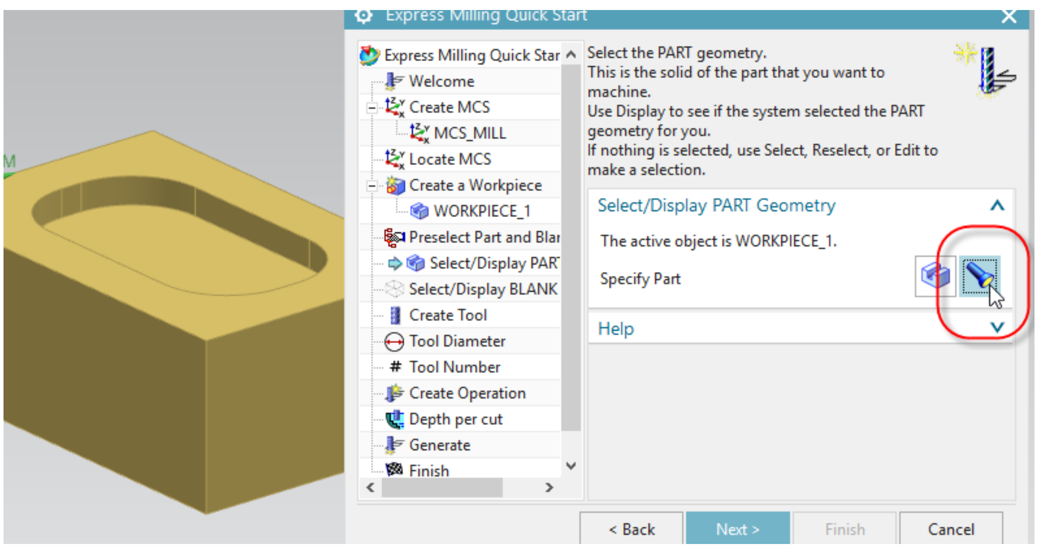


This will open the dialog box. Select the block by clicking anywhere on it.



After clicking on the block select the OK button.

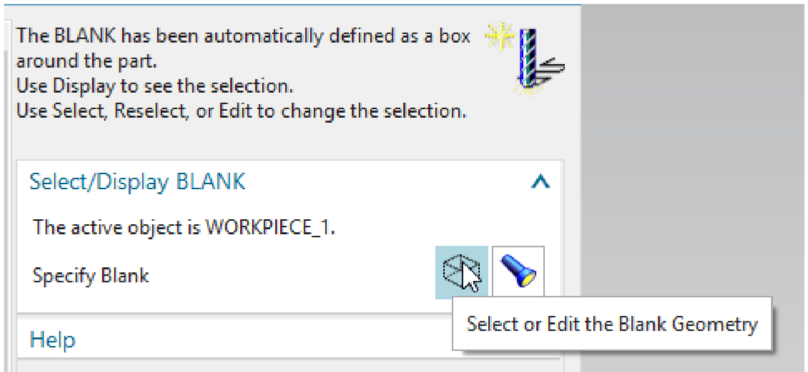
This will take you back to the wizard. Select the Flashlight button to display what it selected. The block should change color if it was properly selected.



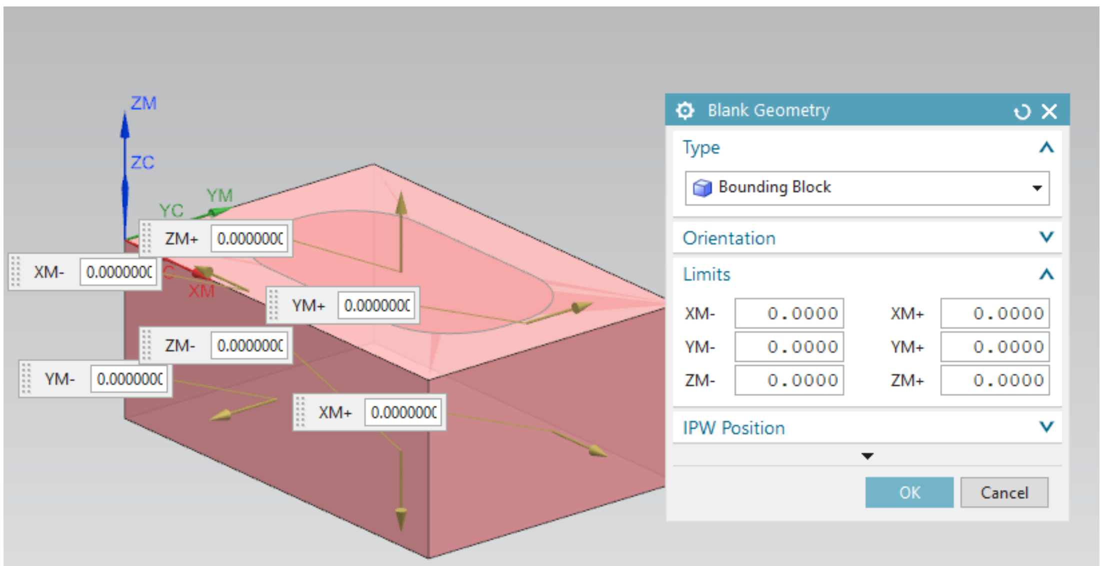
Select the Next button.

The next section is the blank. A blank is a box that surrounds the part you are working on. It represents the un-milled workpiece or raw stock.

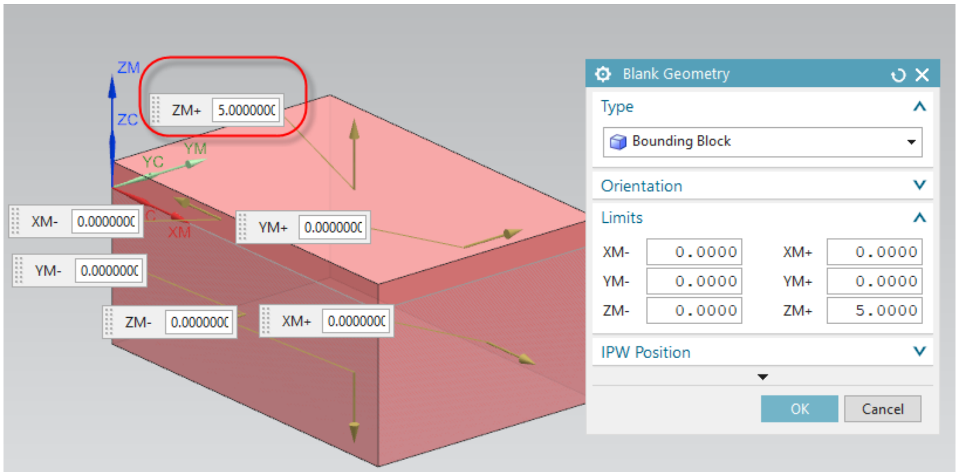
This step defines what the stock is or should be.



In this example the program knows what the blank should be and the selection is automatically made.



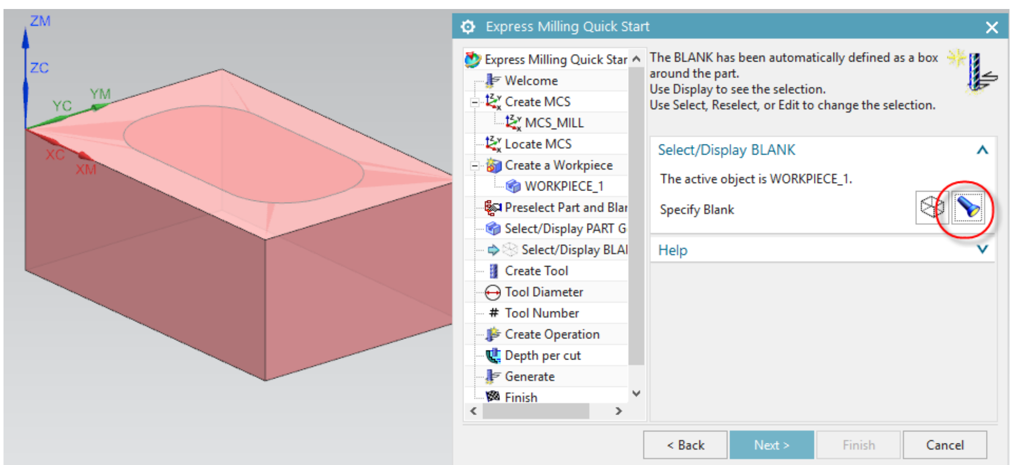
Sometimes the selection doesn't fit the stock you have in mind. You can manually change the blank geometry. Try changing the ZM+ Value to 5 mm see what a larger piece of stock would be in relation to the part.



Change different values to see what happens.

Return all the values to 0 and select OK.

Use the display button to see if the block appears similar to the picture below.

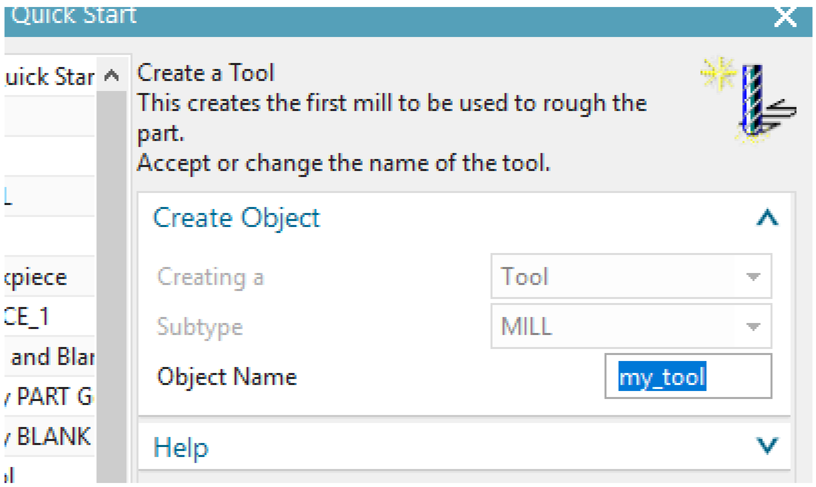


Select next.

The step the wizard will ask is to create or select a tool. For our purposes use a 12mm end mill. An end mill might have two or four flutes, a shaft diameter, and cutting length that will need to be defined.

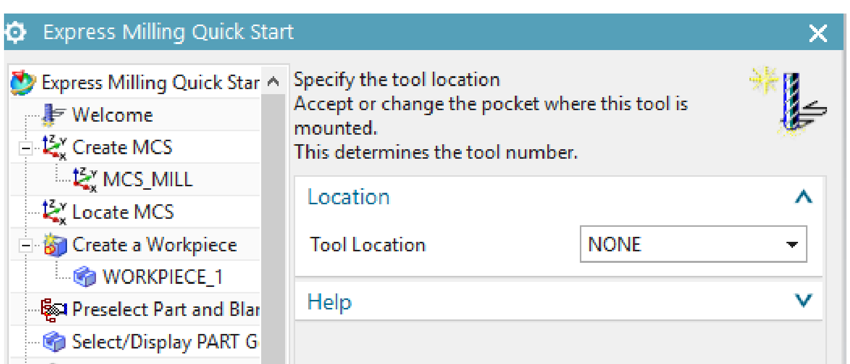
The wizard will need to know information about the tool in order to create a tool path that will remove the necessary material efficiently.

The first thing it will ask is the name you want to provide. Change the default my_tool to Tool_0.



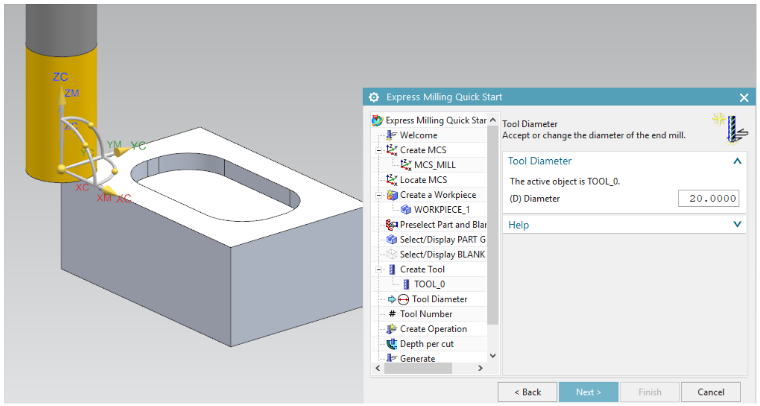
Select next.

It will ask for a location next. If using a milling machine with an automatic tool changer this would be important so the machine could automatically find the proper tool. In our case we can use the default None. This will tell the program the tool is mounted already and will not be changed.

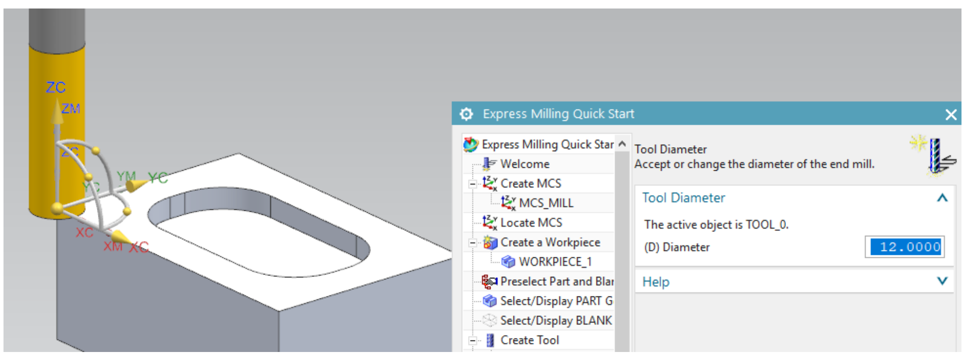


Select next.

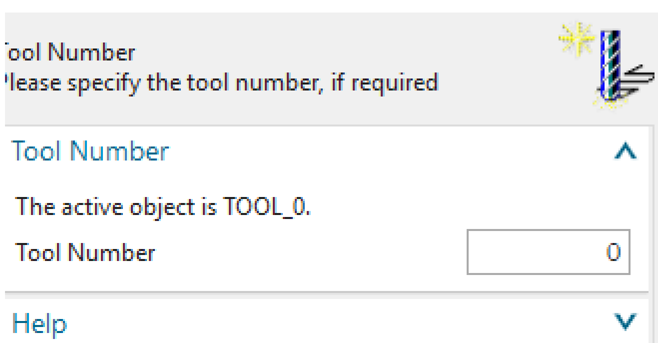
This brings in a default tool. You see the default where the tool is 20 mm.



In this example we are using a diameter of 12mm. Change the diameter in the wizard to 12mm and see what happens.



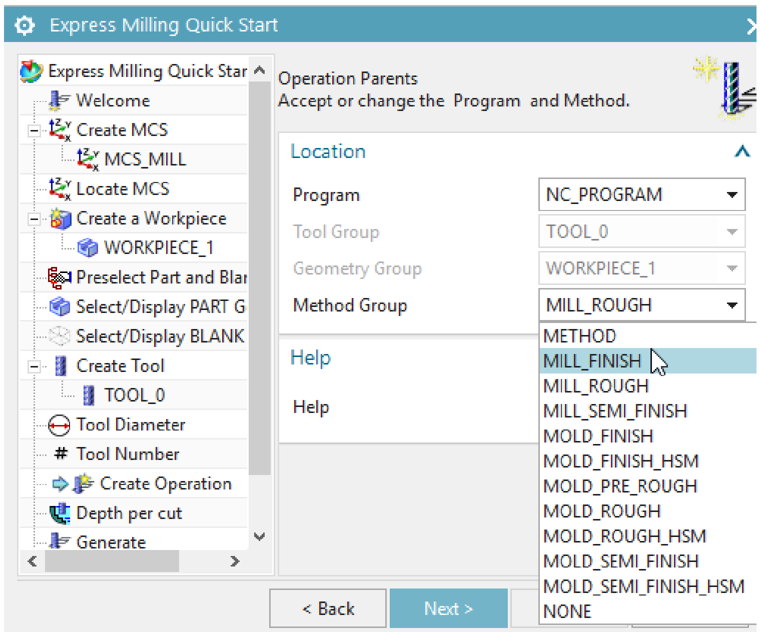
Select next. This should reveal the report indicating that the active tool is Tool_0 and that it is assigned to tool number 0 since that is the first tool slot.



Select next.

The next step is to define how the machine will cut your desired shape. The prompt will have you select the milling operation. The operation describes the tool and how it will cut. The first step is to give it a name. This will appear in the part navigator and allow editing and further processing later. Provide a name that will describe what the operation is doing. This will be important as parts and operations become more complex. The default is my_rough_milling. Name this Pocket_mill.

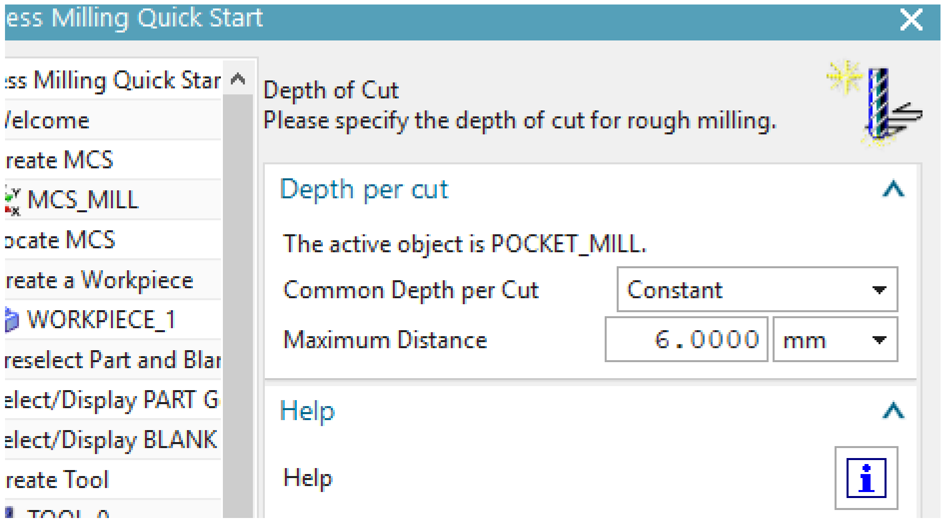
Select next. The wizard will ask for the operation parameters. Use the pull down menus to select the operation desired. Set the program to NC_Program which is the key for the G&M code in use for this project. Change the method to Mill_Finish.



Select next.

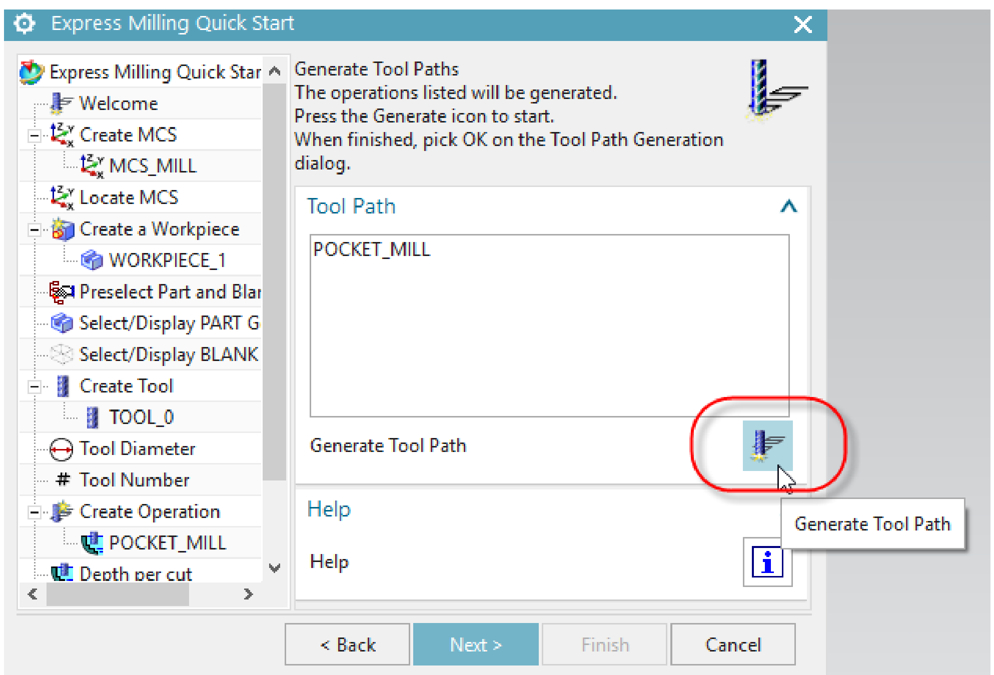
The next step in the wizard is the selection of the depth of cut. This value is important especially with narrow tools. A depth that is too aggressive will cause the tool to bend or break.

Set the maximum distance to 6 mm and the common depth to constant.

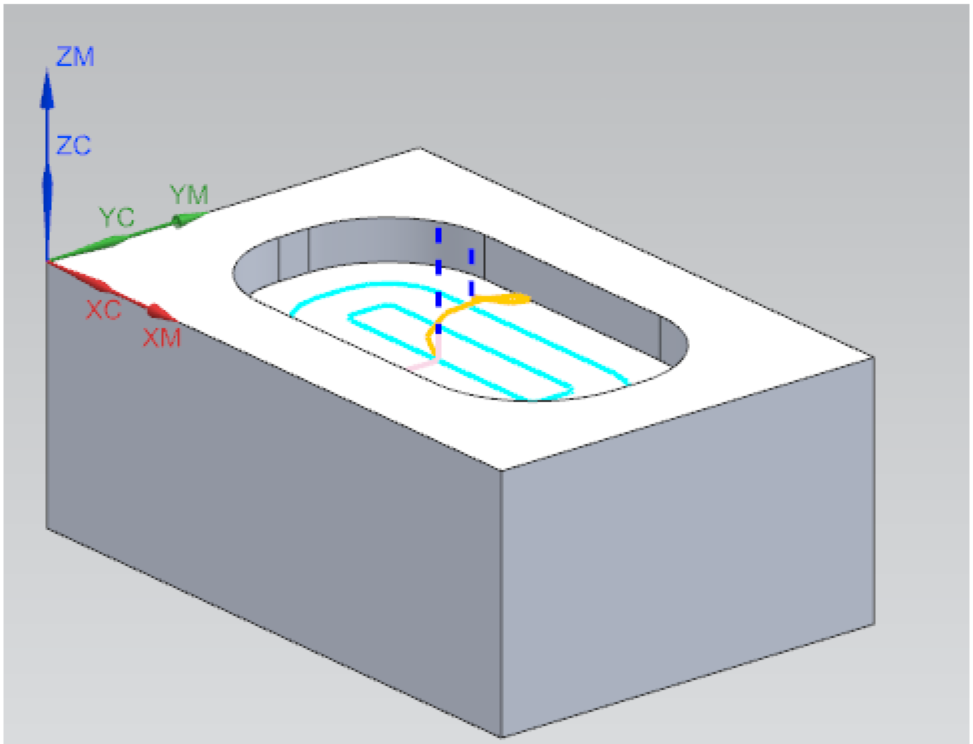


Select next.

The program is now ready to generate a tool path. Select the generate tool path icon.



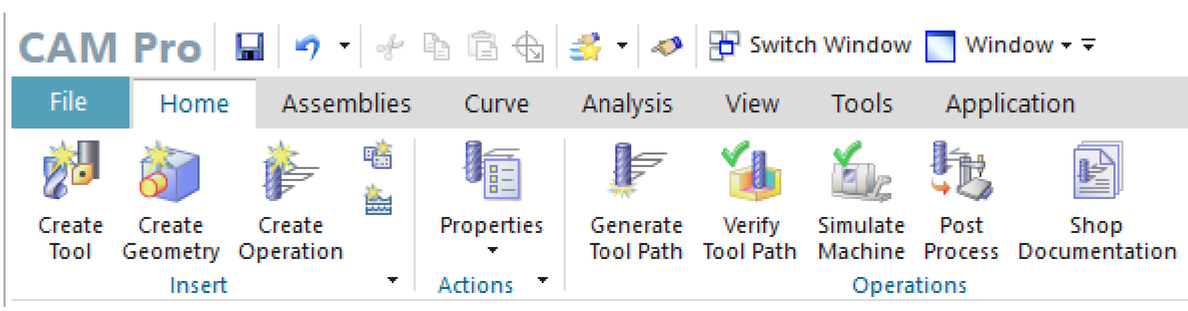
The tool path appears on the part.



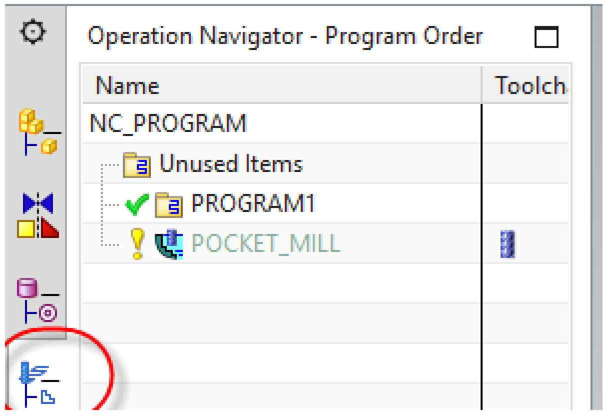
The dashed blue lines show the travel from the safe zone down to the part. The yellow lines are the lead in moves that allow the cutting tool to safely enter the part and then the light blue lines are the cutting moves through the part.

Select next. Then select finish.

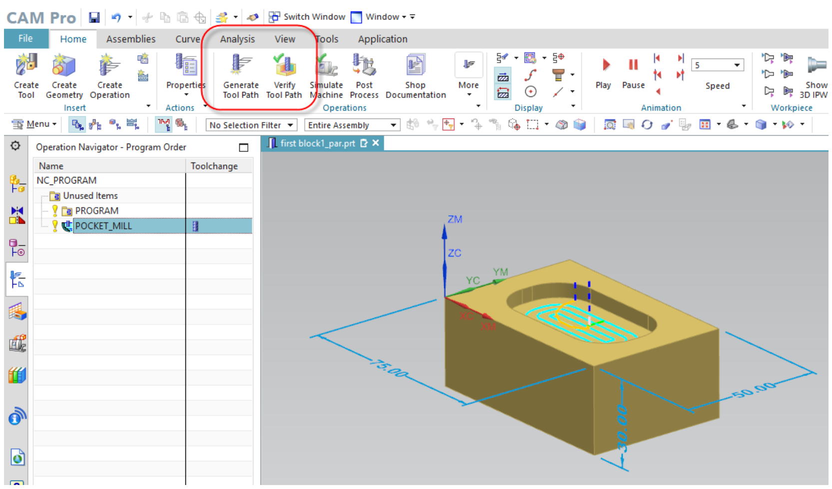
Additional Icons appear on the home ribbon now at the top of the screen.



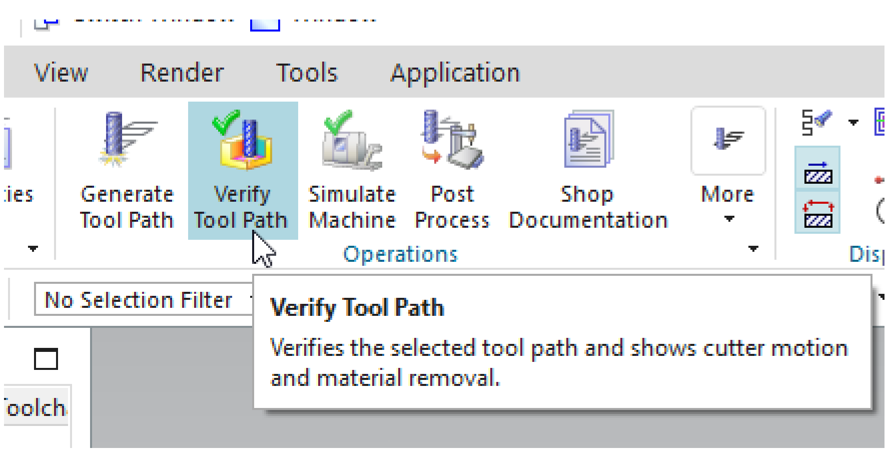
Enter the operation navigator by selecting the icon in the resource bar on the left.



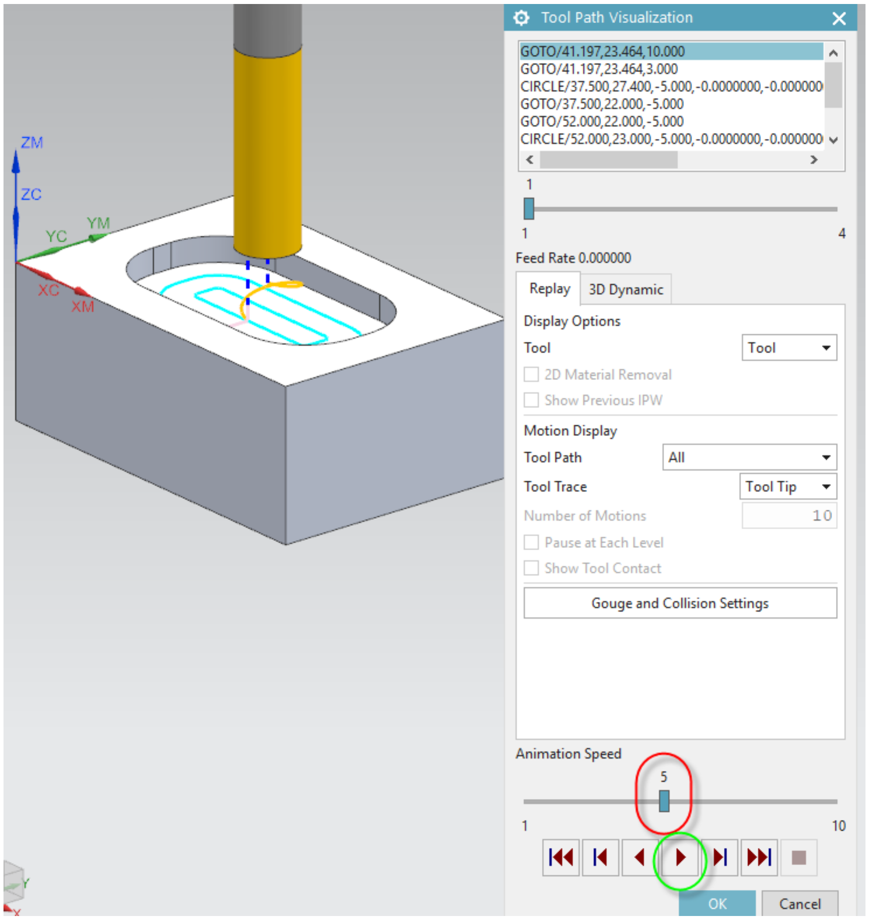
See the Pocket_Mill operation just created. Left click on it to see the home ribbon. This will provide more access to the tools.



From the operation section of the home ribbon select the verify tool path option.

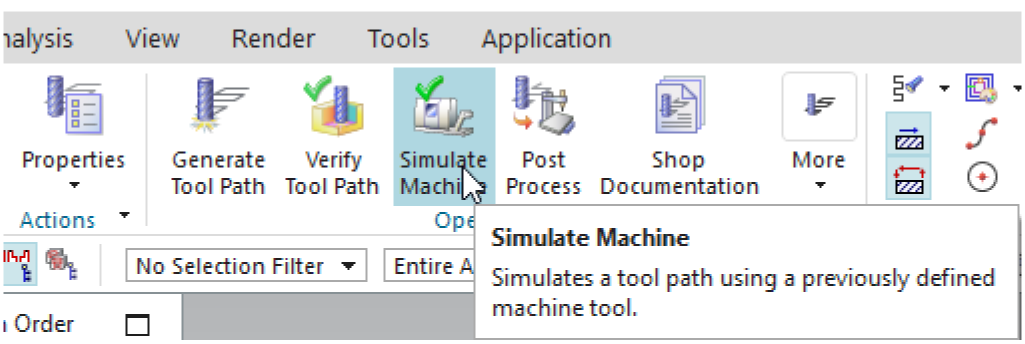


In the dialog box slow the animation speed to 5 and then press play. See the tool follow the path you created.



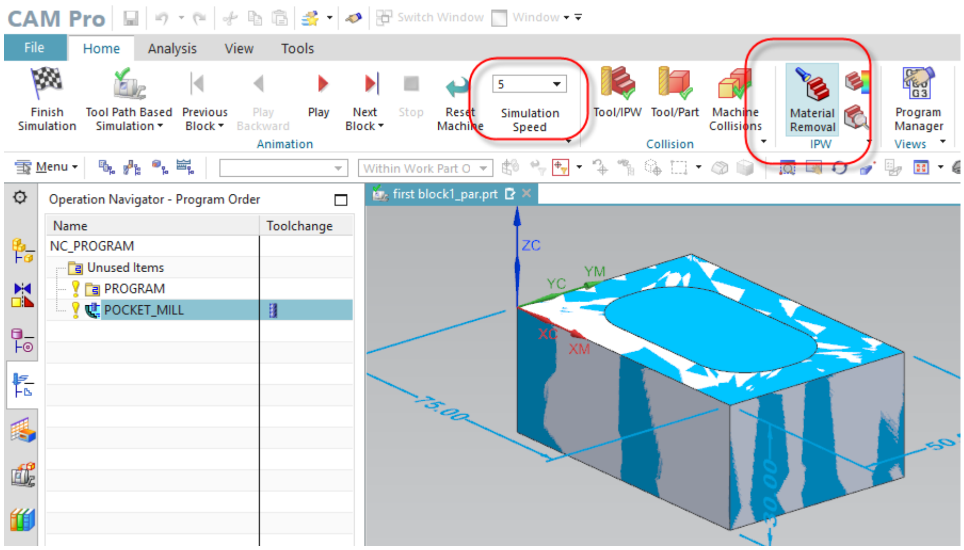
At the end select OK.

Now select Simulate Machine from the operations ribbon.

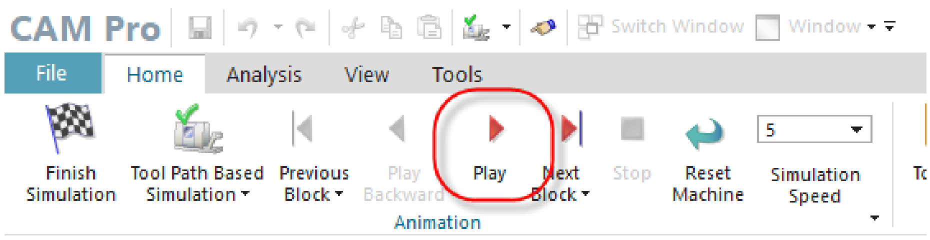


This provides a different view of the tool path created.

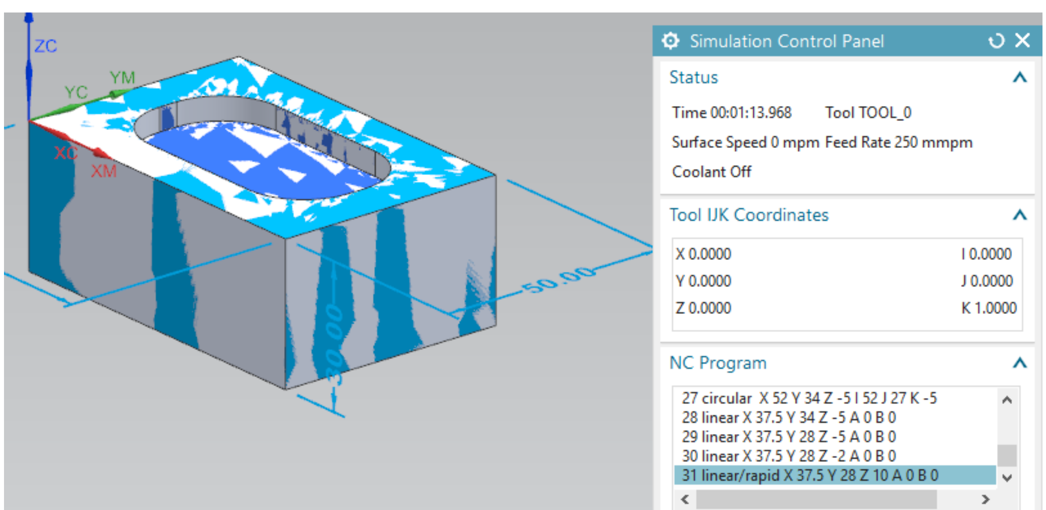
The home ribbon is replaced by the simulation ribbon. On the simulation ribbon click on the Material Removal icon. Then set the simulation speed to 5



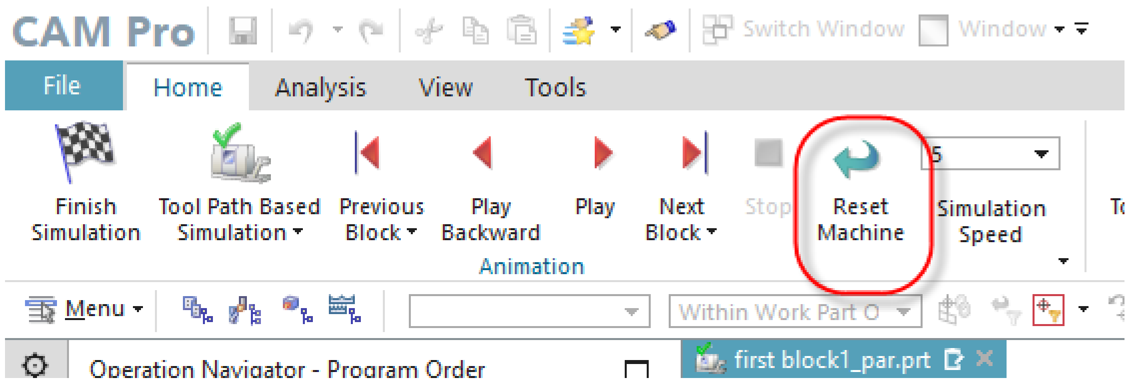
Press the play icon.



Watch the cutting of the block. See the NC code that describes the tool path in the simulation control panel.

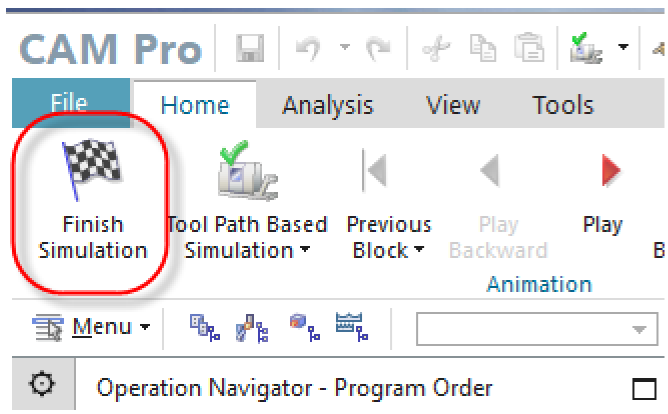


Reset the machine by selecting the arrow circled in the picture below. Slow the speed down and run the simulation again.



Select Close at the bottom of the simulation control panel.

Select the finish simulation icon from the ribbon.



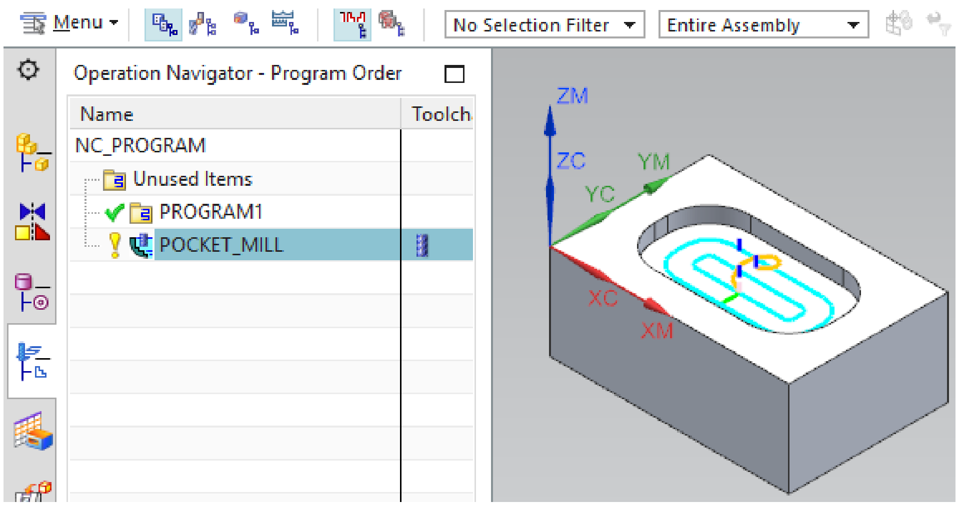
Save the program for future use.

Back

Editing an Operation

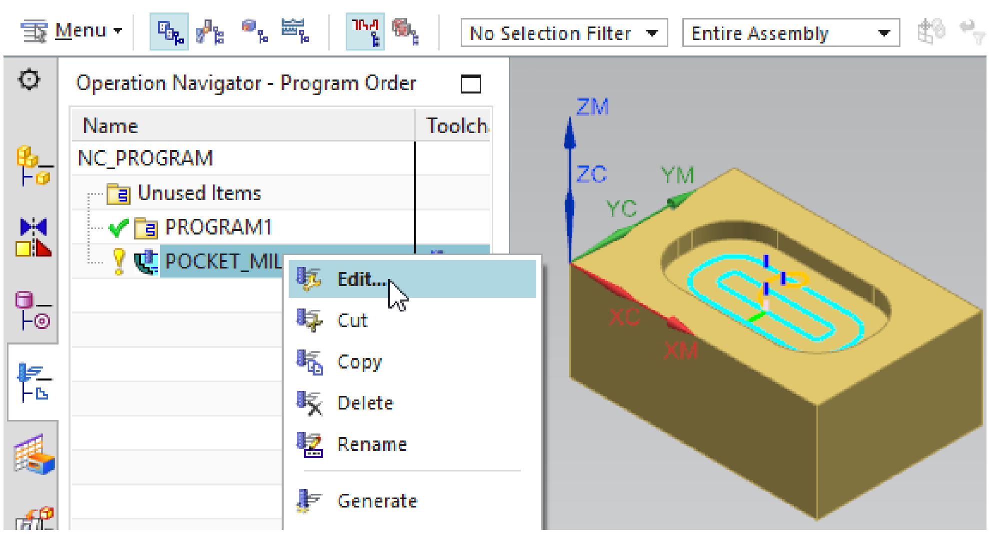
After completing an operation, it may be necessary to edit the operation to change some parameters. It might be the cutting tool or a forgotten move to limit the area being cut.

Open the part you created named First Block in CAM Pro. Click on the operation in the Operation Navigator.

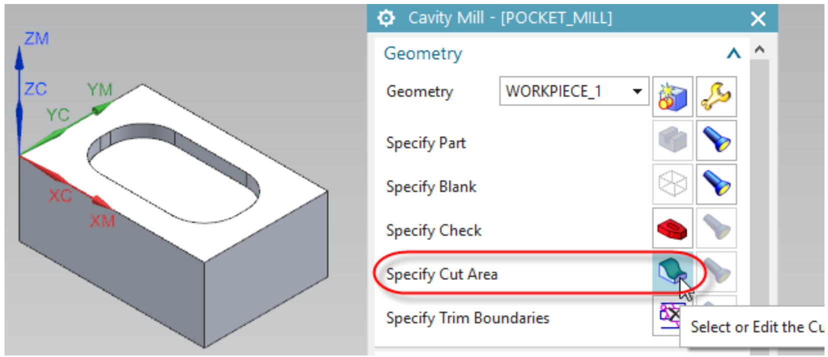


This will bring up the existing tool path developed in the exercise.

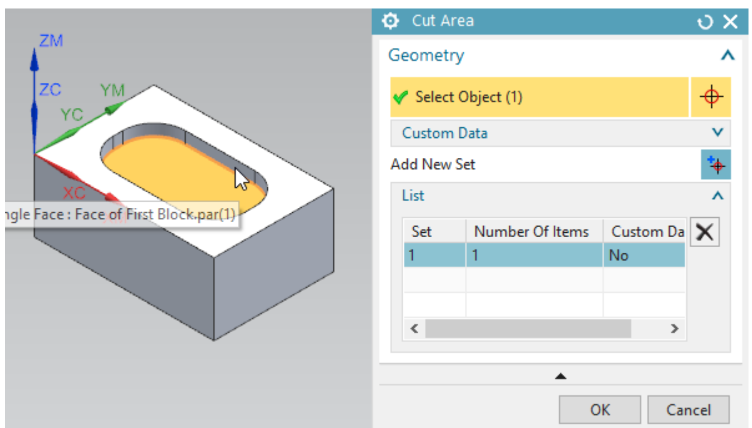
Right click on the operation and select edit from the options.



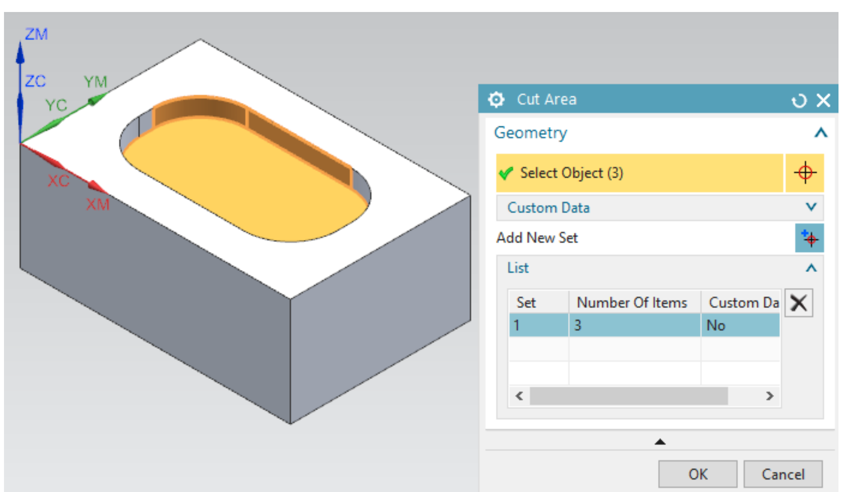
In this example we will limit the area for the tool path to just what is needed for the pocket mill. This allows the tool path to be developed normally but not to go beyond the boundary of the pocket. This will prevent this toolpath from interfering with other operations to be added later. Select Specify Cut Area from the options in the Cavity Mill dialog box.



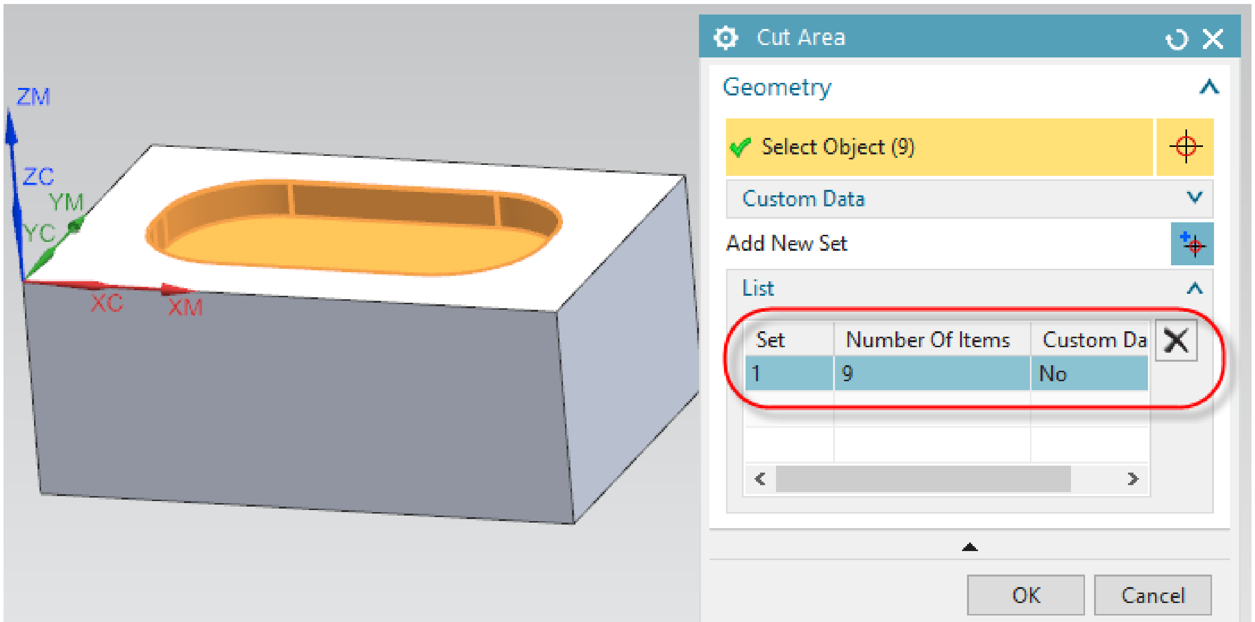
Select the bottom of the pocket.



Then add the sides one at a time until all the sides in the pocket are selected.

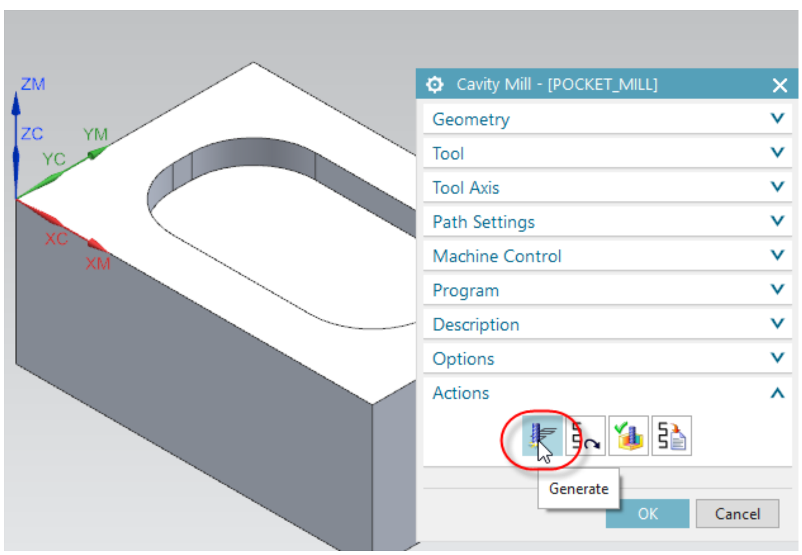


When the selection is completed, the number 9 will be indicated for the number of items. The surfaces are the bottom and the eight surfaces that make up the sides of the pocket. The part will have to be rotated to select the sides. Do this in middle of the command by holding down the mouse wheel button and moving the mouse.



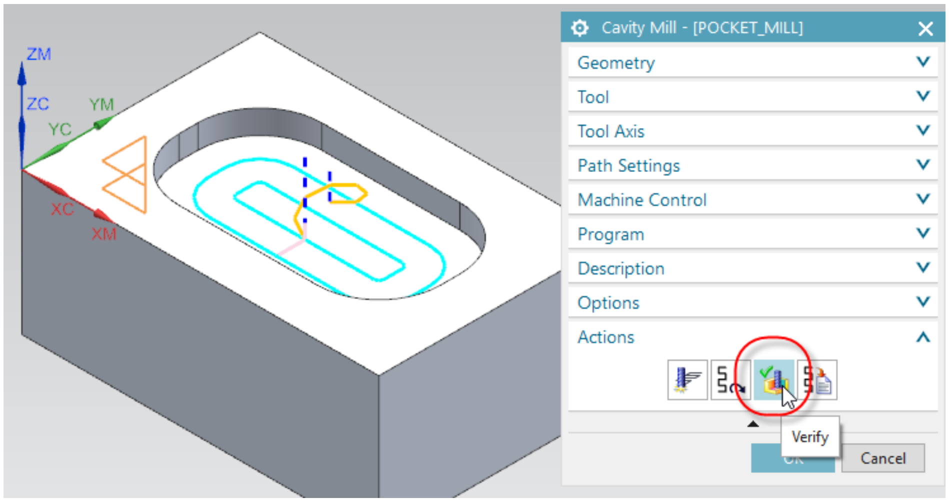
When selection is complete select OK.

From the Actions section of the Cavity Mill dialog box select Generate.



This will regenerate the toolpath.

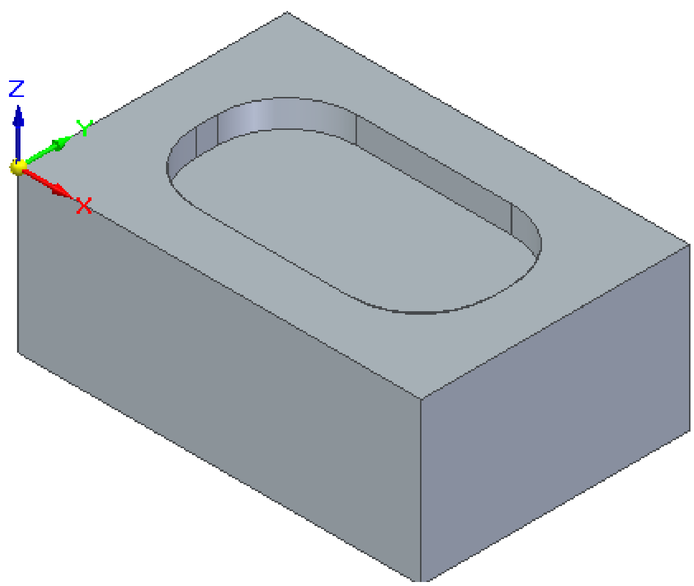
Then select Verify from the Actions menu to preview the cut.



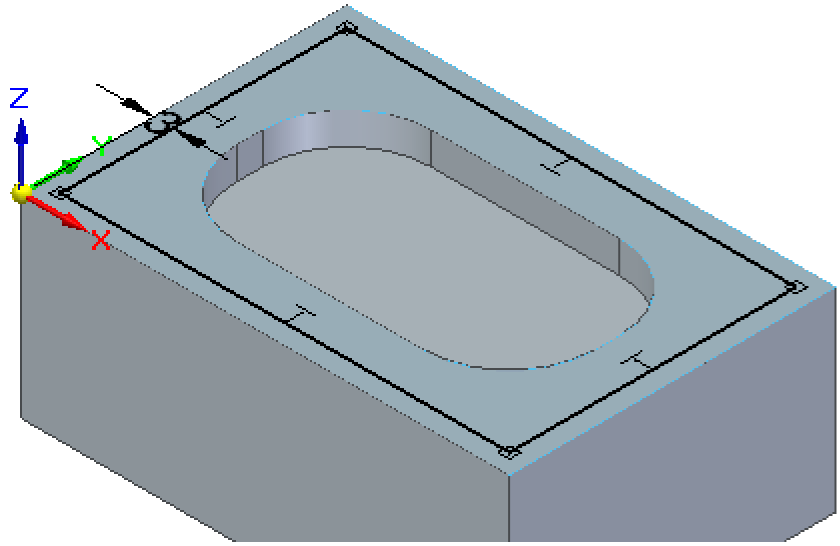
Run the simulation. If satisfied with the path select OK to close the operation editor.

Adding Operations

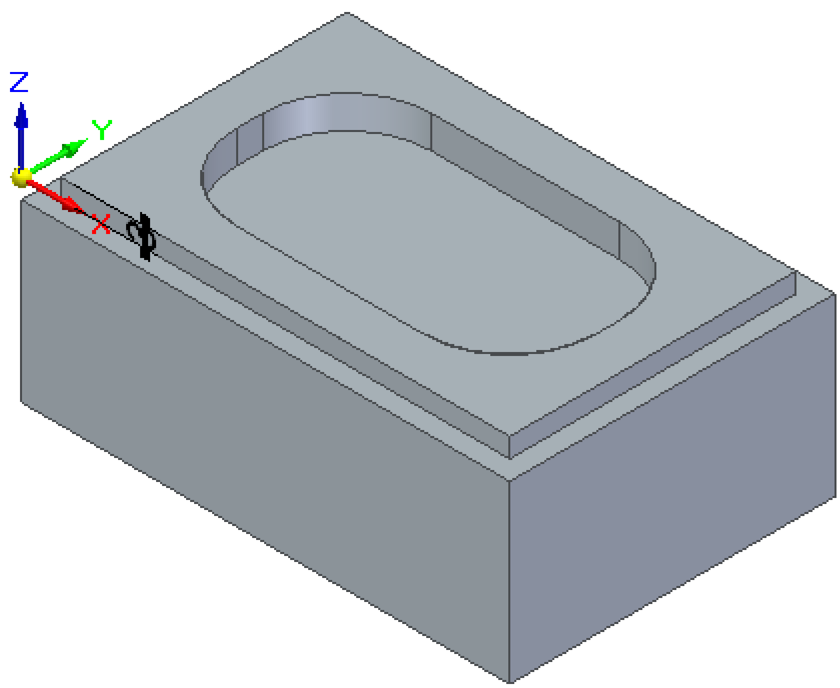
As parts become complex it is necessary to add additional operations to fabricate them. Additional features might also require the operator to add operations and necessary toolpaths. It is possible to make changes to the original part. Open the original part named First_Block in Solid Edge.



Sketch a rectangle offset from the edge of the block by 3 mm.

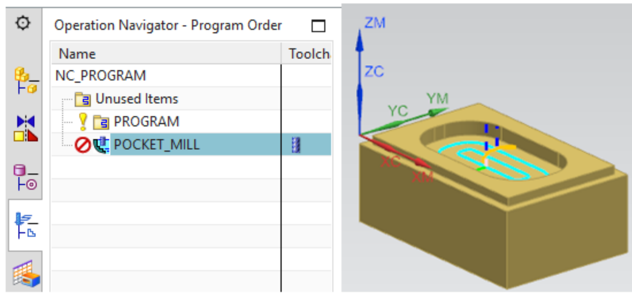


Extrude using the cut function to a depth of 3mm.

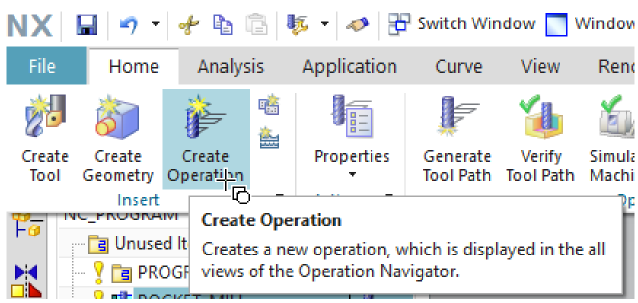


Save the part.

Open the First Block.par part in CAM Pro. This will load the new geometry just created with the tool path already created and apply the prt. extension. The software will remember the work done previously as well as bringing in the new features. Highlight the Pocket_Mill in the operation navigator to see the original operation on the screen.

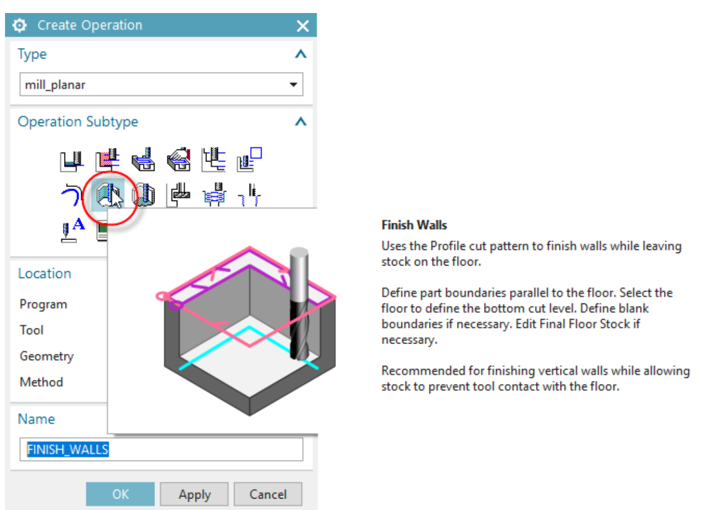


In this example, add an operation to cut the area on the outside of the block. In Solid Edge this depth was set to 3mm. To begin, select the Create Operation icon from the home ribbon.

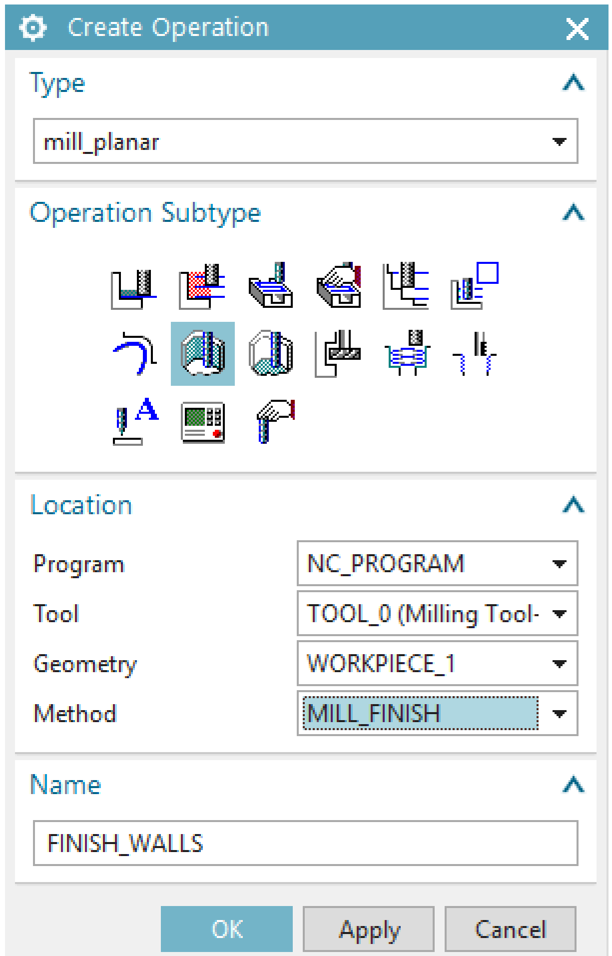


This opens the operation dialog box.

In the dialog box select mill_planar for the type and finish walls as the operation subtype.

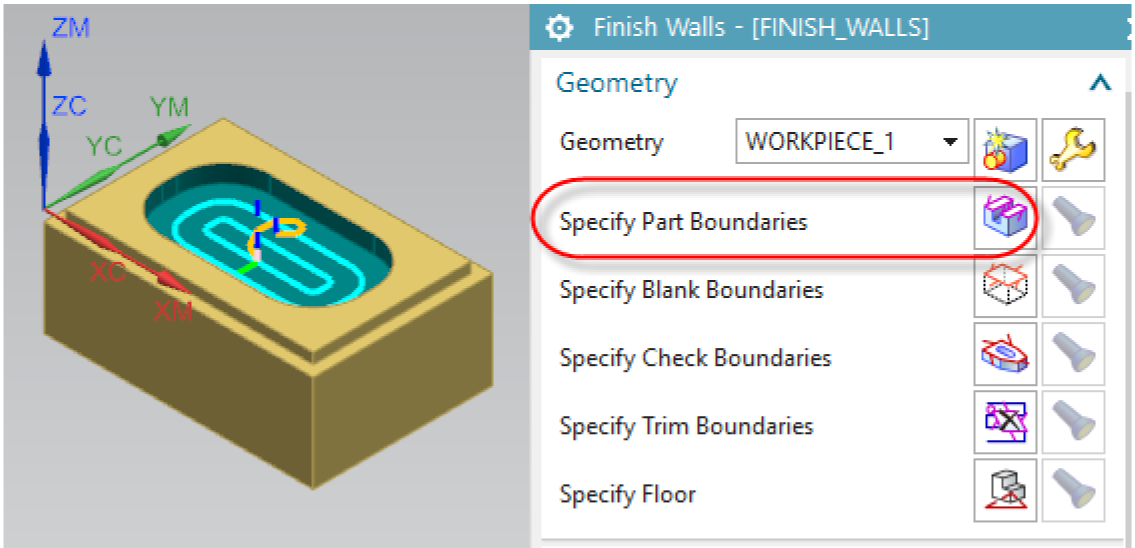


Set the program to NC_Program. The tool created earlier should be available to be selected as the tool. The geometry should be set to the Workpiece1 used earlier. The method should be MILL_FINISH.

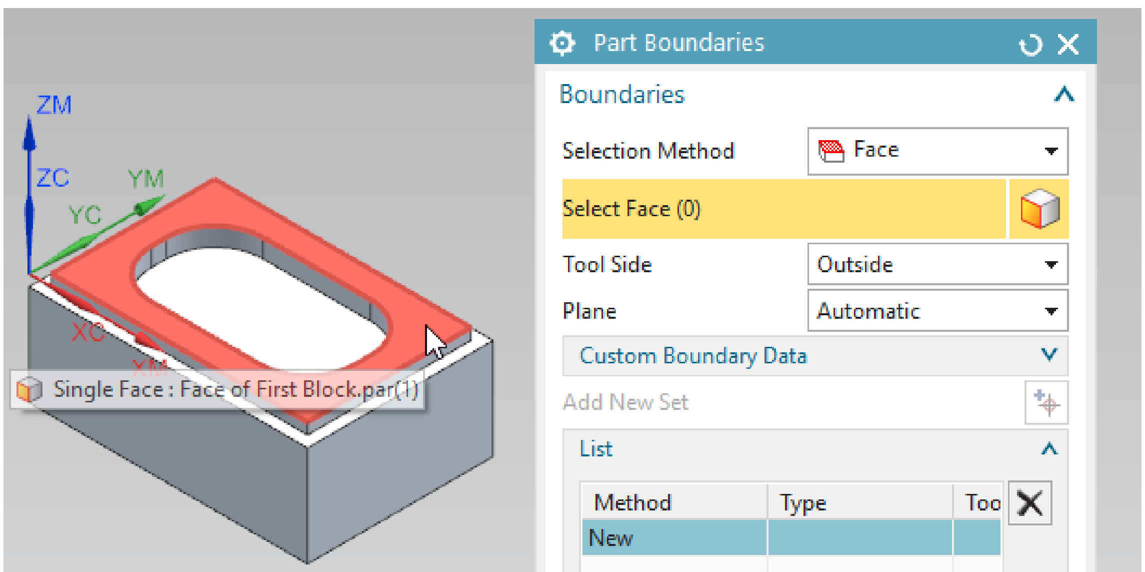


Select OK

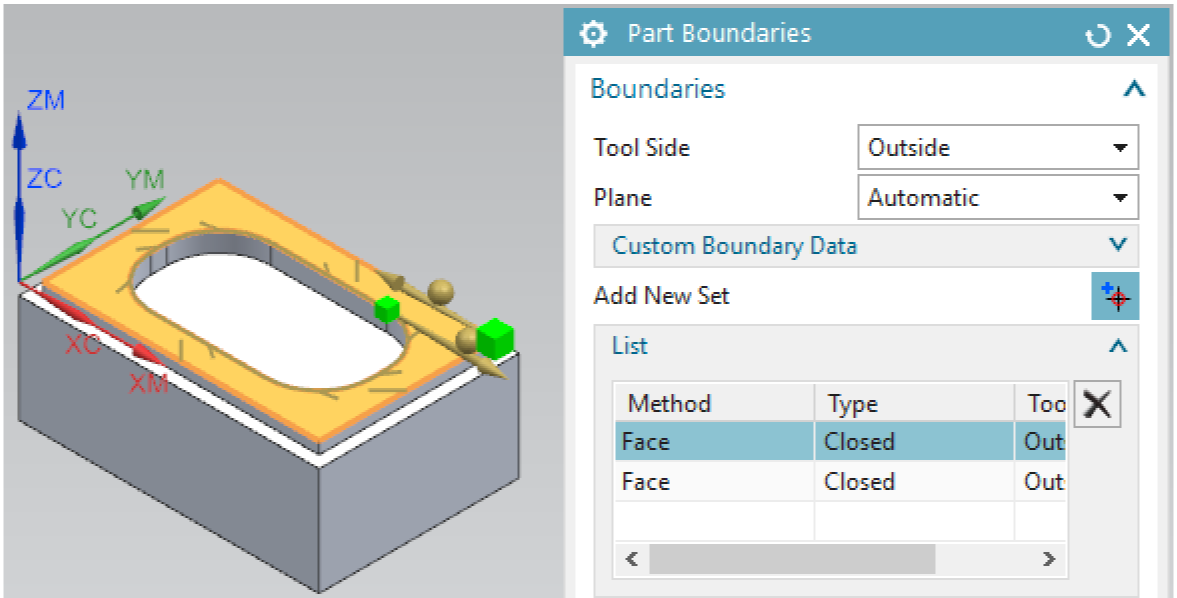
Select the option for Specify Part Boundaries to let the operation know where to cut.



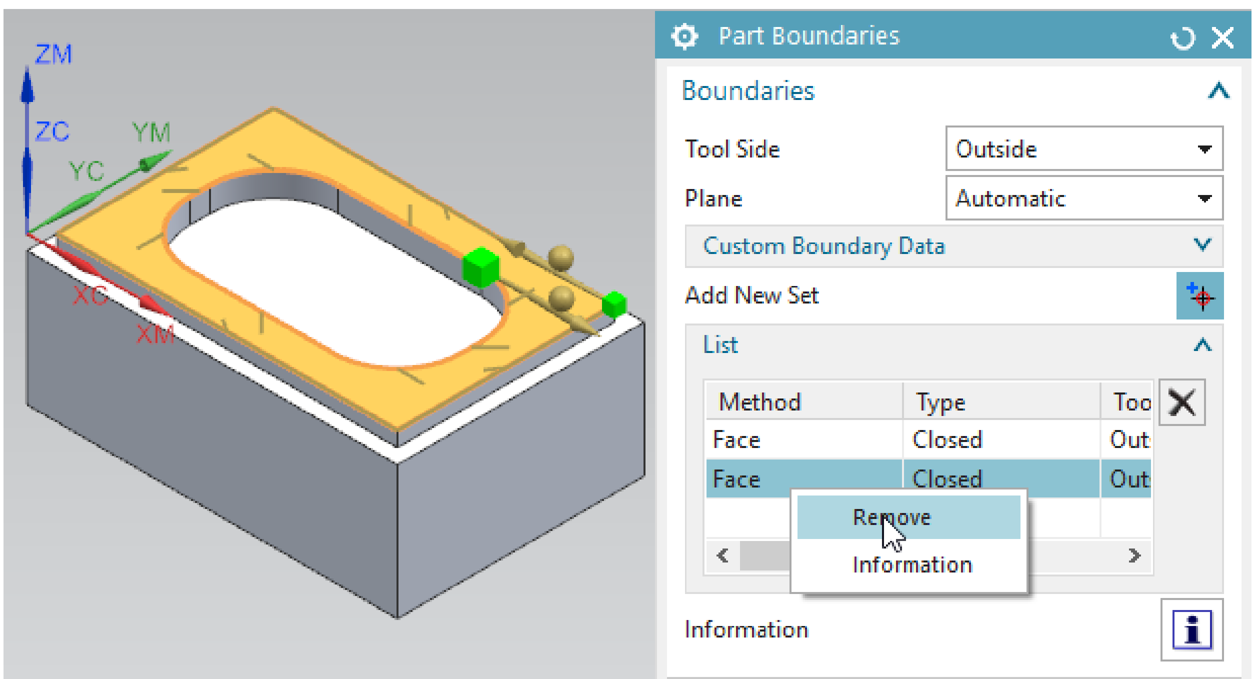
Use Face as the selection method to pick the top of the part. The tool side should be the outside as we wish the tool to be on the outside of the area. Select the top of the block.



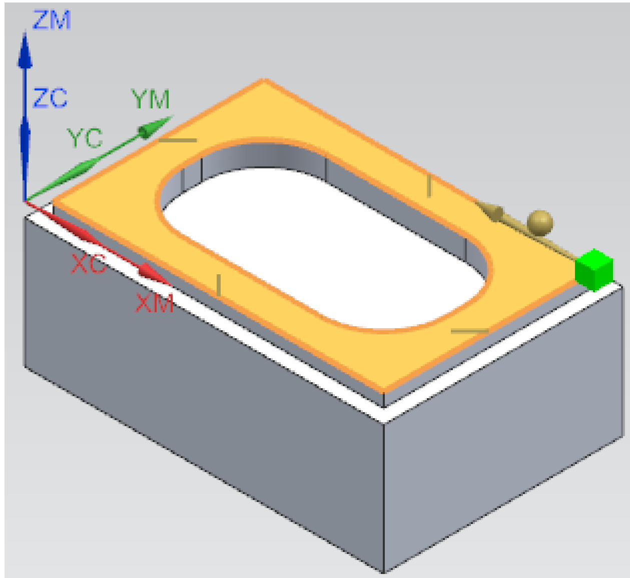
The selection should look similar to the one below.



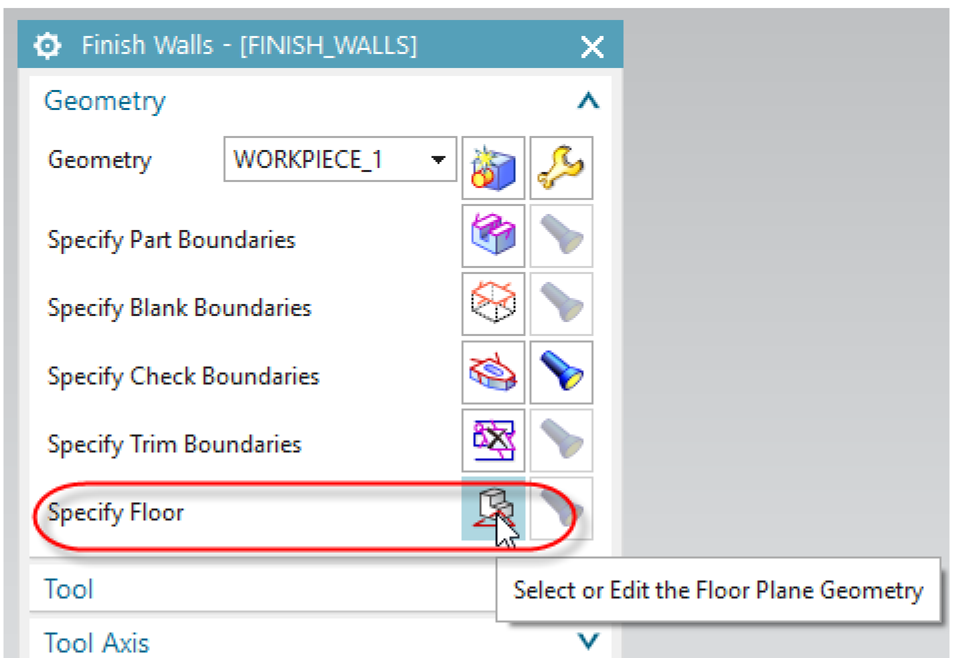
In this example we only wish to cut on the outside of the block. There is a second check boundary area that we will remove. Select the boundary data one at a time. Find the set that relates to the inside wall and right click and select Remove.



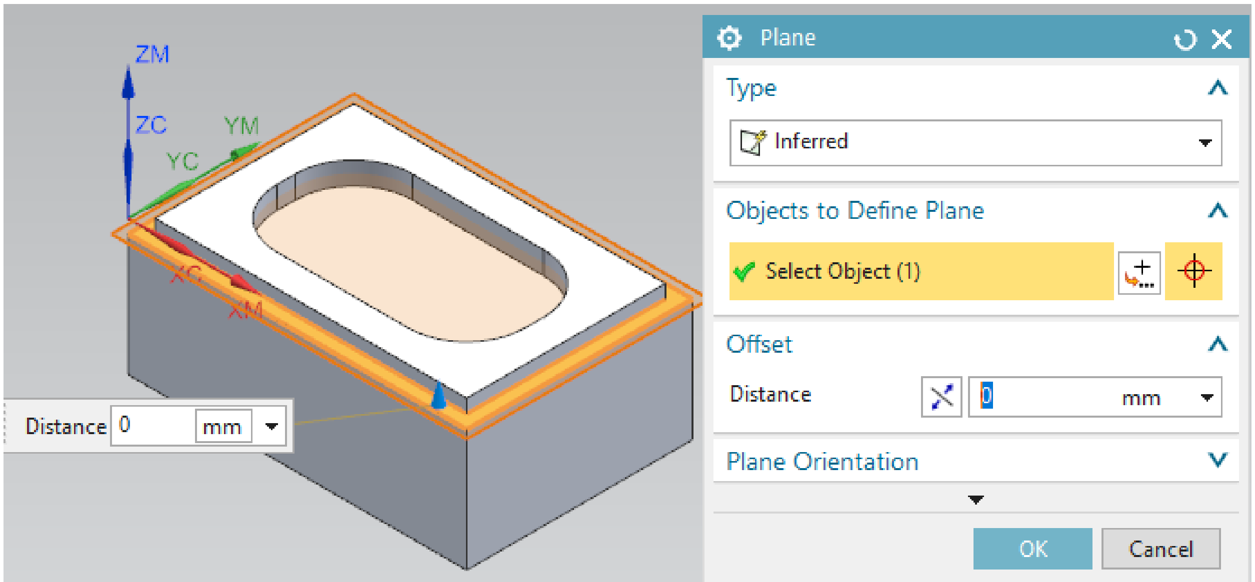
The only one left should be on the shoulder on the outside of the block.



From the Geometry menu select the option for Specify Floor.

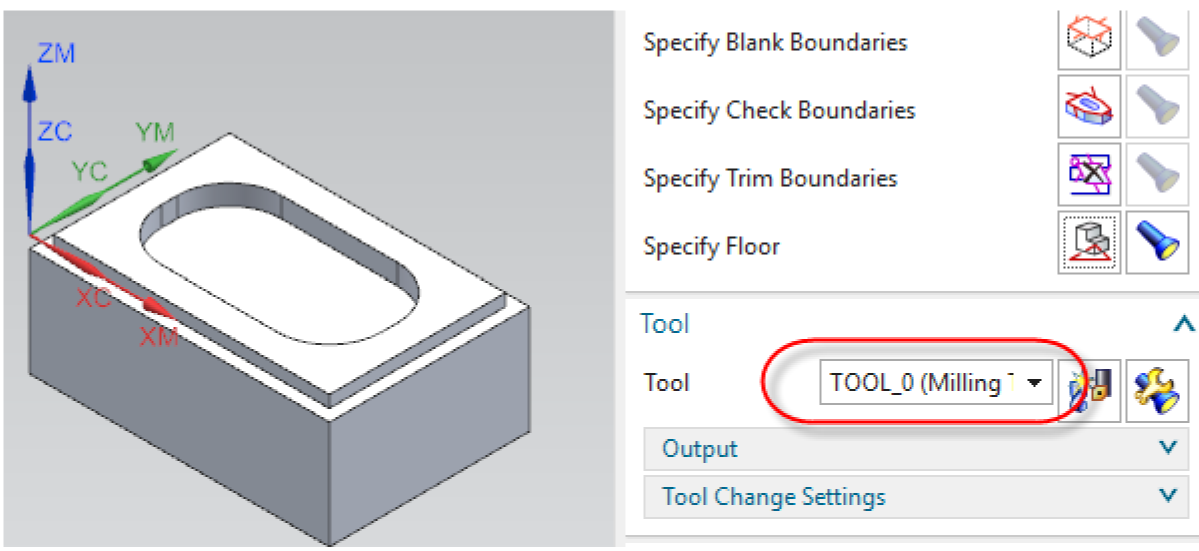


Select the flat part of the edge.

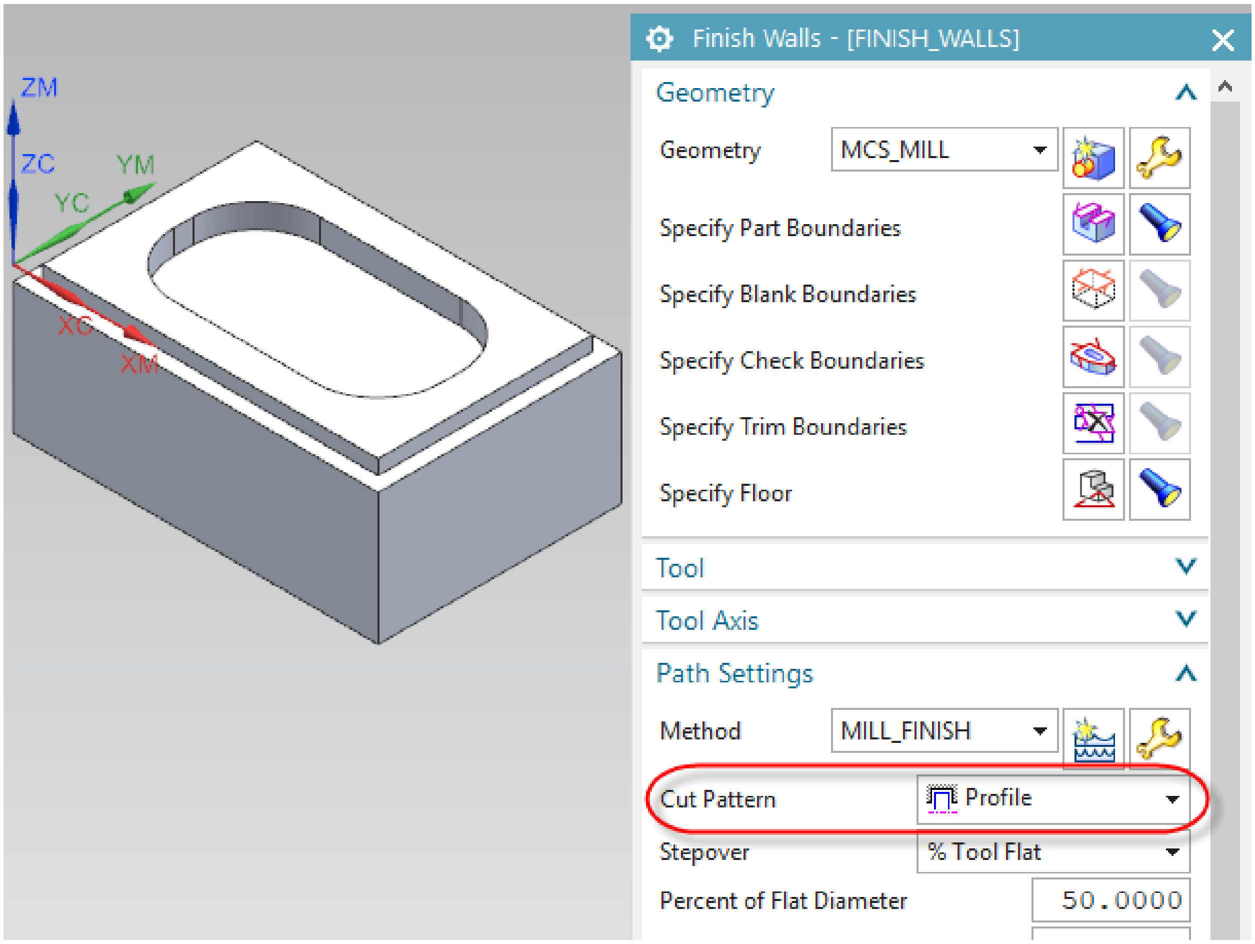


Select OK.

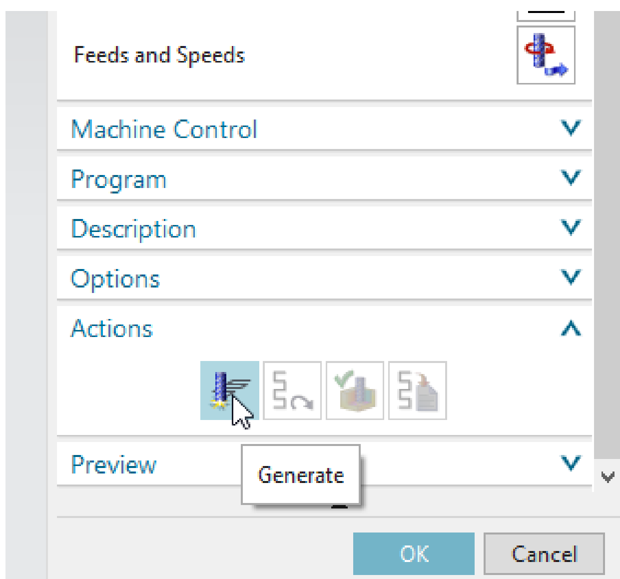
The tool should already be listed as it was identified in the operation menu. Check to be sure.



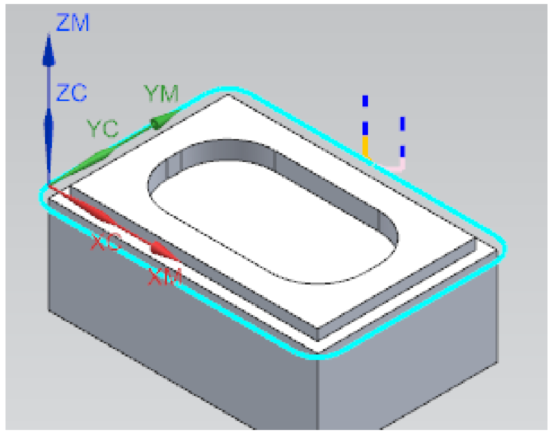
We can now set the path settings. Set the Cut Pattern to Profile. This will force the tool to follow the profile of the outside of the part.



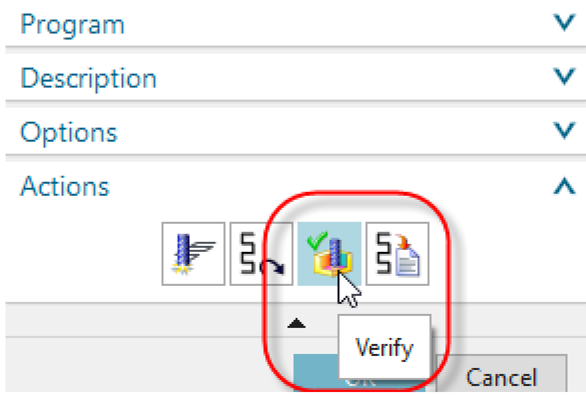
Select the Generate icon from the Actions menu.



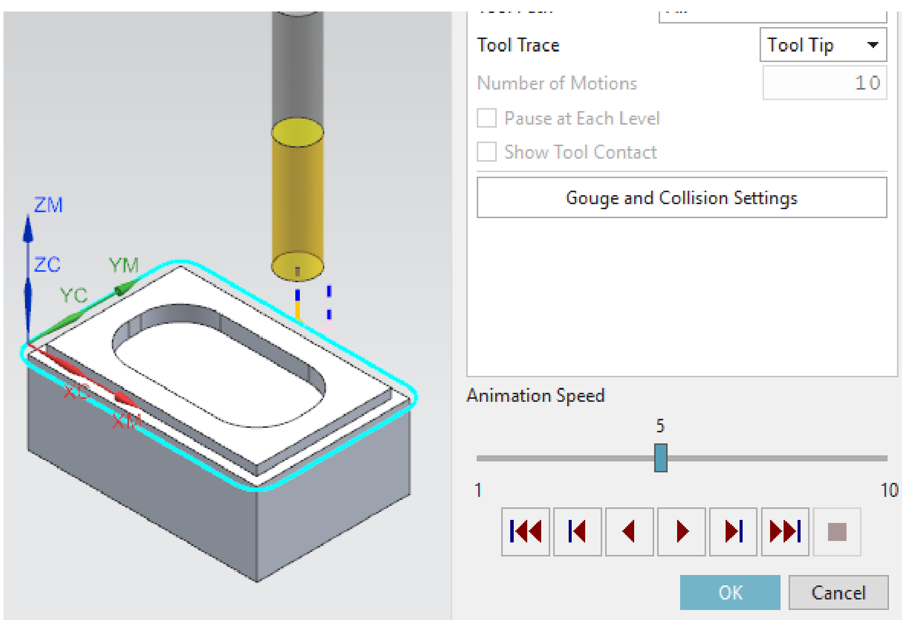
This should produce a tool path to cut the lip on the block.



Now select Verify from the Actions menu.

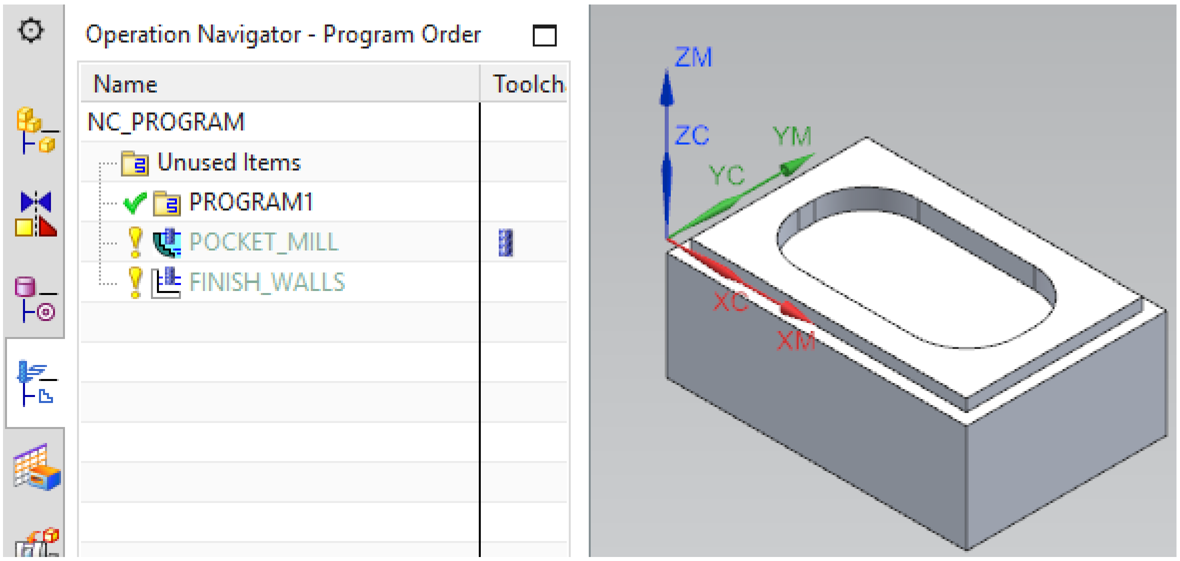


The tool should appear. Set the animation speed to 5 and select OK.

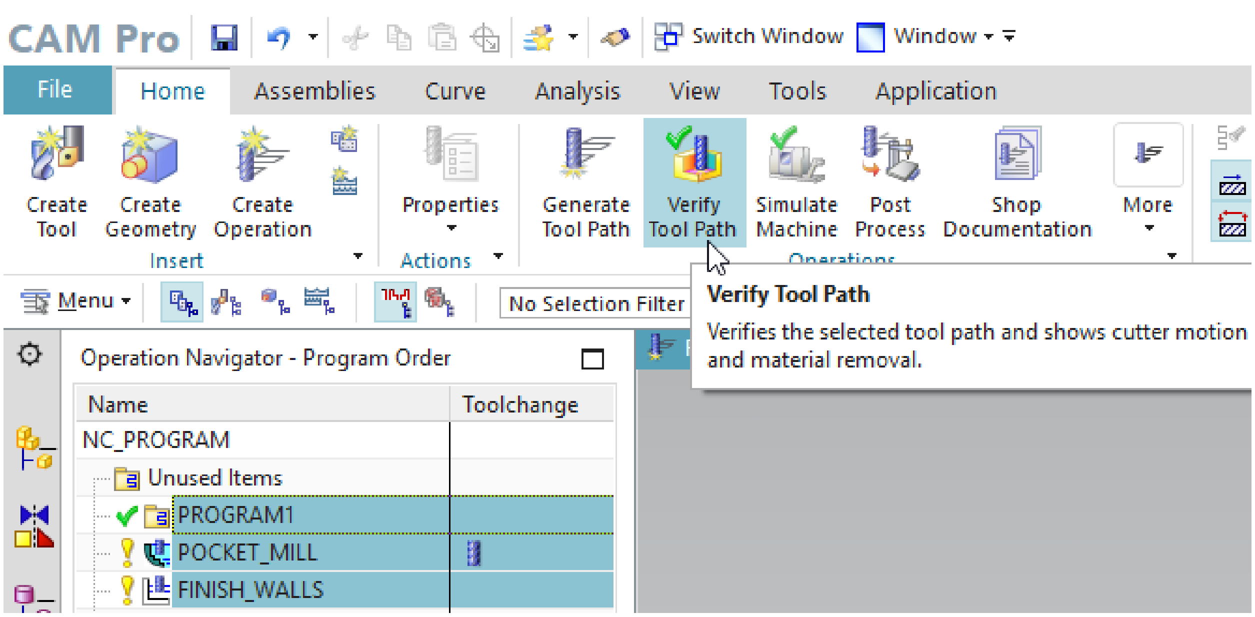


Be sure the tool operates as expected. Select OK to exit the verify menu and OK to exit the operation dialog box.

It should now be possible to see the second operation in the operation navigator.

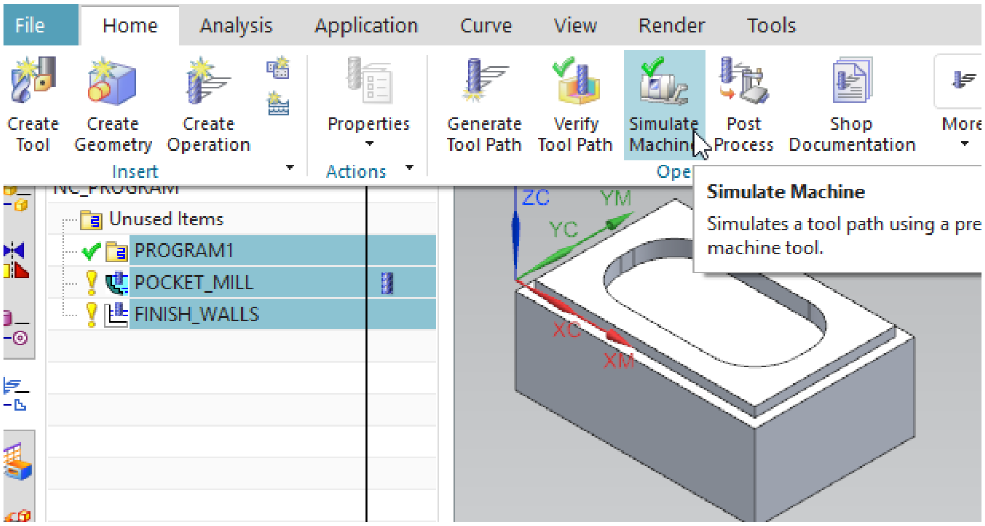


Highlight the Program1 and both operations. Select Verify Tool Path from the home ribbon.

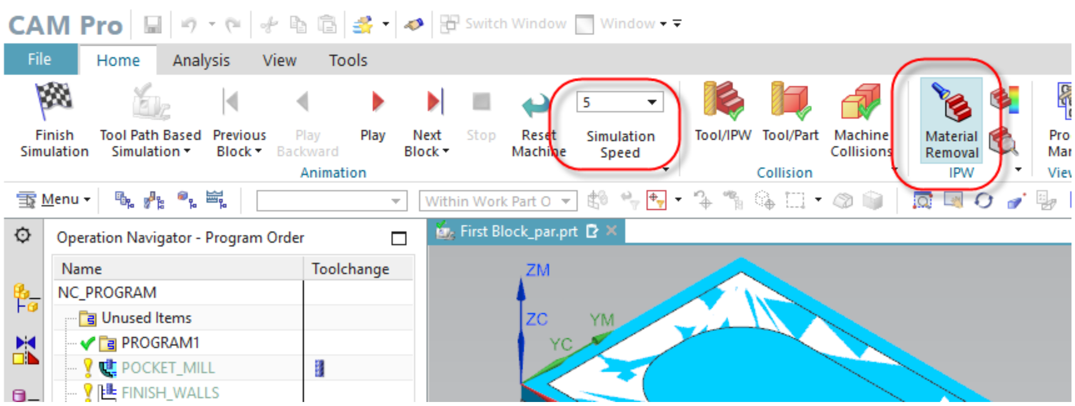


Since the pocket was first on the list, the verify program will run that section first and then come back and cut the lip on the edge of the part.

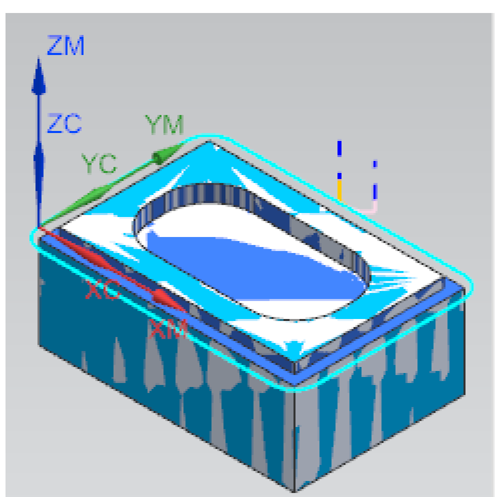
Now simulate the machining by selecting the Simulate icon on the home ribbon.



Select the option for material removal and set the simulation speed to 5.



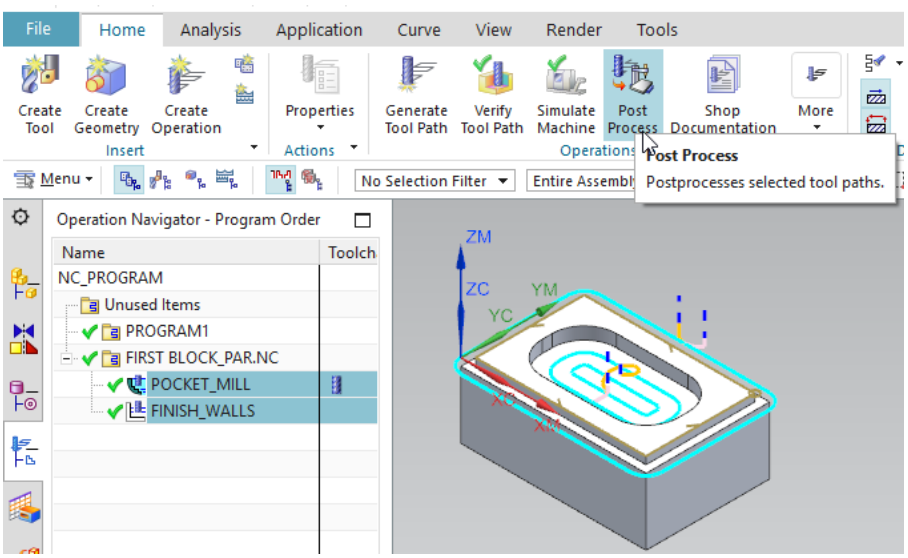
This should produce something similar to the picture below.



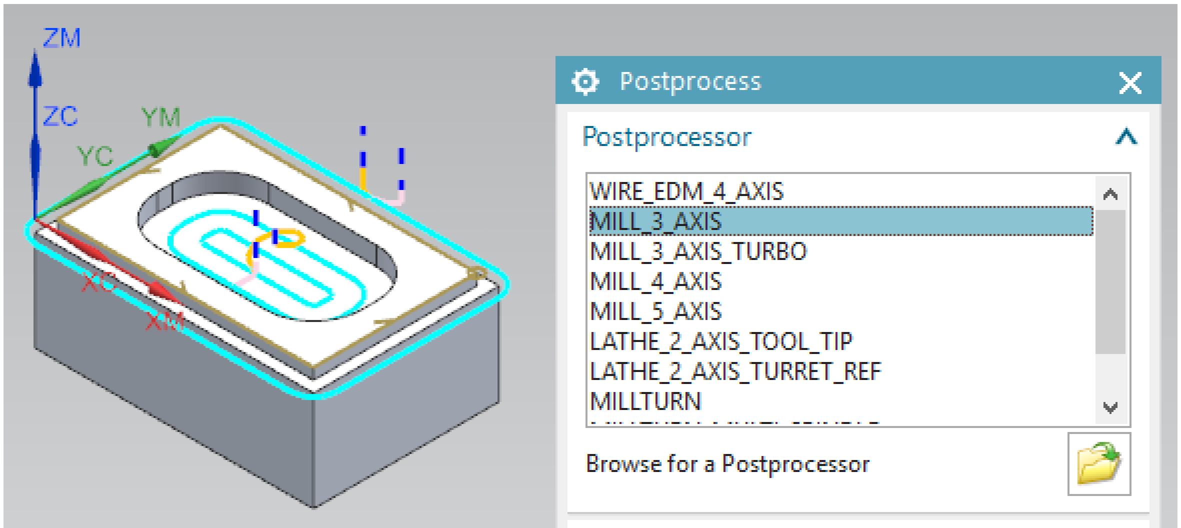
Posting Code

Once you have tool paths designed to create the component parts needed, the next step is translating that to code that the milling machine, lathe, or router can understand. Every machine is slightly different and requires different information. Earlier the code was written by hand and a basic code was inserted that a generic machine understands. In this case we will use a machine definition called a Post. This post allows the computer to interpret the design with the needed detail from the machine. This is called post processing.

Highlight the operations needed to include when generating code. Select Post Process from the home ribbon.

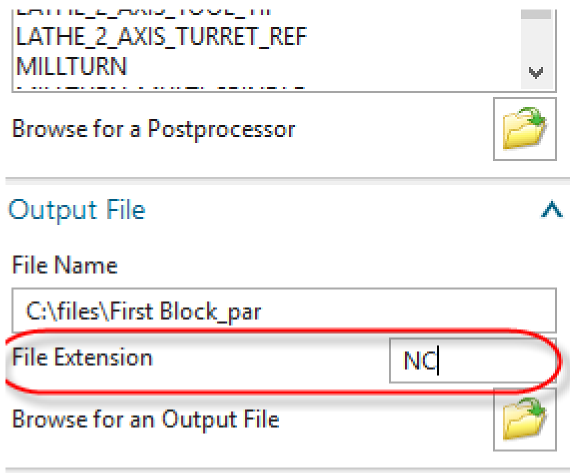


The dialog box allows the user to select the CNC machine. There are a few generic ones listed, or you can use the browse function to find specific machines that are already defined. It is also possible to create one to match your CNC machine and make it available.



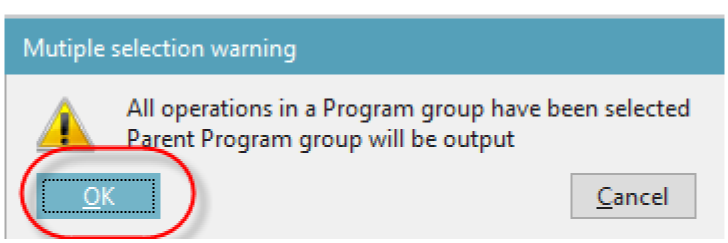
To see how this works, select the generic MILL3_AXIS option.

Lower in the dialog box there is a section for Output File. Set the file extension to NC. Manually enter the name and location or use the browse for an output file to name a location.



Select OK.

See a warning that all operations in a program group have been selected. Select OK.

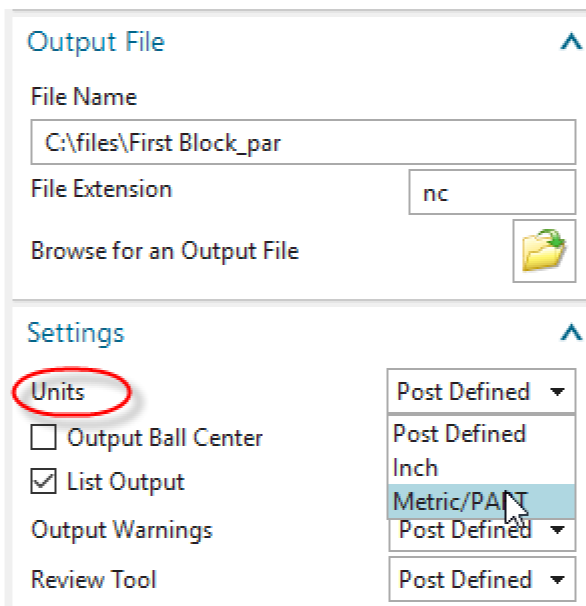


The following output file should be shown. This is what will tell the CNC mill what to do. It might resemble what is below. If you notice the X, Y and Z coordinates have been translated into inches. The settings on the post dictated that.

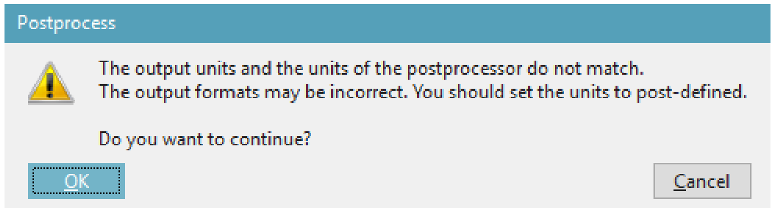
```
%
N0010 G40 G17 G90 G70
N0020 G91 G28 Z0.0
N0030 T00 M06
N0040 G00 G90 X1.6219 Y.9238 S0 M03
N0050 G43 Z.3937 H00
N0060 Z.1181
N0070 G01 X1.6613 Y.9715 Z.1015 F9.8 M08
N0080 X1.6843 Y1.0291 Z.085
N0090 X1.6898 Y1.0908 Z.0684
N0100 X1.6774 Y1.1515 Z.0518
N0110 X1.6481 Y1.2061 Z.0352
N0120 X1.6043 Y1.25 Z.0186
N0130 X1.5498 Y1.2795 Z.0021
N0140 X1.4891 Y1.2921 Z-.0145
N0150 X1.4273 Y1.2868 Z-.0311
N0160 X1.3697 Y1.264 Z-.0477
N0170 X1.321 Y1.2256 Z-.0642
```

We can override that setting to see what it will look like in mm. Close the NC file.

Select the post processor again, select the MILL3_AXIS option, change the file extension to nc, and change the units to Metric.



Select OK again and look at the NC file to see what changes happened. A number of warnings will be shown about the post not being compatible with the selected units. Select OK.



This time the output will show the X, Y and Z coordinates in metric units.

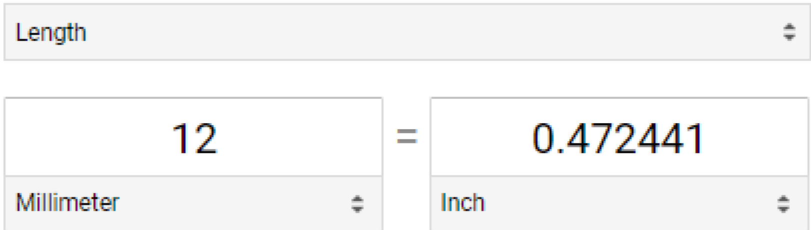
```
%
N0010 G40 G17 G90 G71
N0020 G91 G28 Z0.0
N0030 T00 M06
N0040 G00 G90 X41.1975 Y23.4645 S0 M03
N0050 G43 Z10. H00
N0060 Z3.
N0070 G01 X42.1971 Y24.6757 Z2.5789 F250. M08
N0080 X42.7813 Y26.1379 Z2.1579
N0090 X42.9214 Y27.7062 Z1.7368
N0100 X42.6056 Y29.2488 Z1.3158
N0110 X41.8605 Y30.6359 Z.8947
N0120 X40.7488 Y31.7509 Z.4737
N0130 X39.3639 Y32.5001 Z.0526
N0140 X37.8223 Y32.8204 Z-.3684
N0150 X36.2536 Y32.685 Z-.7895
N0160 X34.7897 Y32.1052 Z-1.2105
N0170 X33.5536 Y31.1298 Z-1.6316
```

It is important to note that while the user can do this to see what happens, the user should never do this and transfer the file to the machine as it will easily drive the tables to hit the limit switches.

The code below was generated by a post written for a Tormach mill using the same code. The Tormach is another machine that prefers its units in inches. This post puts the tool library at the top so it can be checked before being run.

```
(========================================================================
(                                    T O O L   L I S T
(========================================================================
(
(------------------------------------------------------------------------
(MILL                  DESCRIPTION          DIAMETER   COR RAD    FLUTE LE
(------------------------------------------------------------------------
(TOOL_0                MILL                 0.4724     0.0000     1.4961
(========================================================================
%
N0010 G90 G20 G40 G17
N0020 G91 G28 Z0.0
N0030 T00 M06
N0040 G90 G00 X1.6219 Y.9238 S0 M03
N0050 G43 Z.3937 H00
N0060 Z.1181
N0070 G03 X1.4764 Y.8661 Z-.1969 I-.1456 J.1549 K-.057 F9.8
N0080 G01 X2.0472 M08
N0090 G03 X2.0866 Y.9055 I0.0 J.0394
N0100 G01 Y1.063
```

The tool was set to 12 mm. Looking at the diameter of the tool, the post set the diameter to 0.4724 automatically.



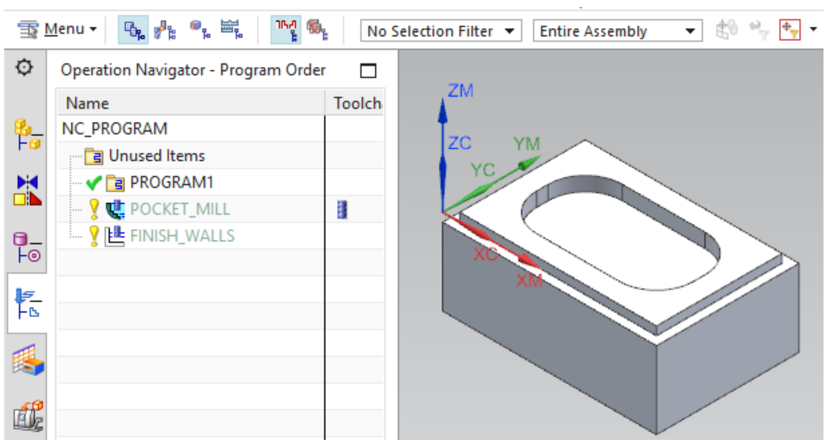
Save your work.

[Back](#)

Adding Text

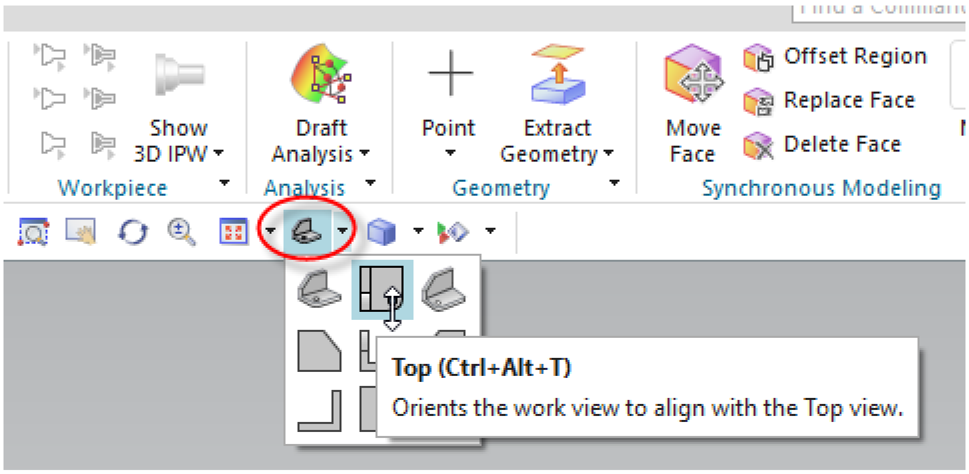
This tutorial will illustrate how text or images are milled into workpieces.

Open up the First Block_par.prt.

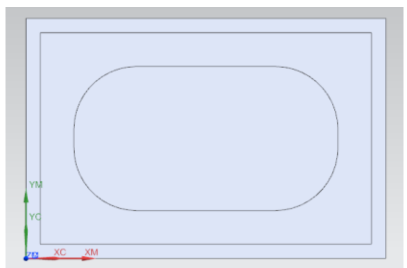


This action should show the two operations completed earlier. This example will be engraving text on the bottom of the central cavity.

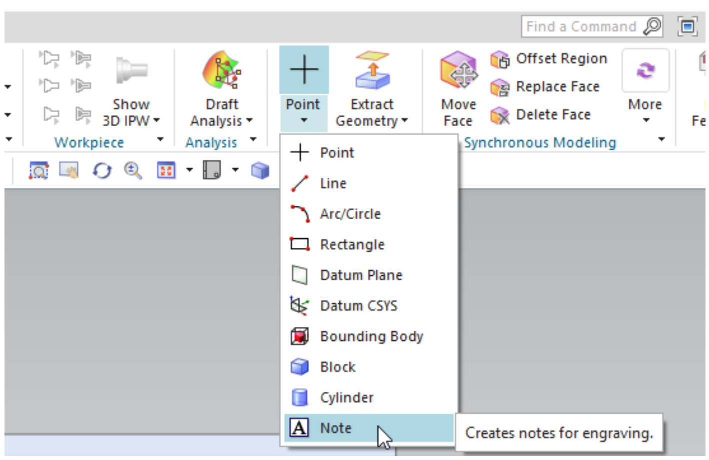
If you want to align the test you should look at the top view. From the top border bar select the option to see the part from the top view.



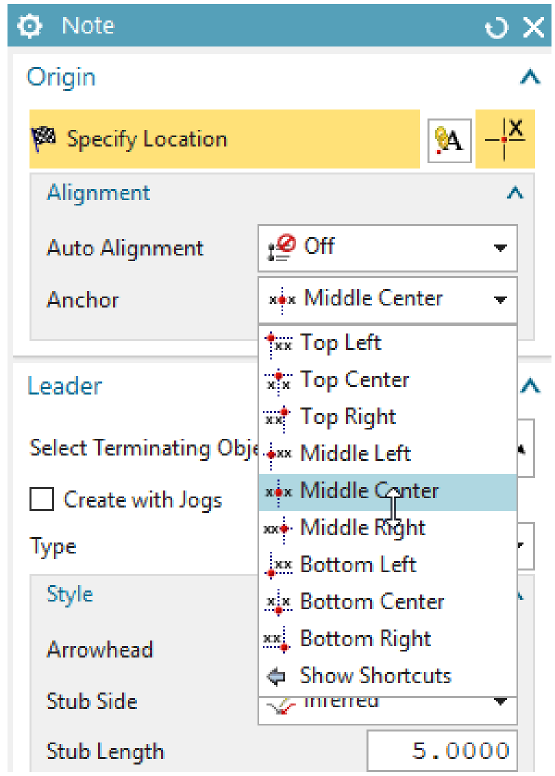
This command is also found on the View ribbon.



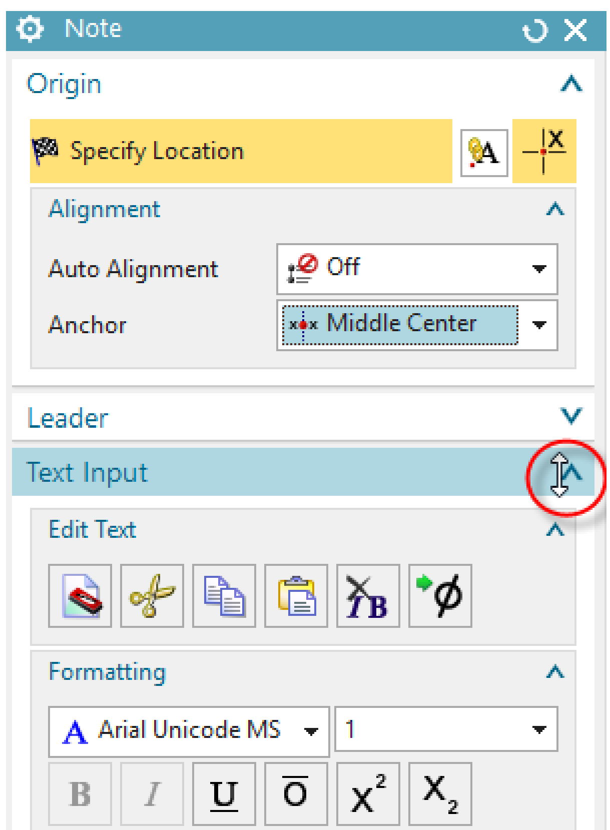
From the Geometry section of the Home ribbon, select the pull down menu and then the Note option.



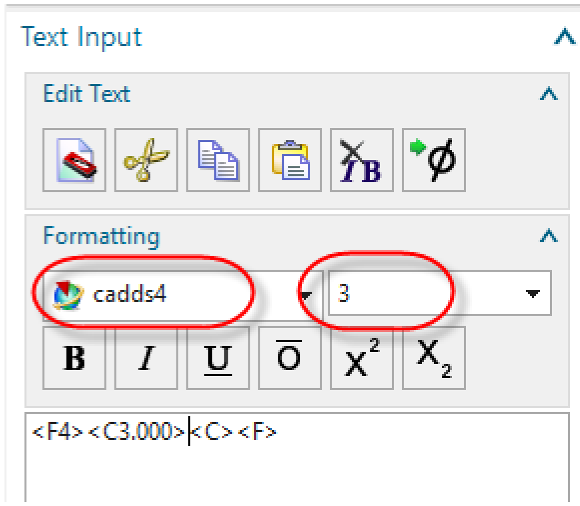
Adding text this way will allow it to be used in generating a tool path. You will have to decide on a font style and how large you want the text and several other attributes. Begin by turning the Auto Alignment to Off. Then, for the anchor, select the middle center option.



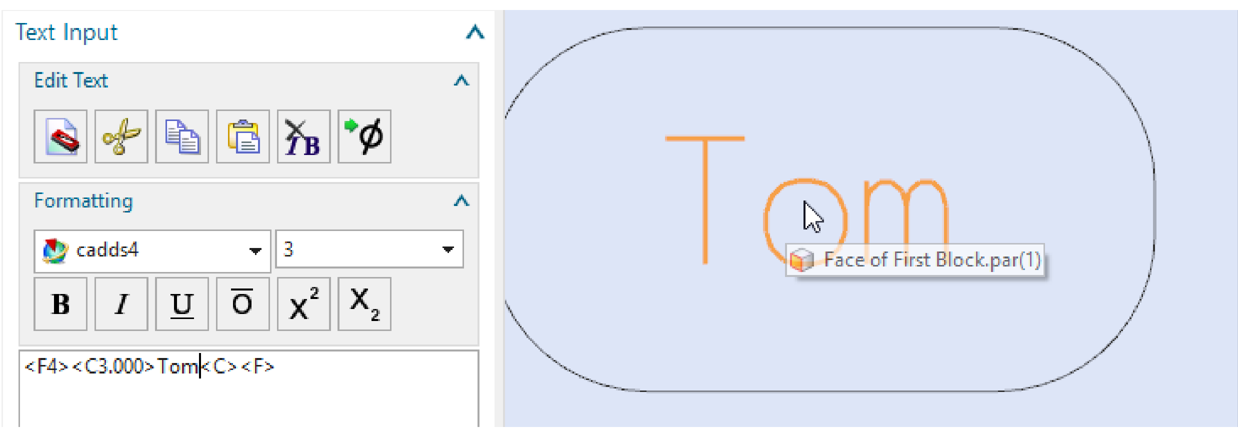
Expand the Text Input section.



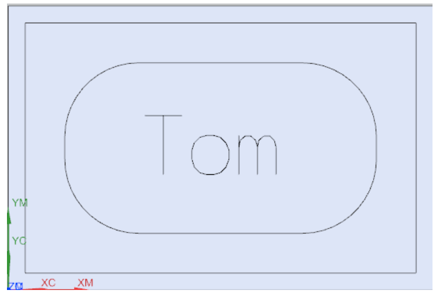
In this example we will select the text and size by clicking in the windows in the formatting area. There will be hundreds of different text types to select from. This example will use the cadds4 font. The size has been changed to 3. In the text area some code appears beginning with <F4> This is representing the font selected and then the size is shown as <C3.000> The curser appears in the center and that is where you begin typing.



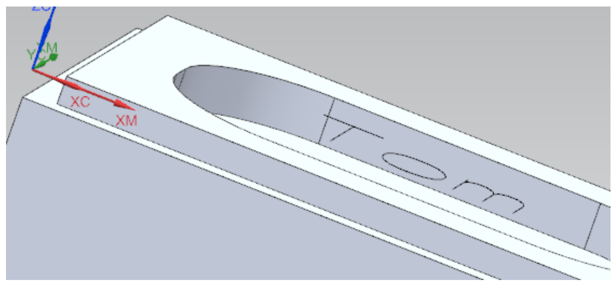
Once you begin typing, you will see the text stuck to the mouse curser. Finish what you want to engrave and then select the center of the block.



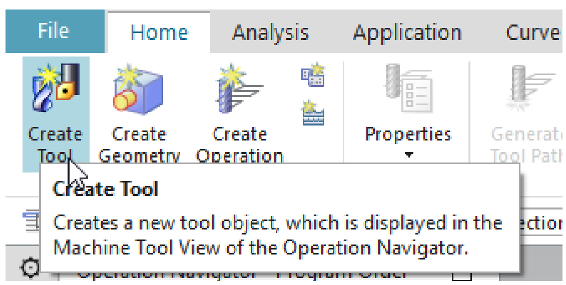
At the very bottom of the dialog box select Close. The text should be where you selected.



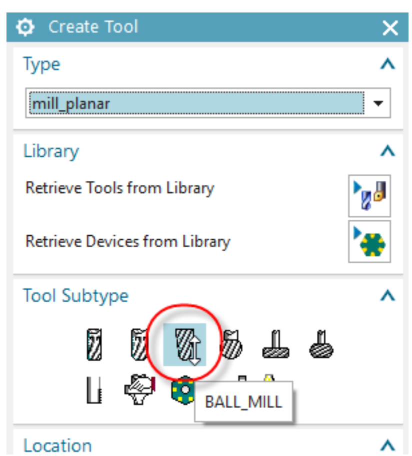
Once the text is in position, return to the isometric view. If you rotate the part you should see the text floating over the part.



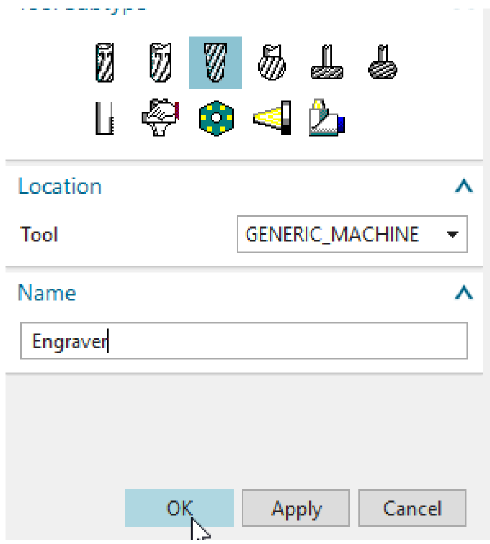
From the Home ribbon select the option for Create Tool.



When the Create Tool dialog box appears, select BALL_MILL for the tool subtype.

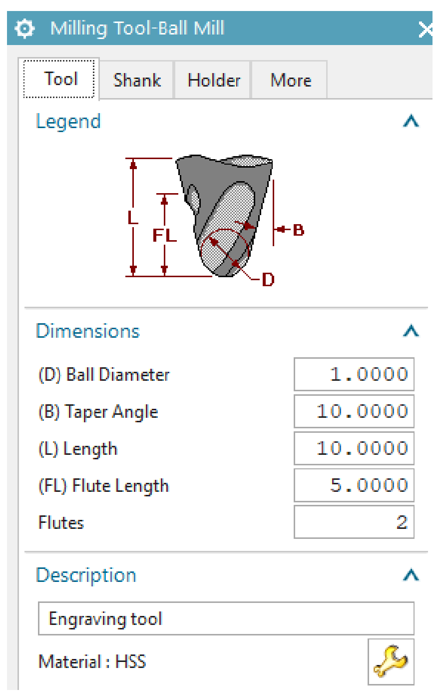


For the location, select the option for Generic_Machine and give it a name that you will remember. In this example it is called Engraver.

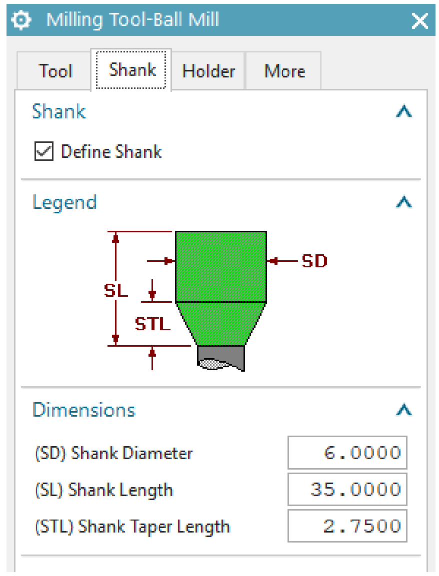


Select OK at the bottom of the dialog box. This will bring up the dialog box where the parameters of the tool are defined.

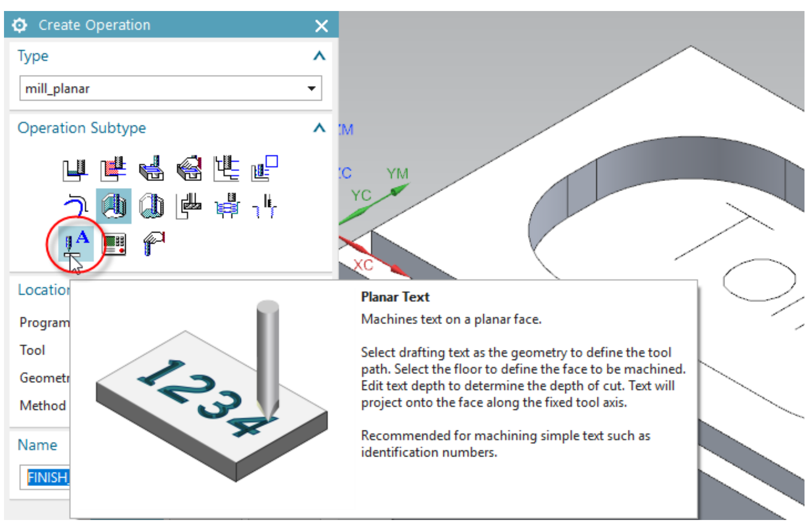
In this example, we set the ball diameter to 1mm, the taper angle to 10 degrees, the length to 10mm, and the flute length to 5mm. The tool number is set to 1.



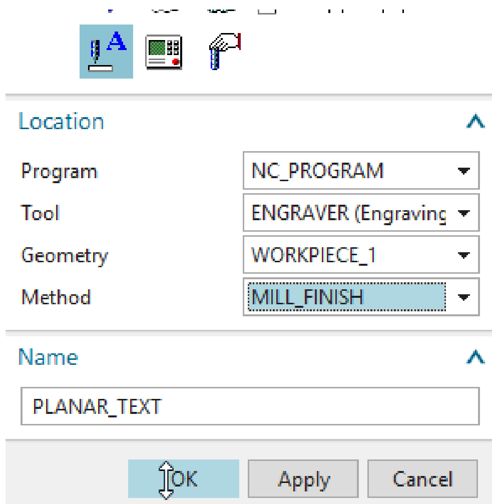
Select the Shank tab at the top. The shank diameter should be 6, the shank length should be 35, and the taper length should be 2.75.



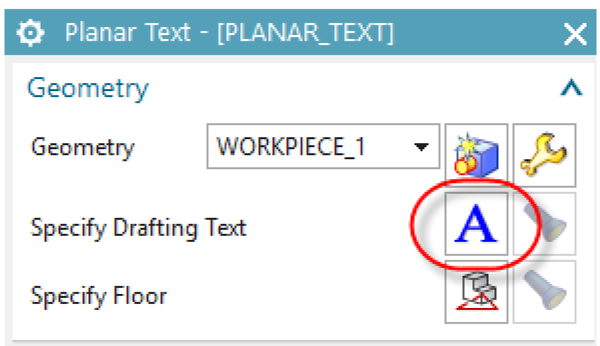
Select OK at the bottom of the dialog box.
Select Create Operation from the home ribbon. Select Planar Text for the operation subtype.



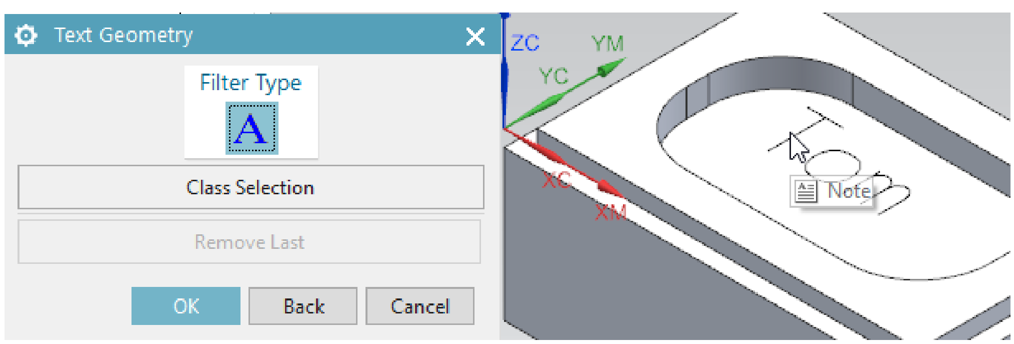
Select NC_PROGRAM for the program. Select the tool just created. In this example it is called Engraver. For Geometry this example will select the geometry created and defined in the first operation, Workpiece1. MILL_FINISH is the method. Select OK.



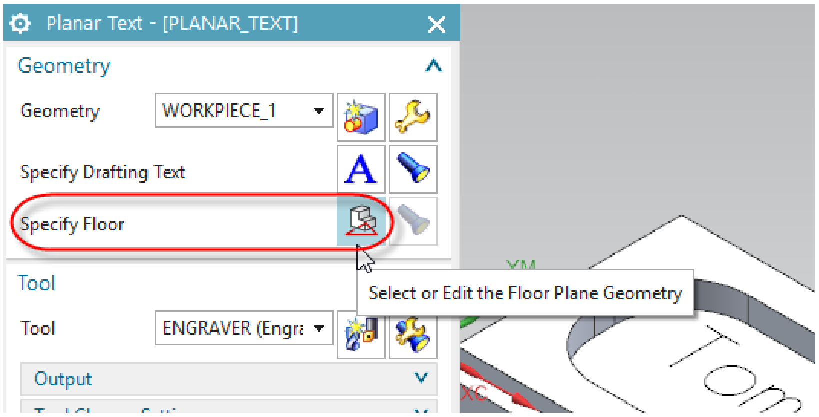
This will open up the Planar Text dialog box. You should see workpiece_1 as the geometry already fill in. The first thing to do is specify the drafting text. Select the icon.



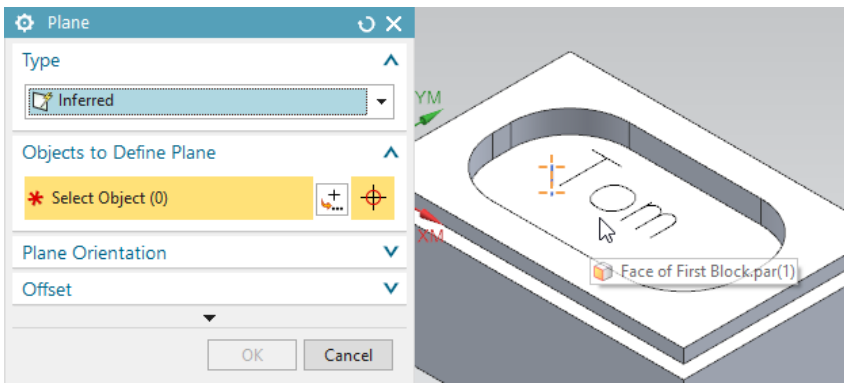
Hover over your text and it will highlight. Select your text. Select OK



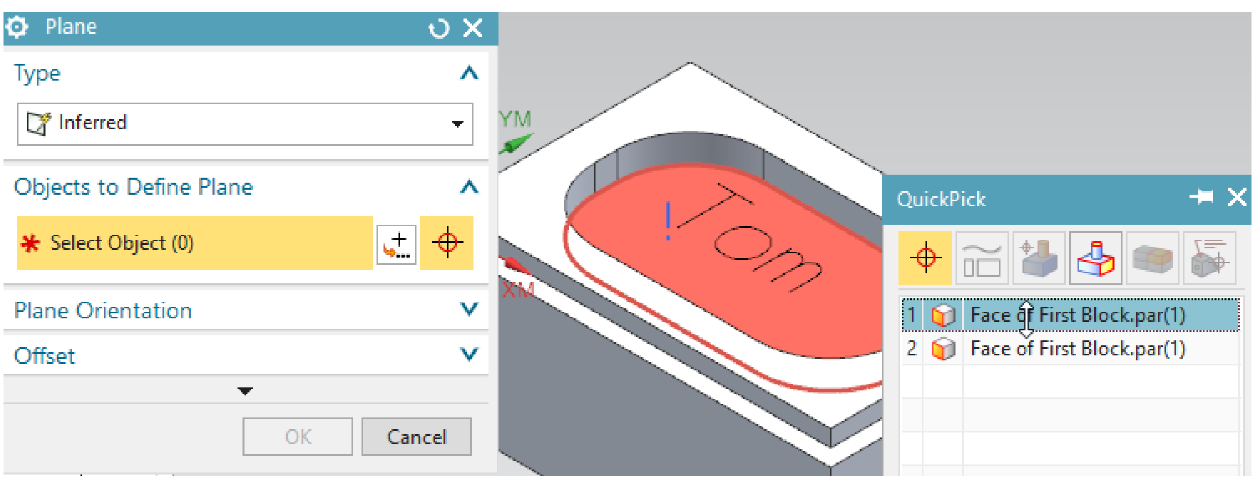
When the dialog box returns you will see the flashlight next to the Specify Drafting Text is now active. Select the icon for Specify Floor.



Move your mouse around the piece until it finds the face of the first block. When it is highlighted, click to accept this as a choice.

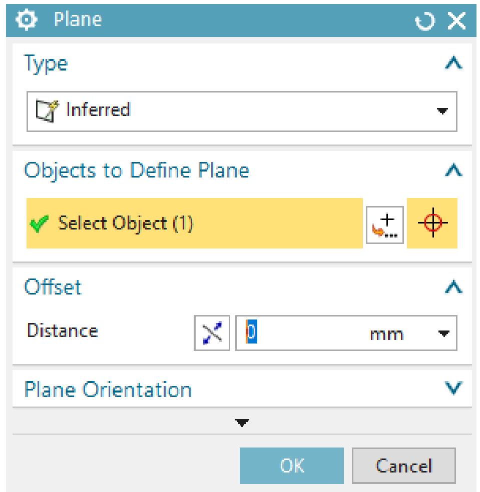


Several entries may appear. Select them one at a time to be sure you have the correct face.

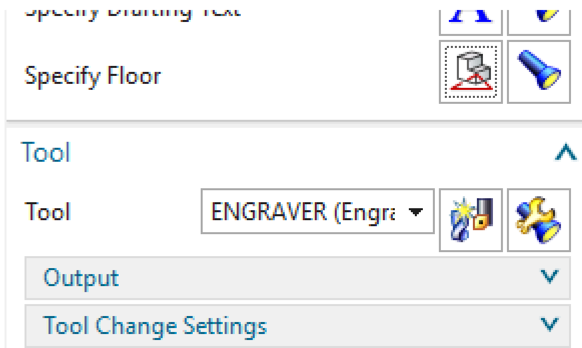


Click on the correct face.

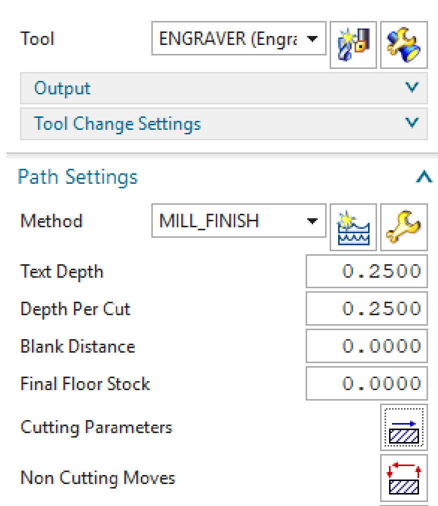
The dialog box returns. The Offset Distance should be 0mm. Select OK at the bottom of the dialog box.



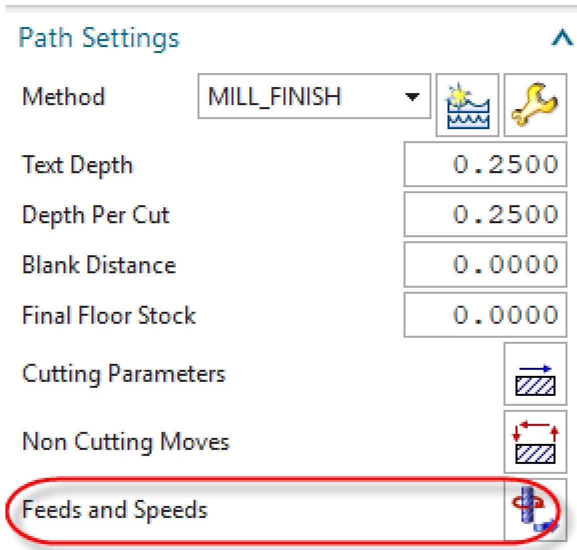
Be sure the name, ENGRAVER, is showing in the tool area.



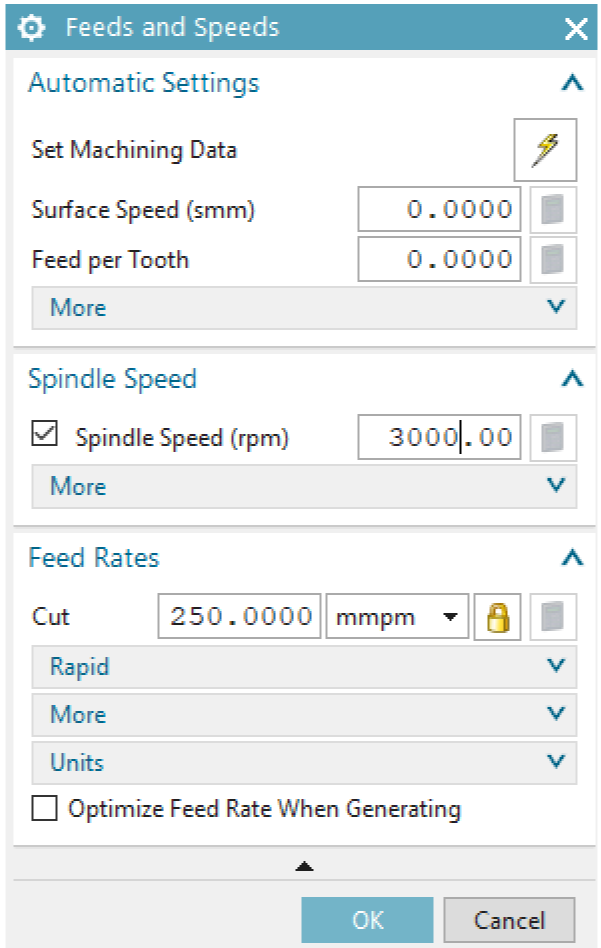
In the path settings, select MILL_FINISH for the method and .25mm for the Text Depth and Depth Per Cut.



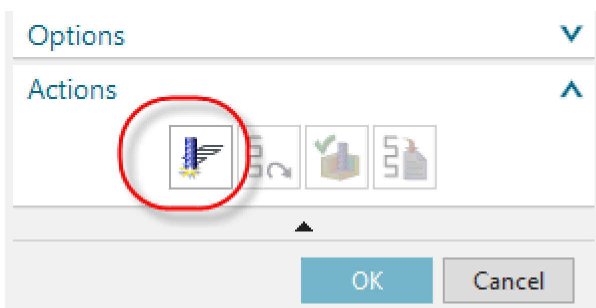
Just below this area we will set the Feeds and Speeds.



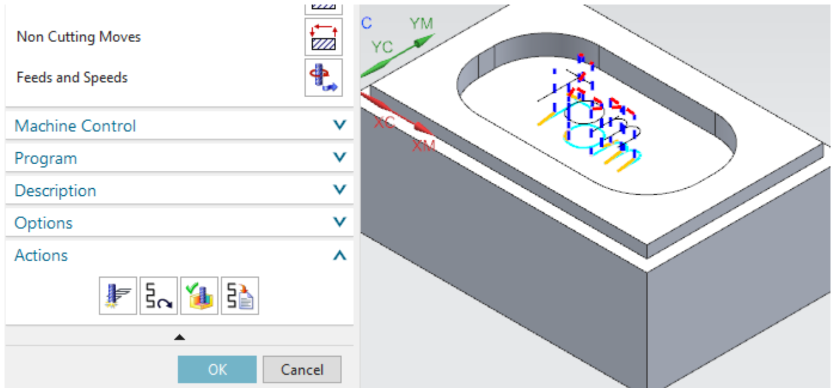
Set the Spindle Speed to 3000 rpm and the Feed Rate to 250 mmpm.



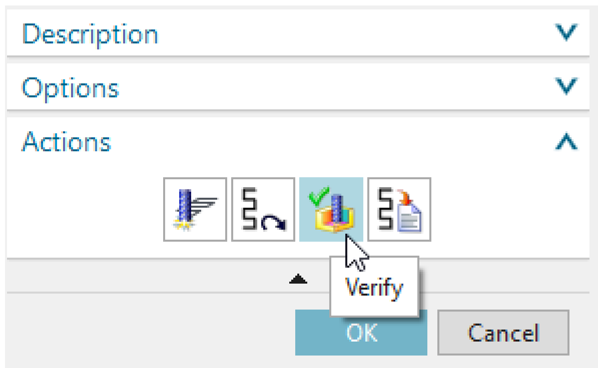
At the bottom of the dialog box in the Actions section select Generate Tool Path.



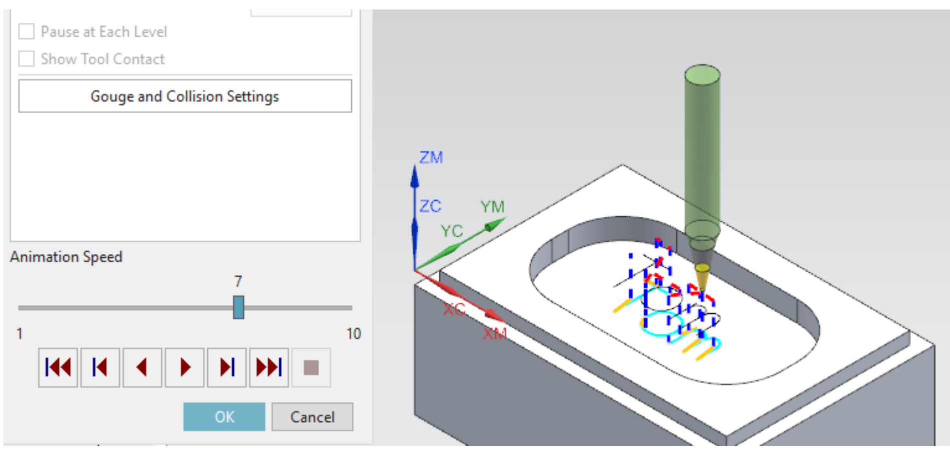
You should now see a tool path.



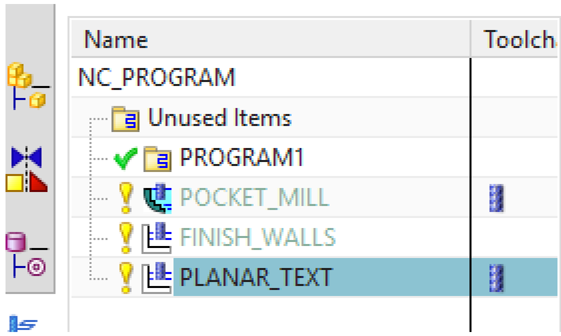
Now select Verify from the Action section.



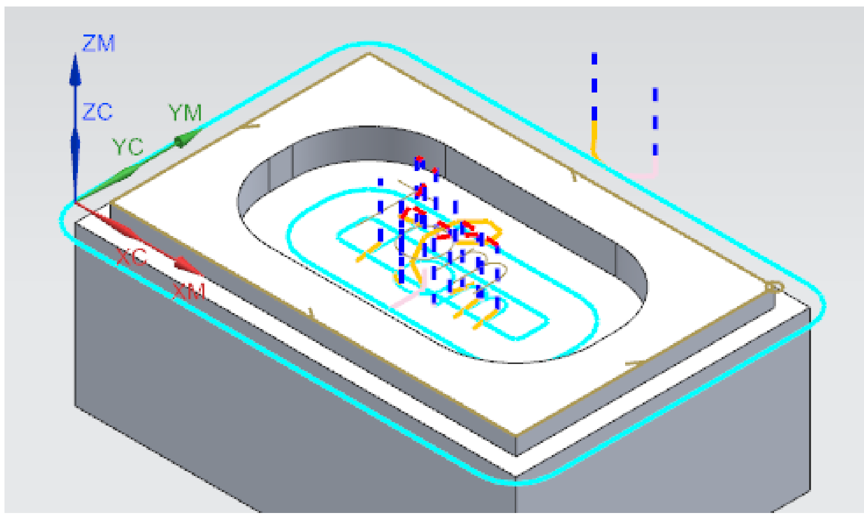
Run the Verify and you should see your engraver tool follow the tool path.



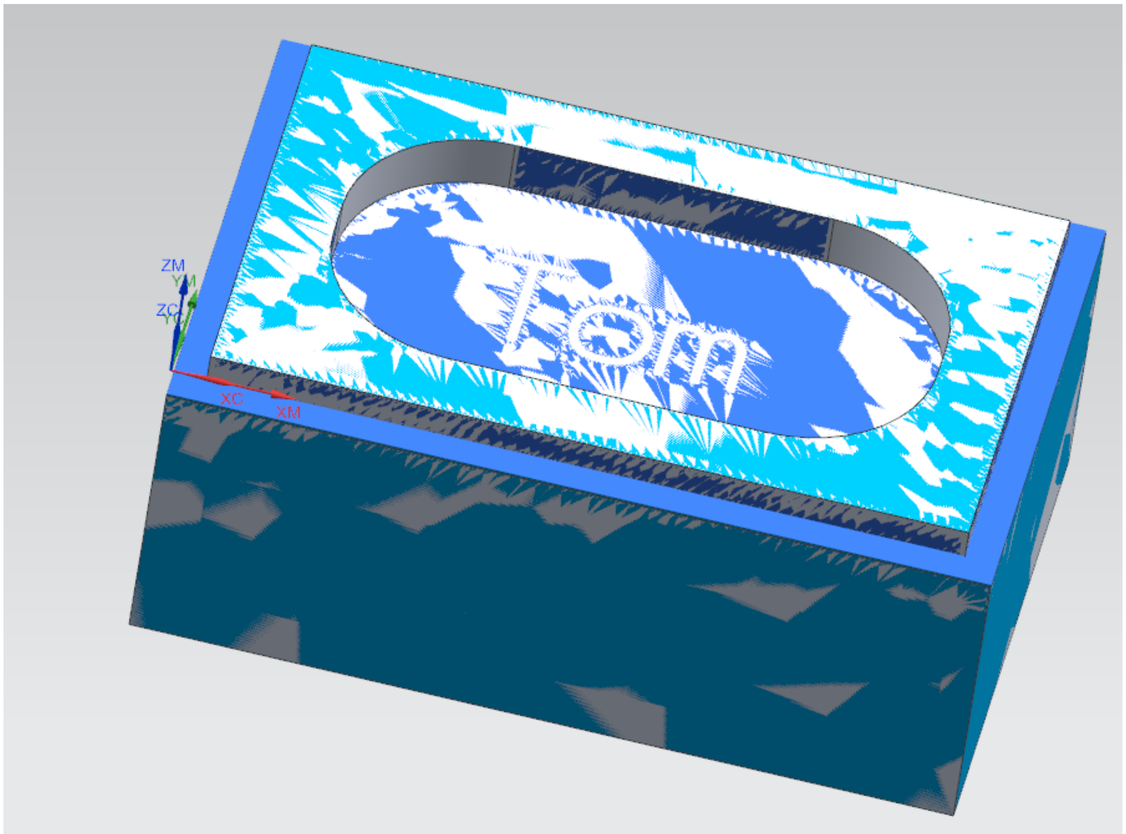
Select OK at the bottom of the dialog box. Select OK at the bottom of the operation dialog box. You should see the operation appear in the list of operations in the operations navigator at the side of the work area.



Highlight all the tool paths and then select Simulate machine from the home ribbon. All the toolpaths should be visible.



This will show you all the operations.



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Introduction to the PLC

Programmable Logic Controllers (PLC) are hardened computers specializing in sensor inputs and output control. The operating systems are suited to performing repetitive tasks of automation with reliability. These hardened computers protect sensitive components from dust, dirt, and electrical interference. Typically they are modular devices easily assembled to perform operations with the desired functionality. Frequently these devices are set up to control thousands of inputs and outputs. They exist in every industry, cars, and even appliances.

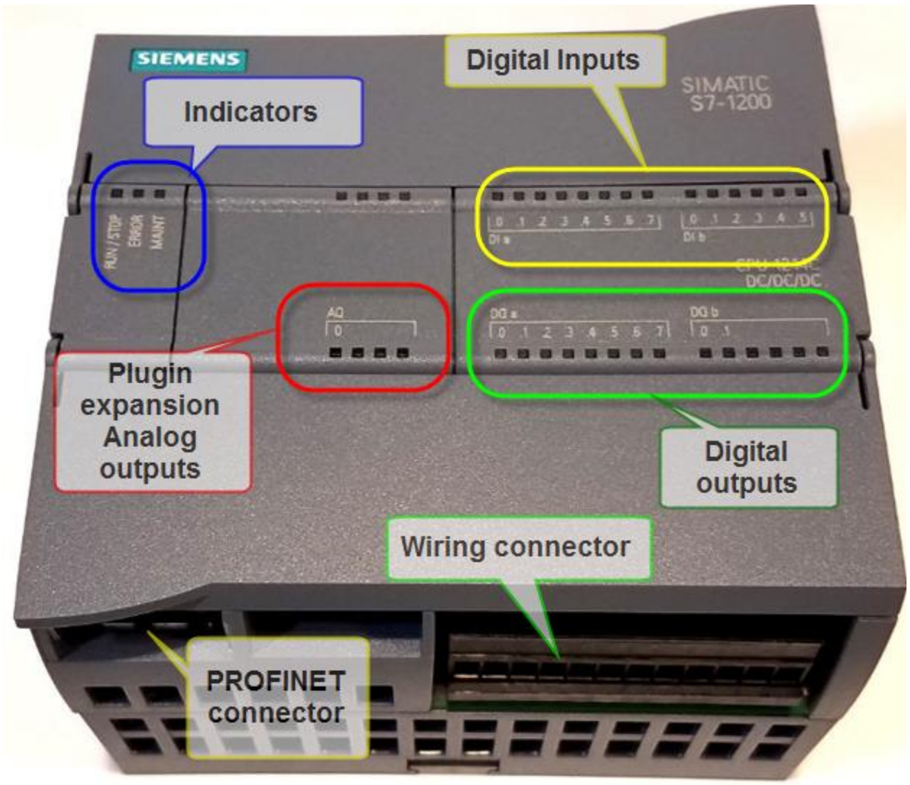
This course examines all aspects of PLCs including electrical wiring, mechanical connections, inputs, outputs, logic, and programming languages. There are methods that automation specialists use to plan, design, implement, and organize their work. When designing and documenting complex processes or programs, flowcharts and state diagrams are used. A flowchart is a type of diagram that represents an algorithm or process, showing the steps as boxes of various kinds, and their order by connecting these with arrows. State diagrams allow us to see desired processes and what events will cause a change in output functions. The planning must also account for needed inputs and outputs and what addresses are used. The planning must also include needed hardware and electrical supply. Schematic diagrams are used to plan, document and communicate necessary electrical supply and wiring.

In order to communicate with the PLC the programmer needs to have a language that can be translated into control functions. Graphical programming languages using blocks of code represented by symbols, are in the class of object oriented programming languages. In the case of PLCs the most common language is ladder logic. Ladder logic programs are collections of instructions that tell the computer how to interact with inputs, make decisions, and enable outputs.

In Boolean algebra, mathematical evaluate expressions simplifying expressions to one of two values) True or False. Boolean expressions often involve comparison operators that can be evaluated to determine if they are: True or False. Programming languages allow the central processing unit to make decisions. Control statements called networks select or "control" which sections of code are executed. Control statements can be Sequential, Conditional (decision making), and/or Iterative.

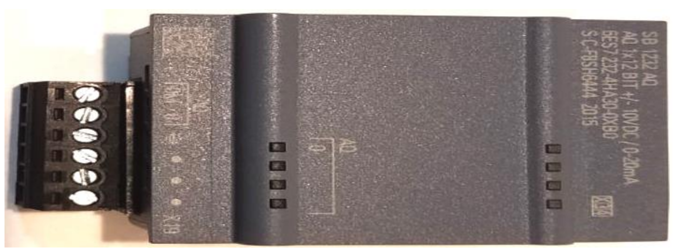
Getting Started
Introduction to the CPU

A central processing unit (CPU) is the brain of the controller. This device handles the higher level functions. Typically they consist of circuits defined by function, those being arithmetic, logical, and input and output control. The picture below shows The S7-1200 Series controller from Siemens. The CPU has status indicator LEDs to show when an input or output is functioning. The doors on the top and bottom cover the wiring connectors used for inputs and outputs. The PROFINET connector is used with CAT5 Internet cables to allow the PLC to connect directly with networks and programming computers.



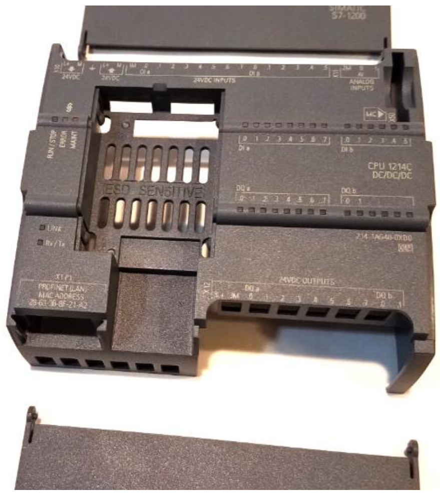
The S7-1200 is one in a series of controllers. The picture below indicates this is a 1214C DC DC DC controller. The letters following the 1214C explain the power supply and control voltages. Every controller also has a specific number associated with it. In this example it is a 6ES7 214-1AG40-0XB0. This number is important as it defines the driver necessary for communication. Find the number on the side of your controller and write it down.

This series of controller has a plug in that allows for analog output. It comes in a small box as one of the components.



To install the plug in, remove the top from the CPU by inserting a small screwdriver in the indentation on the side of the CPU (circled in red.) Apply slight outward pressure by prying to allow the top to pass the latches circled in green.

The doors and the insert can be removed by gentle pressure on the hinge to allow it to exit the slots.



Place the insert in the opening and apply gentle pressure until it fits snuggly in the space. Take care not to bend the pins on the bottom of the insert.

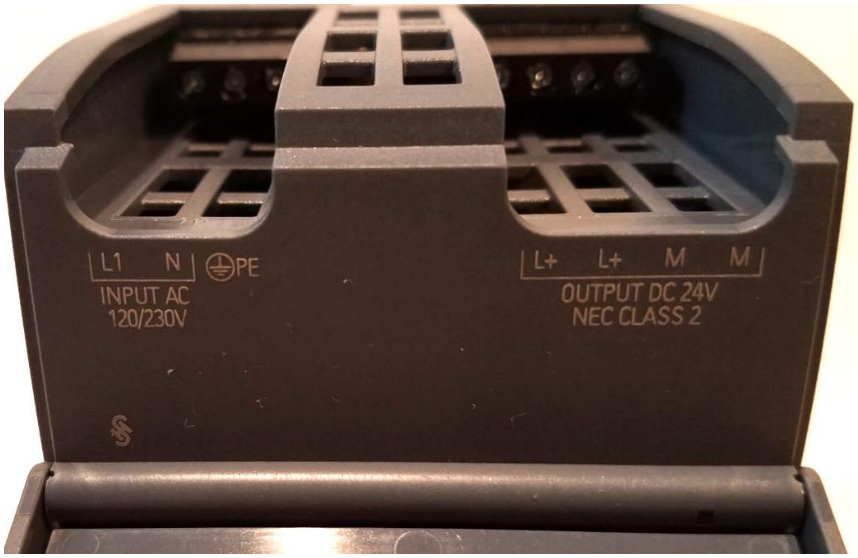
Slide the top back on the CPU. Apply gentle pressure over the pins on the insert to be sure they engage the socket on the mother board of the CPU.

Reattach the doors by hooking one end into the recess on the side and then applying slight pressure to engage the other side.

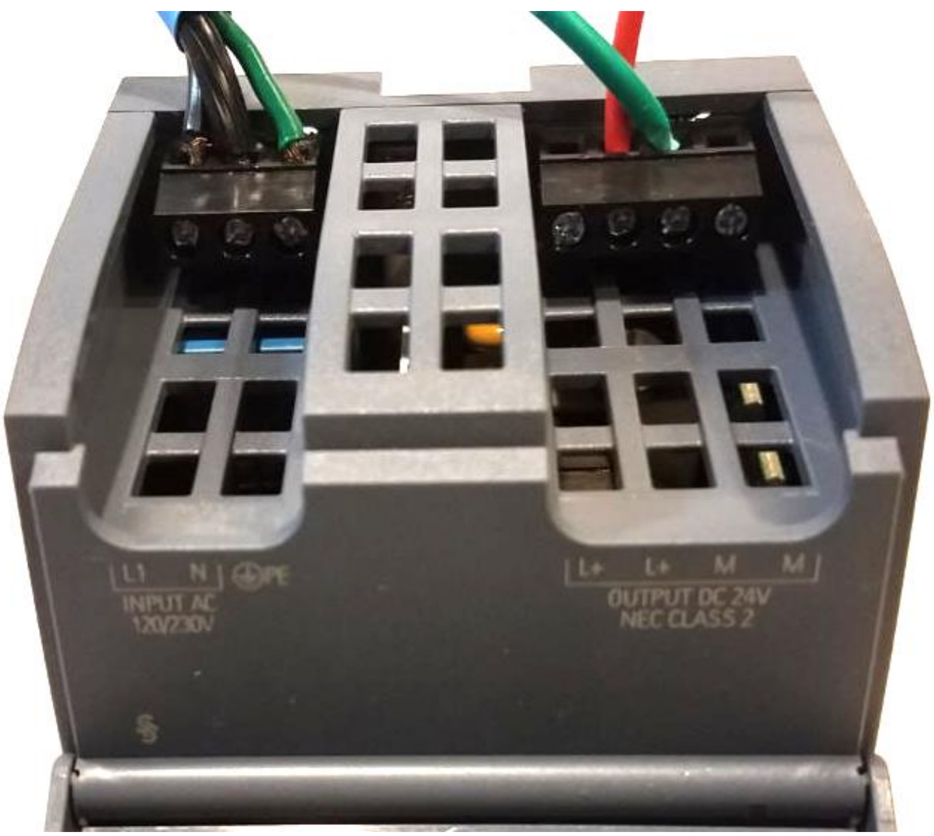
Wiring the S7-1200 CPU

Power Supply
The S7-1200 series has a power supply included in the kit. This has a rail mount just as the CPU does on the back. Mounting on a rail allows for them to be anchored side by side and leaving enough airspace top and bottom for cooling.

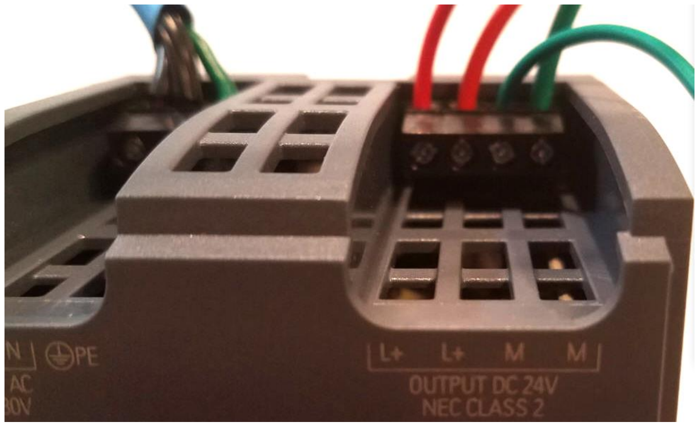
There are two sets of connectors on the power supply. The ones on the left are marked L1, N and PE. L1 is the designation for the wire with the line voltage. This can be either 120V AC or 230V AC. Line voltage is dangerous and you must follow proper electrical safety procedures. The N connector is the neutral or return wire and the PE is the protected earth or ground connection. Consult with the teacher if there is any doubt about correct wiring. The other side is the 24 V DC output. In the picture below there are two terminals marked L+ (Leiter or conducting line) which is the supply voltage or positive 24V terminals. The connectors marked M (Mana or ground) are the common mode connector also known as ground.



When using a power cable to supply power follow applicable rules to assure proper polarity and electrical safety. Plugs designed to work with AC will have a smooth wire and a ribbed wire. Smooth, red, black or brown wire are typically the line wire (hot.) The ribbed, grooved, striped, white or blue wire is generally the neutral wire. Ground wires are typically green in color. Double check with a meter to be sure correct polarity is used.

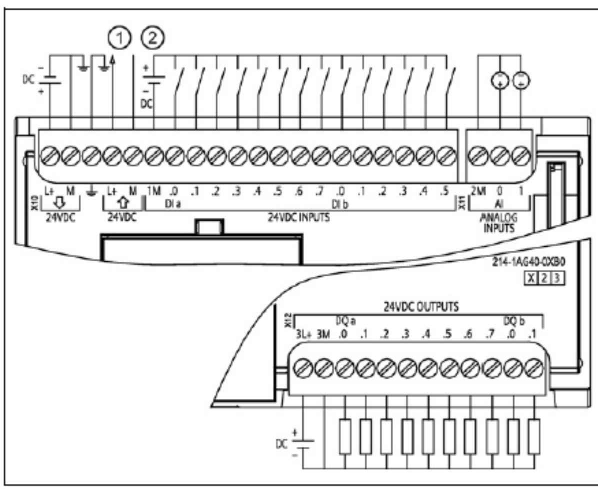


Follow the DC power circuit wiring color codes standards of the national electrical code when connecting the DC side. Use red wire to denote the hot (L+) or positive connection. Green typically is used for the ground (M) connection.

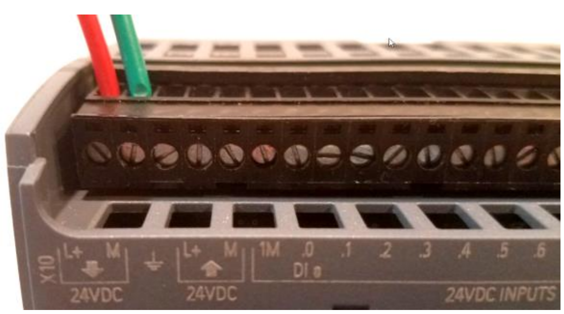


The table below shows the electrical connections for the sections of the CPU.

Table A- 65 CPU 1214C DC/DC/DC (6ES7 214-1AG40-0XB0)

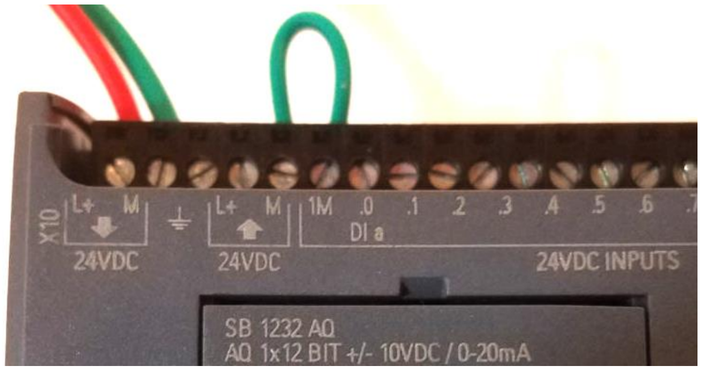
	①	24 VDC Sensor Power Out For additional noise immunity, connect "M" to chassis ground even if not using sensor supply.
	②	For sinking inputs, connect "-" to "M" (shown). For sourcing inputs, connect "+" to "M".
	Note 1: X11 connectors must be gold. See Appendix C, Spare Parts for article number.	
	Note 2: See Device Configuration (Page 145) for information about the Ethernet port of the CPU.	

The 24 volt supply lines are brought to the CPU. Check to be sure the L+ connector connects to the L+ of the power supply and the M is connects to the M. Damage may result if power is connected improperly.

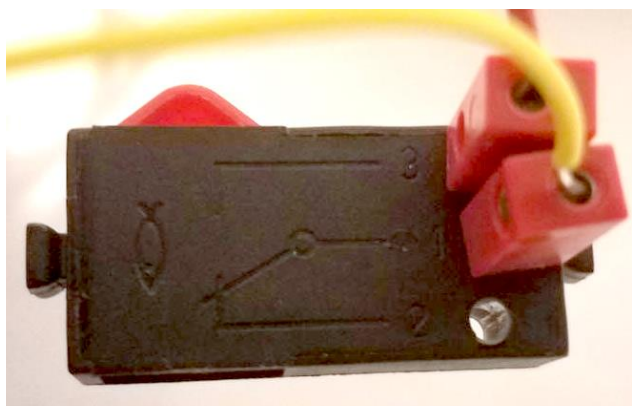


Digital Input Wiring

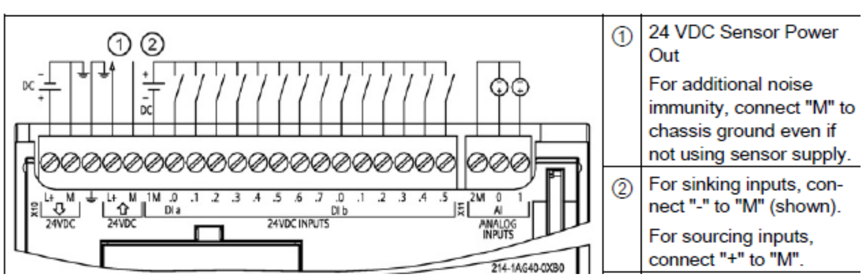
Digital inputs must have a complete electrical circuit. Connect a wire from the M terminal to the 1M terminal to help eliminate electrical noise.



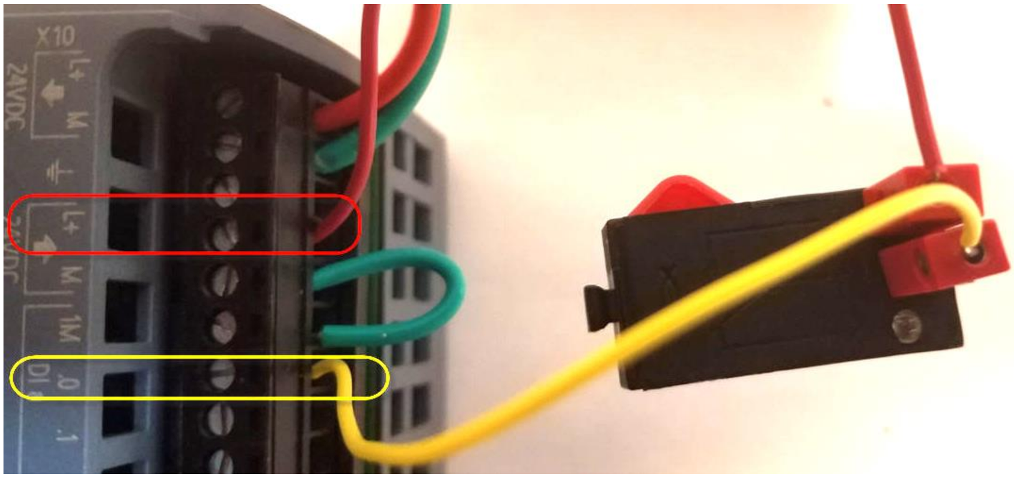
Use any type of digital device to connect to the inputs. This example uses a normally open switch. Voltage is brought to the number 3 terminal and the wire from the number 1 or central terminal is connected to the input.



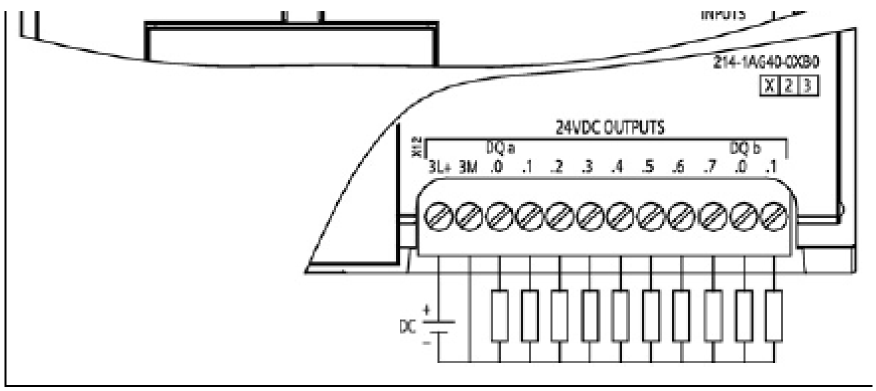
The schematic below indicates the ground or negative power source is connected to the 1M terminal and the hot side is connected to the various inputs.



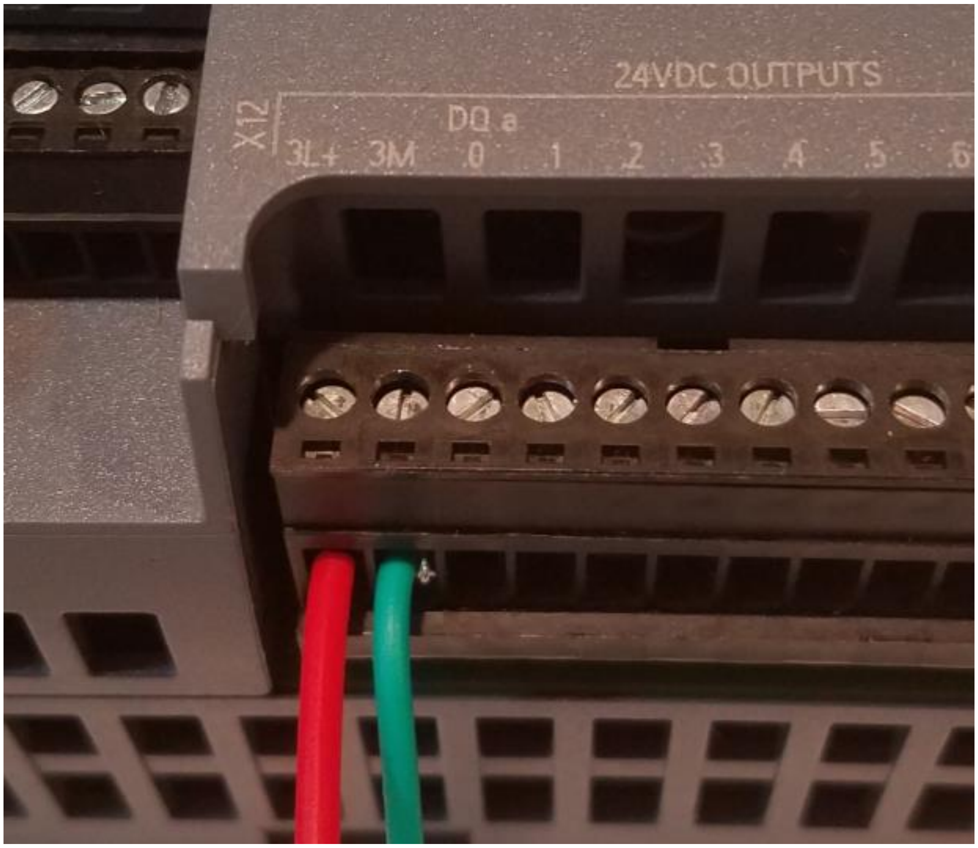
The picture below shows a switch connected to the L+ terminal and the yellow wire connecting the switch to the digital input connector 0. Most digital devices will use similar connections. The exception would be devices that need their own power supply to run. The ground connector on those would be connected to the M or M1 terminals so the connection can be completed to the input pin.



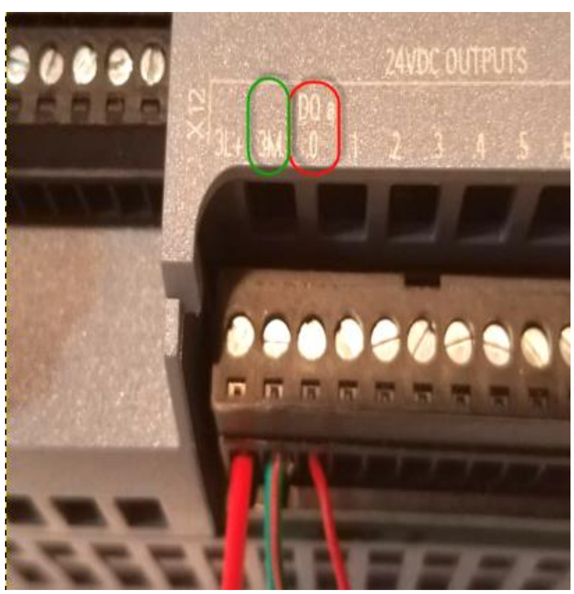
Output Connections
Connecting to devices is fairly easy. The schematic section below shows the voltage for the outputs connected to terminal 3L+ and the return to the supply power supply connected at 3M. Current is limited in each channel. Each channel is rated at .5 amps. To run equipment at higher current ratings connect the output to a relay that can handle the current.



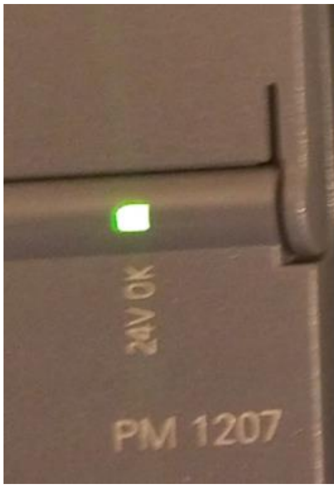
In the example below, in the DC outputs section red and green wires are providing power by connecting to the L+ and M connections from the CPU power supply. Separate lines run from the power supply and connect to the output terminals.



Connecting a typical output requires that the positive output go to the device and the return from the device be connected to the 3M connector. In the example shown below the wire to a small 24V Fischertechnik™ motor is connected to DO0 and the return wire connected to 3M.



Testing the power Connection
When first powered up the power supply will indicate it is operating by the green LED. The CPU will then indicate it is starting by blinking the run/stop, error and maint LEDs. Once the CPU is running the run/stop will be either yellow (stop mode) or green (run mode.) If there is an error such as an unplugged module the error light will blink red. The maint LED lights when maintenance is needed such as a new driver or inserted memory card.



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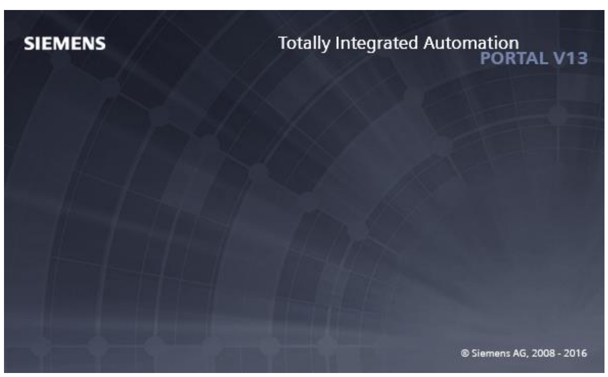
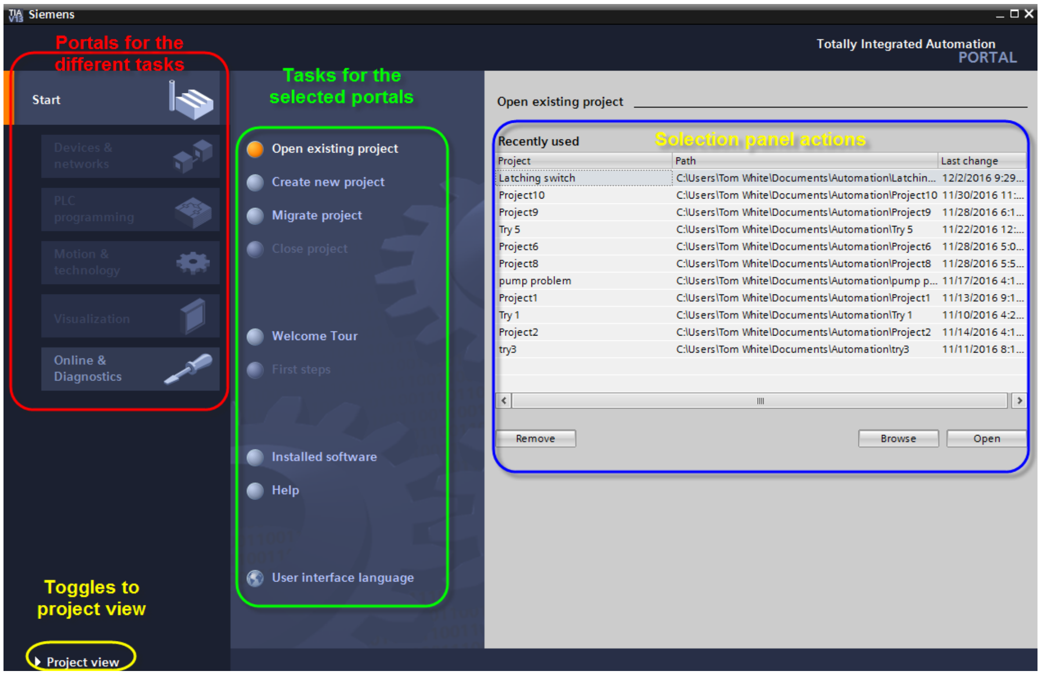
Setting up the Programming Environment

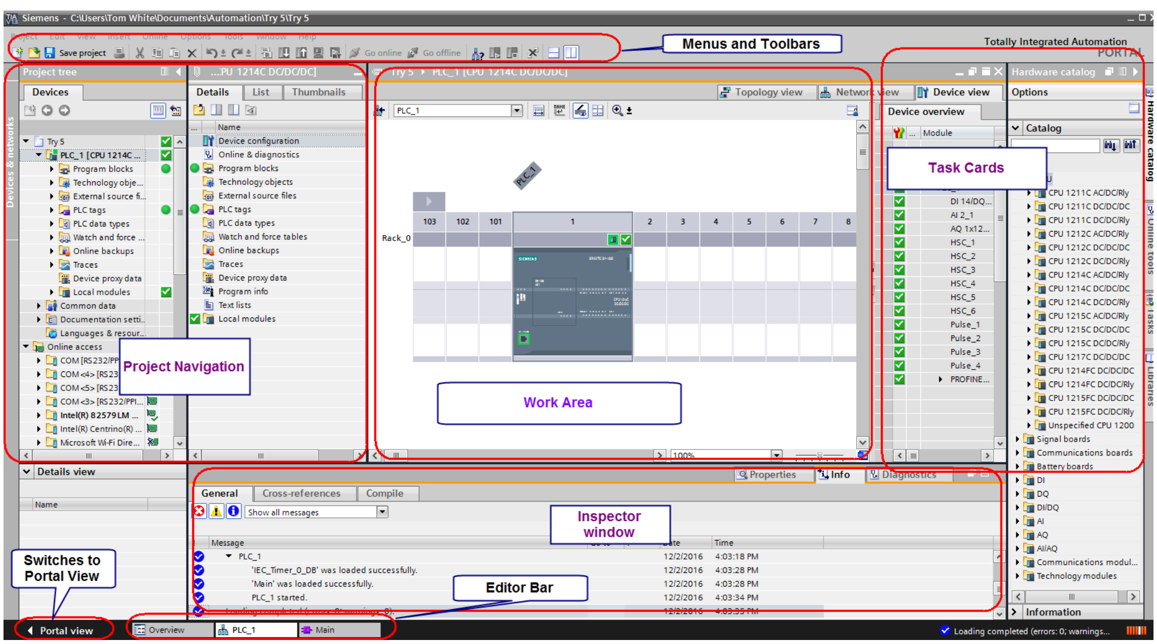
The programming for the PLC is done with the Totally Integrated Automation (TIA) Portal Software. It takes a while to install so plan ahead. Open the TIA Portal software.



The software will open to the Portal view. There are two different views of the project. The portal view allows for the selection based upon the functionality of the tools.



The project oriented view provides access to all the various components that make up a project. The picture below shows different areas of the screen. The user can customize the layout and minimize areas as needed.



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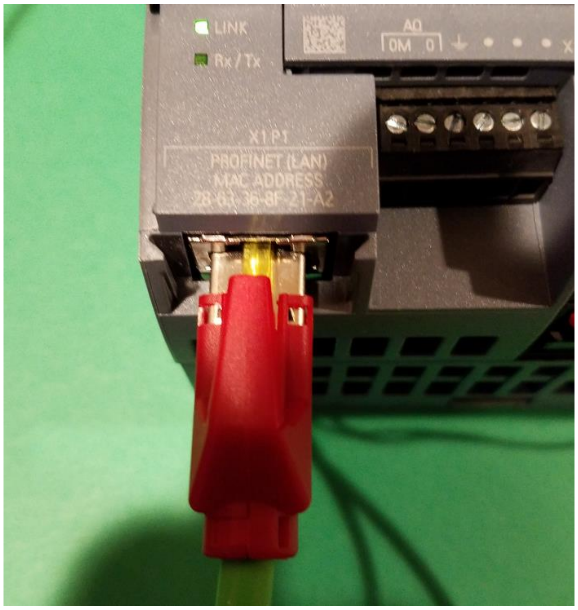
Setting up Communication

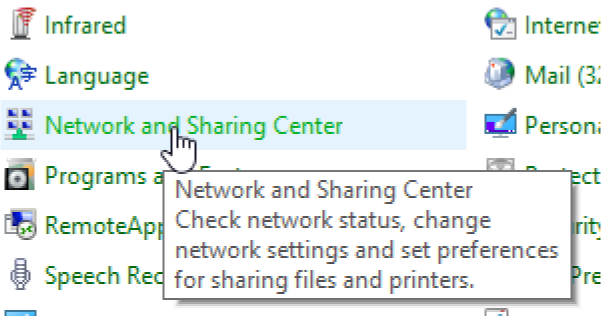
Once programmed, the CPU will remember its program and run it until the program is changed. Even shutting the power off to the CPU will not cause the PLC to forget the program. The computer is able to communicate with the PLC through an internet connection called the PROFINET. The connection is on the bottom of the CPU.



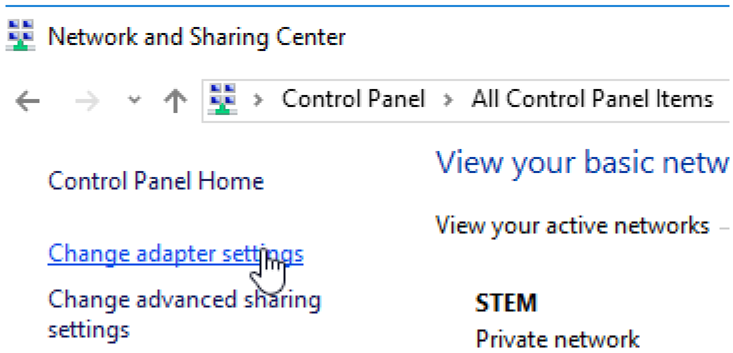
To connect with the computer the programmer must meet several conditions. The easiest way to accomplish the connection is with the use of a special cable provided in the kit. This cross-over cable allows the computer to talk directly to the PLC. This communication requires that the computer and the PLC be on the same sub-net. They need similar IP addresses. The default IP address of the PLC is 192.168.0.1. To communicate over the cable the computer needs an IP address with the first three groups identical and the final group of numbers different from the PLC. For example if the PLC is 192.168.0.1 then the computer will need an IP address between 192.168.0.2 to 192.168.0.255.

Setting the Computers IP Address

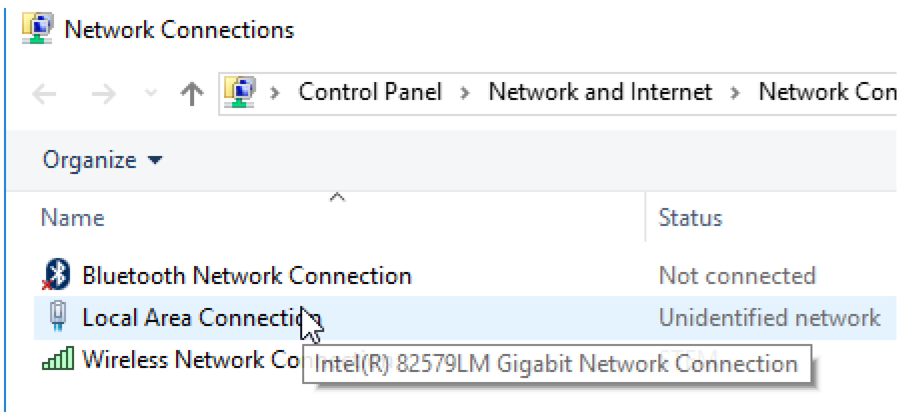
To adjust the settings so the computer and PLC can communicate, Administrator privileges are needed on the computer connecting to the PLC. Log in as the computer administrator. Open the control panel and select the Network and Sharing Center.



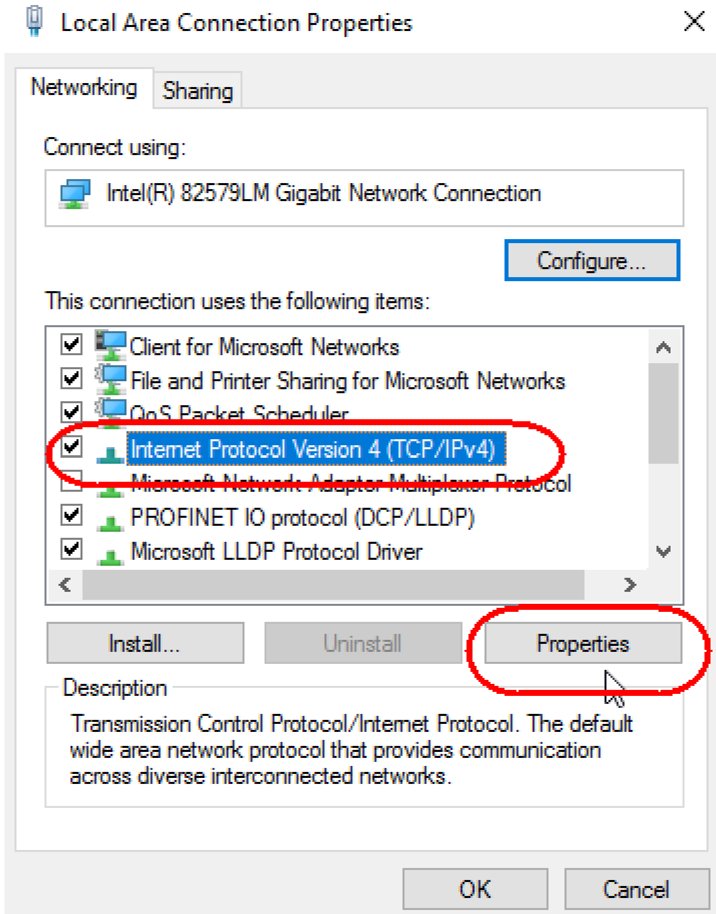
In the network and sharing center dialog box, select the option for “change adapter settings”.



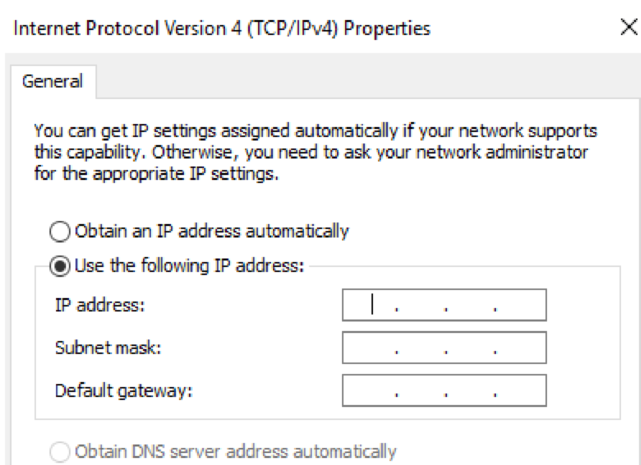
Select the local area connection which communicates to the internet by cable. In this example it is an Intel® 82579LM. Right click and select Properties from the options.



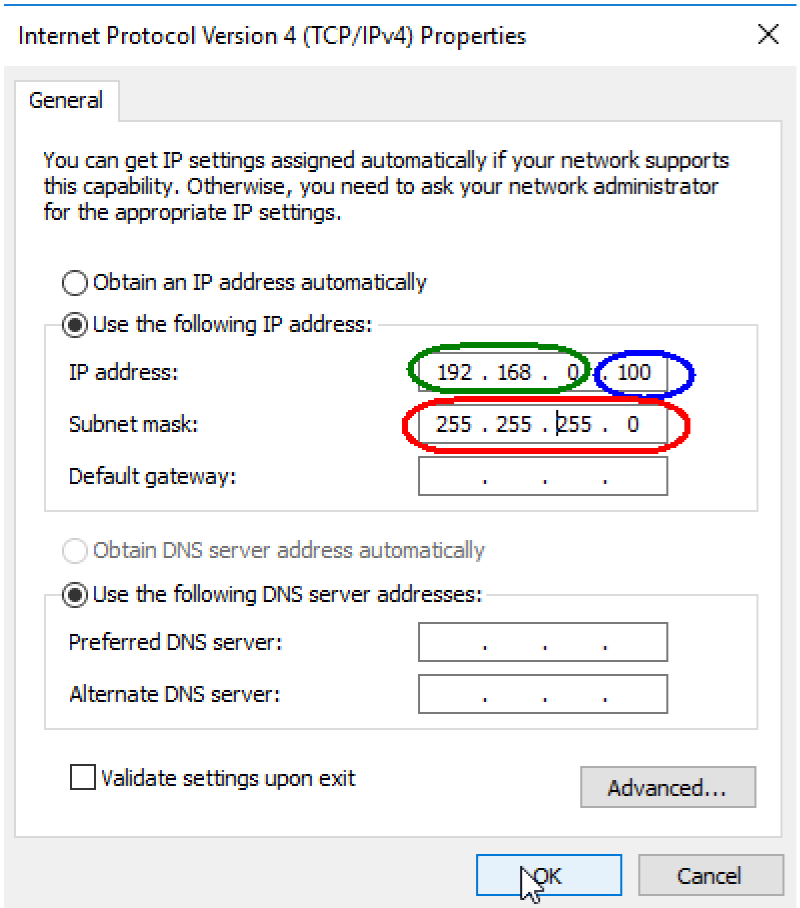
Highlight the Internet Protocol Version 4 (TCP/IPv4) and select properties.



Select the option for “Use the following IP address”.



In the space for IP address add the desired address. Do not enter 192.168.0.1. See the picture below. The first three groups must be the same. In the picture below they are highlighted in green. 192.168.0. The last group must be different. In this case the number 100 is used (highlighted in blue). After entering the IP address click in the area for the subnet mask. The default address of 255.255.255.0 will enter automatically.



Select ok at the bottom of the dialog box.

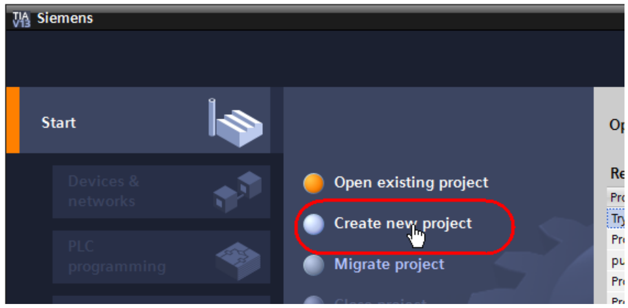
Back

Introduction to a Project

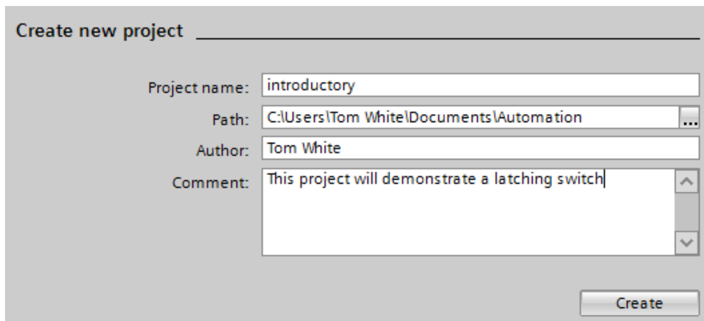
Setting up the Hardware

Connect the PLC to the computer and power the PLC.

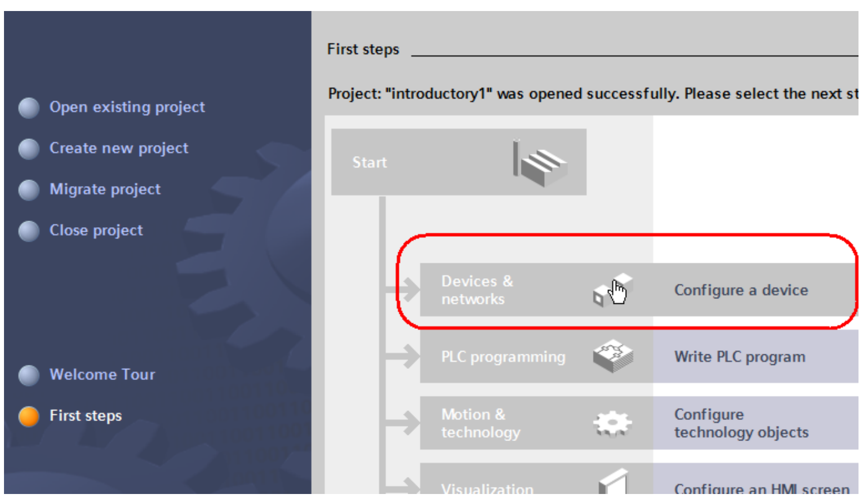
Select the option for create a new project in the portal view.



In the dialog box give the project a name that communicates the intent the project. This becomes important when several projects have been created.

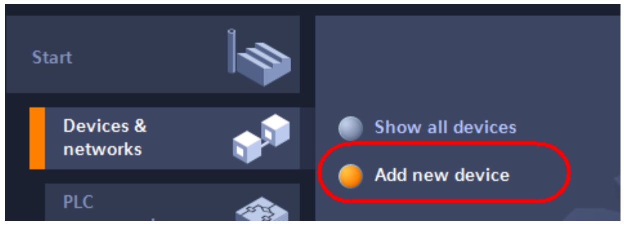


Select the Create button. See the program think and then return to the portal view. The portal now switches to the first steps. This will allow the user to add components to the program a piece at a time. Later, when familiar with the project window, more time will be spent in that view.



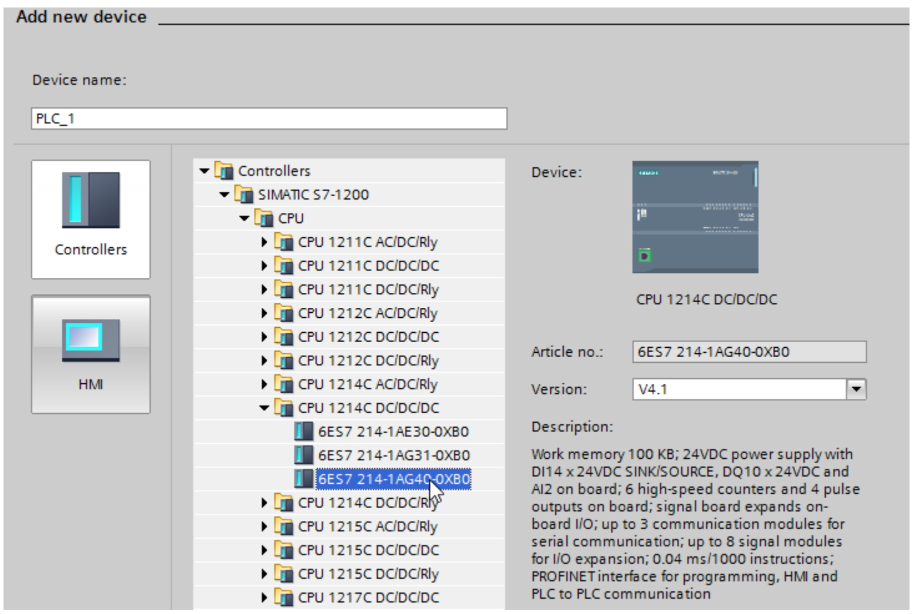
In order to communicate with the CPU the program must select the proper driver for the CPU. There is information on the side of the CPU with specific information. This information will be needed for the proper selection.

In the portal view select Add new device.



This brings up the dialog box to select a device.

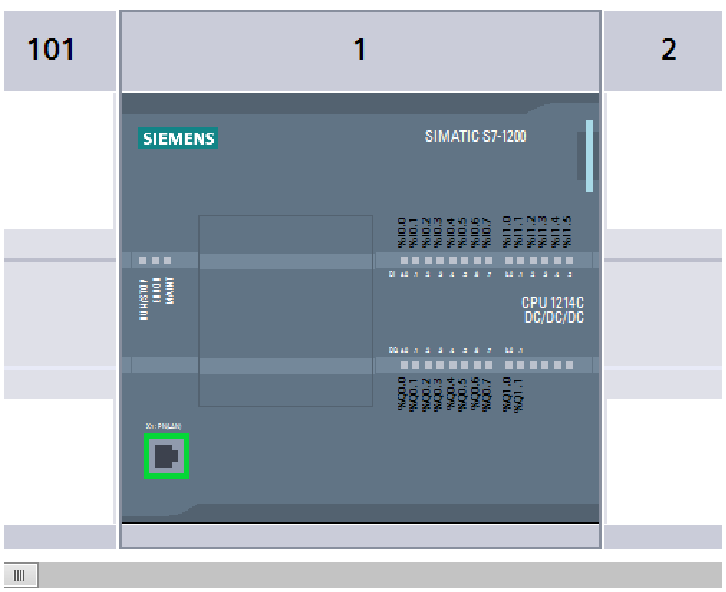
Using the information printed on the side of the controller that was previously recorded in your note book, expand the controllers menu. Expand the SIMATIC S7-1200. Expand the CPU. From the list, look for the number on the side of the controller. Expand the number and look for the driver number in the choices.



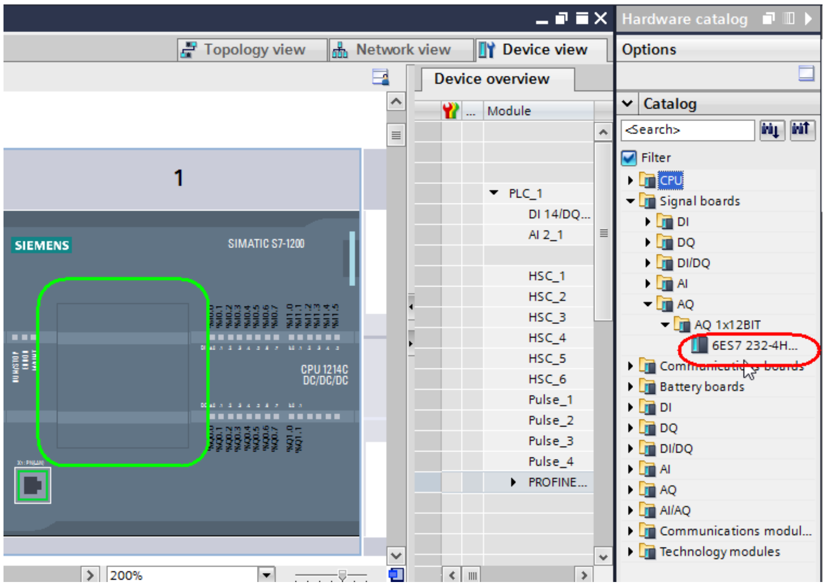
Be sure the number selected matches the controller you have.

From the bottom of the dialog box select the Add button. The program will pause while it loads the driver.

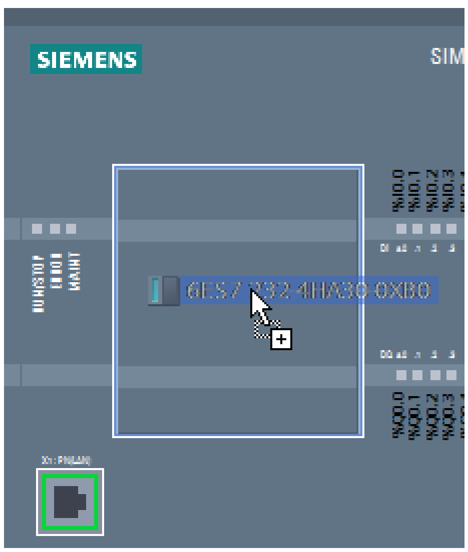
The program will switch from the portal view to the project view. See your controller on the screen.



In this example an additional board was added to theS7-1200. An additional analog output must be added. On the right hand side of the screen is the hardware catalog. In the signals boards section expand AQ. You will see the AQ 1X12BIT entry. Expand that and find the entry with the same identification code on the analog output board. Left click on the entry circled in red in this example and drag it to the area on the picture circled in green below.

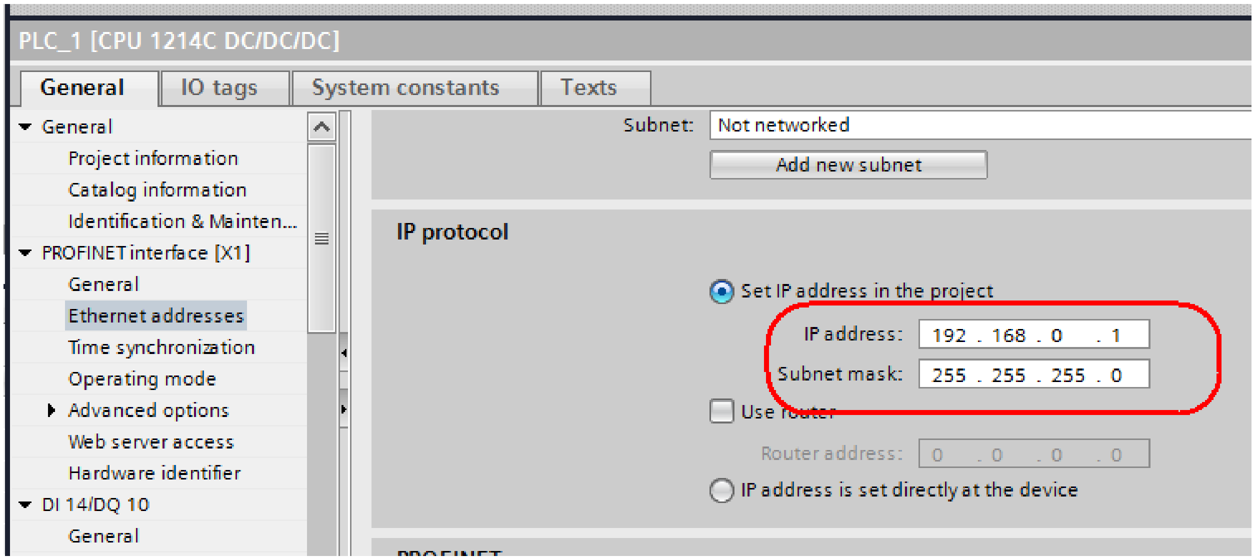


When you let go the analog output will be there.

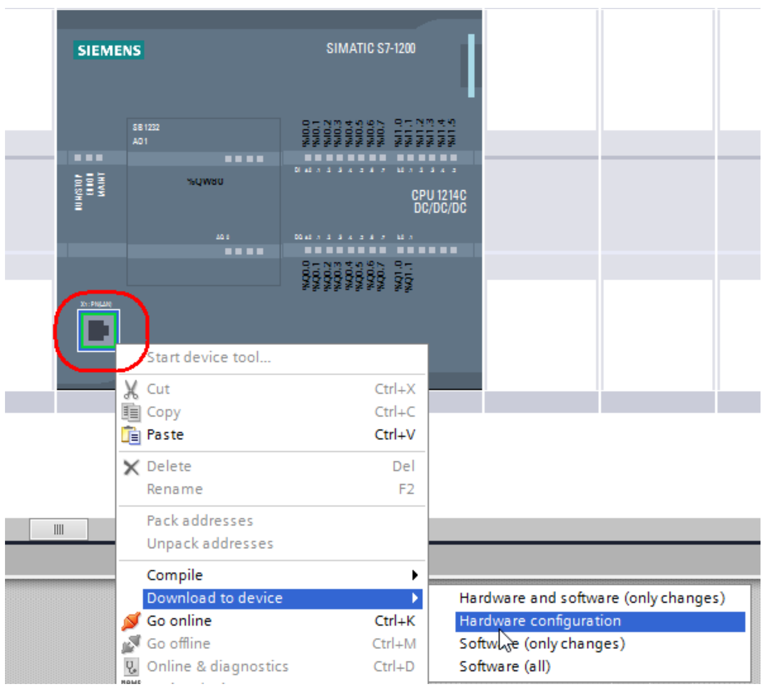


Double click on the image of the controller and it should open up the PLC properties in the Inspector window at the bottom of the screen.

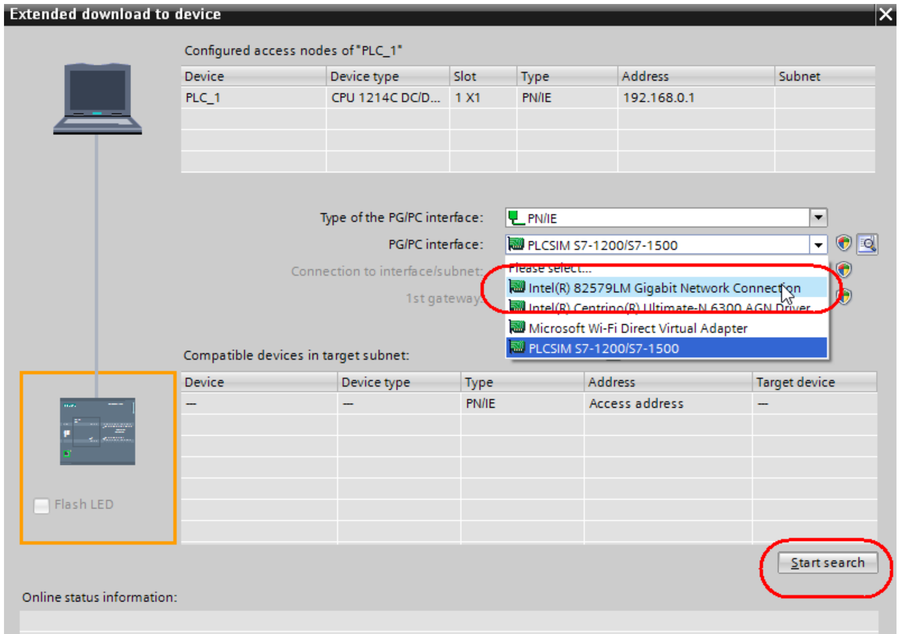
On the general tab expand the PROFINET interface section and highlight the Ethernet address. Click the radio button for set IP address in the project and set it to the IP address of your card. In this example the default address of 192.168.0.1 is used. The default subnet mask of 255.255.255.0 is also used. Remember to communicate, this address must be in the same subnet as your computer. See the section on setting the computers IP address.



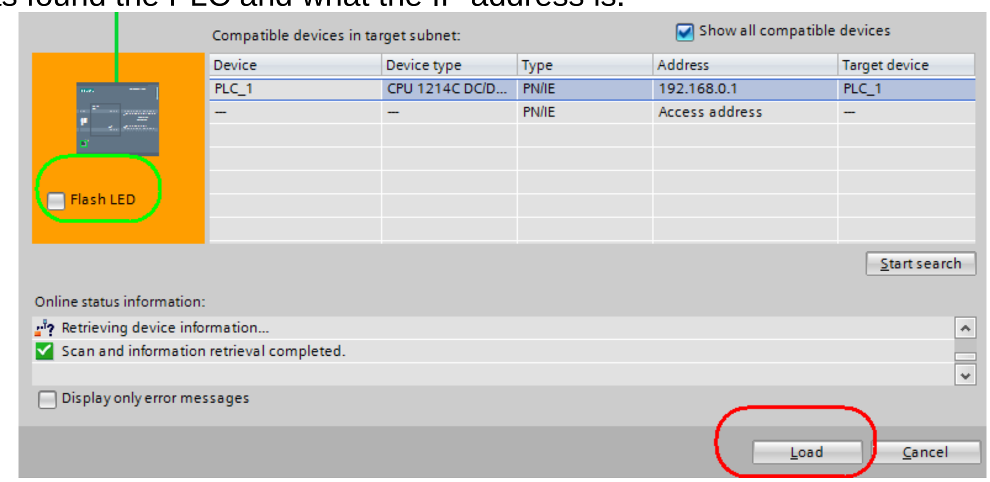
Return to the work area. Right click on the PROFINET connector of the PLC and select the option for download to device and select hardware configuration. This establishes the link to the PLC and prepares the project with the correct hardware information.



This will bring up the Extended download to device box. Select the internet connection used, circled in red in this example and then click the start search button.



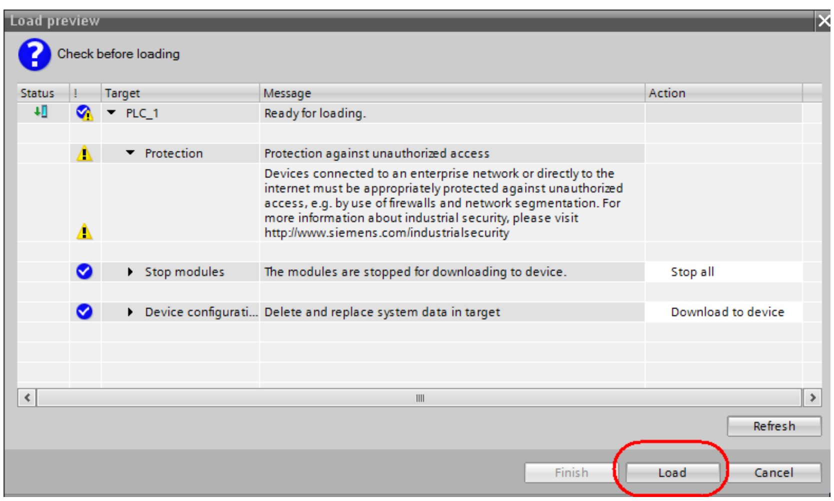
The program should now be able to find the PLC. The screen shot below is indicating that it has found the PLC and what the IP address is.



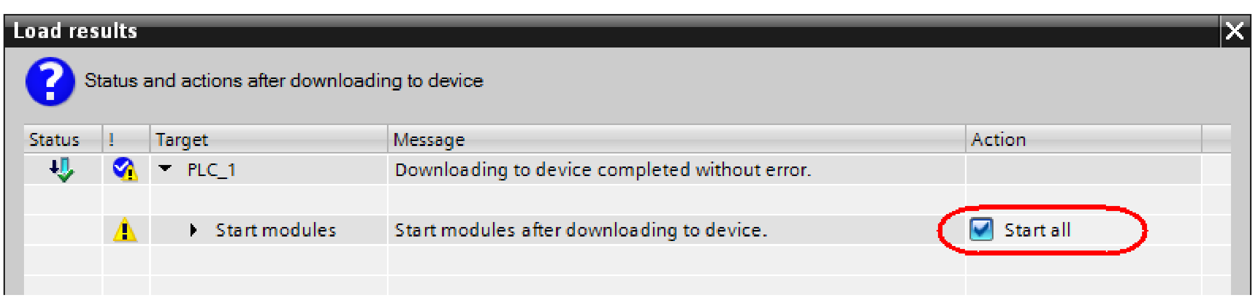
There is a flash LED check box circled in green in this example. Checking that box will reveal the LEDs for run/stop error and maint blink. Uncheck the flash LED box.

Click on the Load button at the bottom of the dialog box. This will begin the process to load the hardware into the program and PLC. See a box indicating a communication in progress.

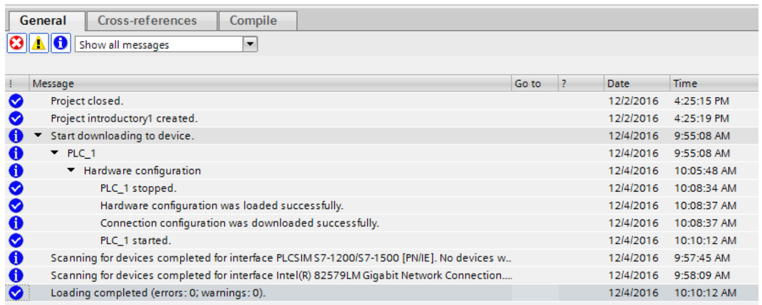
This brings up a report about the communications. If there are no errors select Load at the bottom of the dialog box.



This brings up the load results. Check the box for start all. Select Finish at the bottom of the load results window.



The inspector window will provide you with feedback on what happened and the time it occurred.



This indicates the PLC is ready for your program.

Back

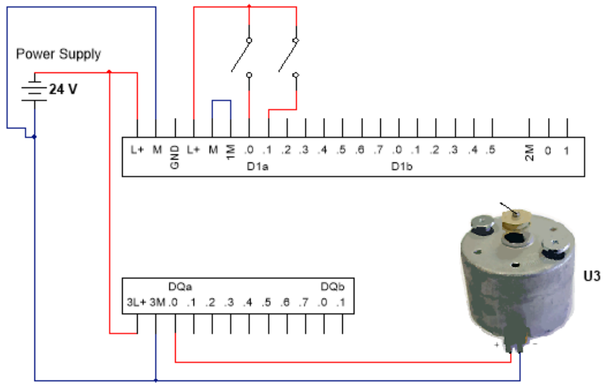
Writing a First Program

Controllers are devices that allow machinery to be turned on and off. Programmable Logic Controllers (PLC) as their name implies turn on and off circuits based upon Boolean logic. The program defines the logic in use for that logic. As industry moved to computer control the folks that worked with machines in plants upgraded their skill sets to include programming. A programming language based upon electrical schematics was developed. This language is ladder logic as the schematic symbols represent a ladder with vertical elements representing supply voltage and the horizontal rungs representing Boolean logic, inputs, timers, and outputs needed for the step. There are many languages in use for communication with PLCs. Knowing Boolean logic shortens the learning curve when transferring from language to language.

Most makers of PLCs have a ladder logic program to communicate with the PLC. Knowing the basics of the language will allow you to utilize the controllers on the market.

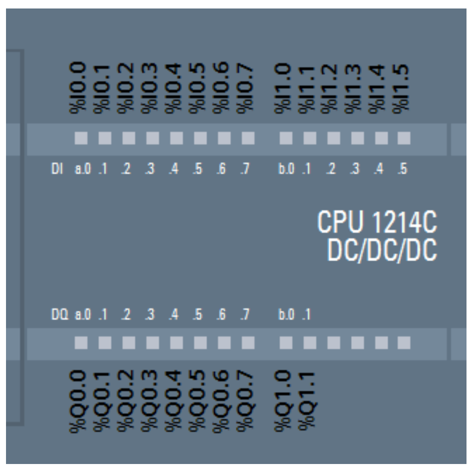
Hardware setup

For the introductory project you will need two switches and one motor. The schematic is below. There are two switches connected to the inputs. The first switch is connected to DIa.0 and the other to DIa.1. We will use the designations later to map to the pins. Connect the motor to DQa.0.

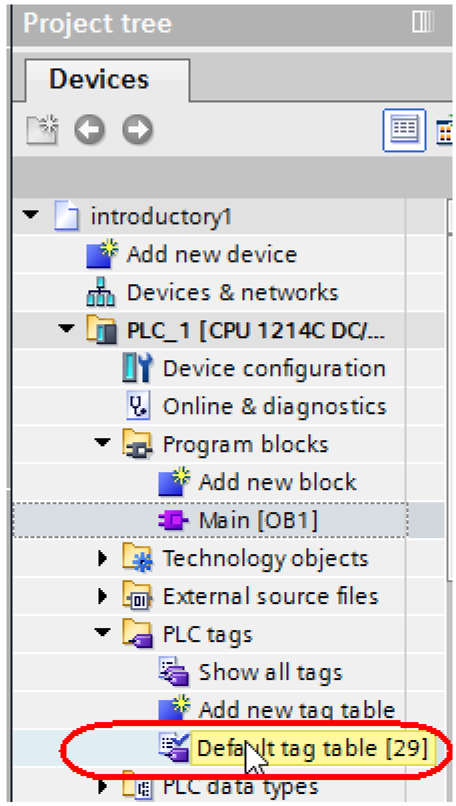


PLC Default Tag table

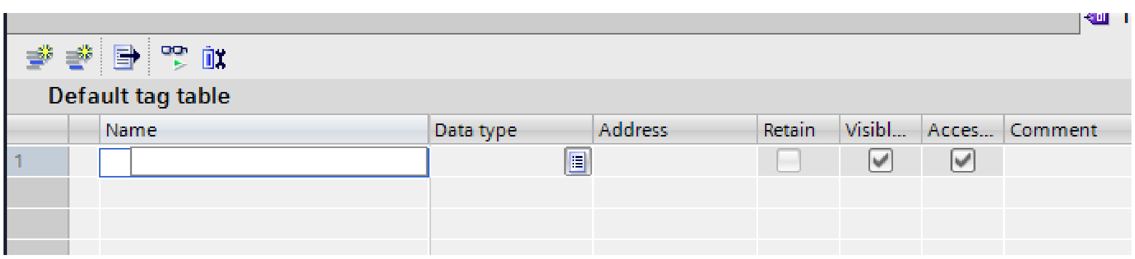
Once the hardware is connected the PLC needs to know what is connected and the pins it will use for communication. The picture below is the current view of the PLC.



The tag table contains addresses and symbolic constants and provides information about the each pin. Expand the PLC Tags folder in the project tree. Select the Default tag table.

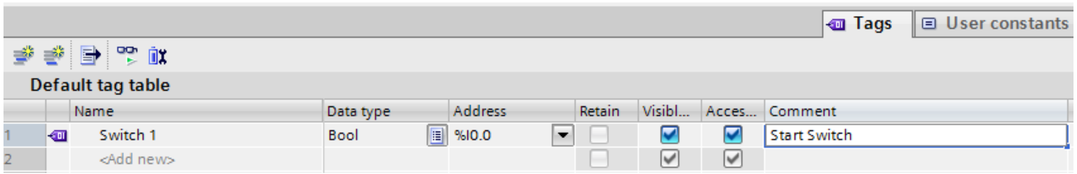


This will open up the tag table.

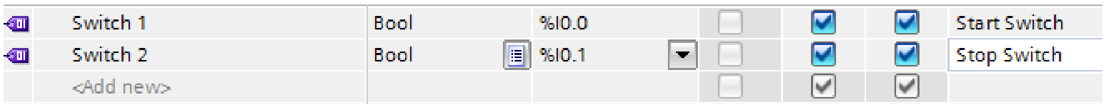


Click in the name section of line one.

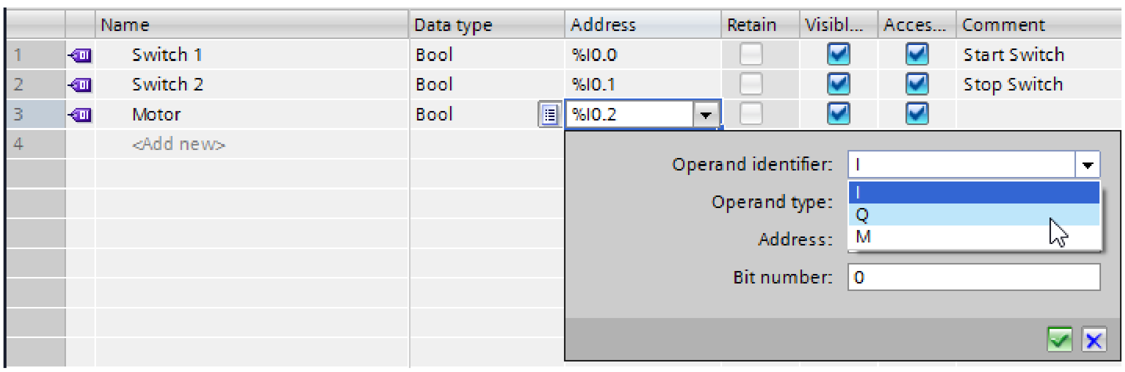
Type a name that will let you know what the item will do. In this case it will be switch. This example uses Switch 1. Click in the comment section of line one and add a comment to indicate what is expected from the device. Later when the table has many entries these comments will help a lot. When you click in the comment section you will see that it automatically entered Bool short for Boolean in the data type. This is a true/false data type. The address begins with the character % and adds I0.0. This is the first possible digital input.



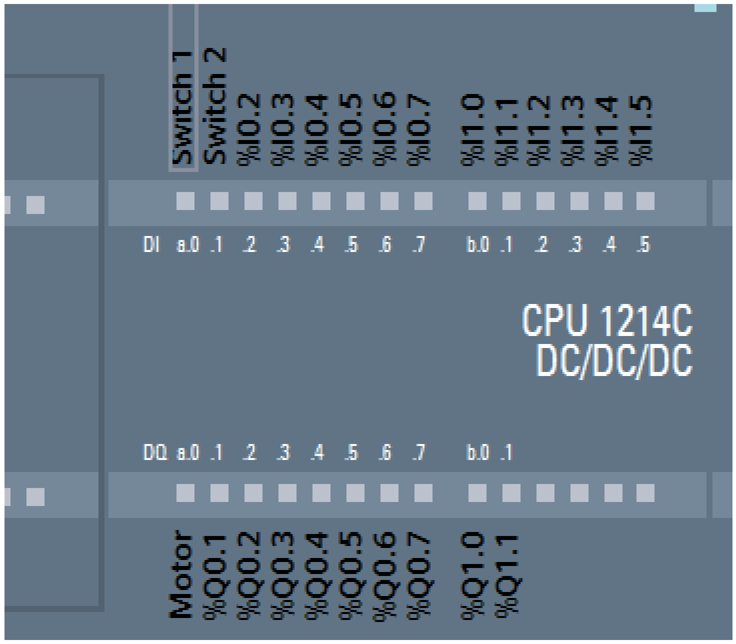
Add the second switch similar to the one below.



We also attached a motor. In line 3 we enter motor. This time click in the address line. Select the down arrow and change the operand identifier to Q. This describes this pin as an output. Change the Bit number to 0 to connect to the pin where you wired the motor.

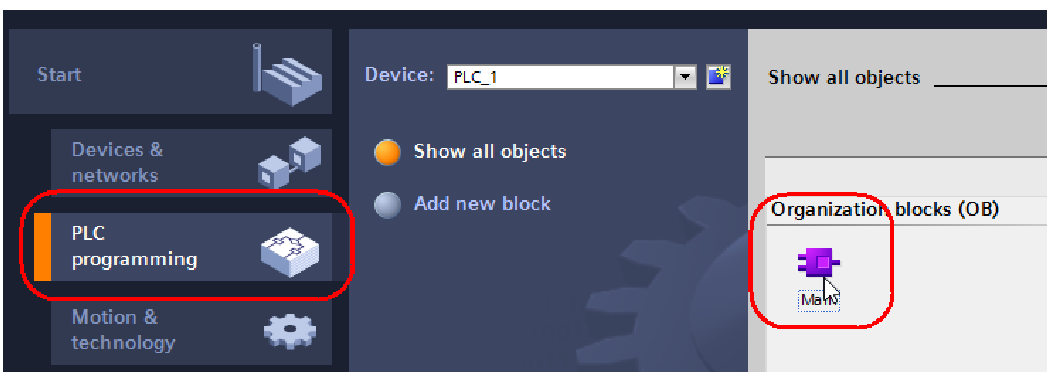


When looking at the picture of the PLC now, the image will reflect what you placed on the tag table.

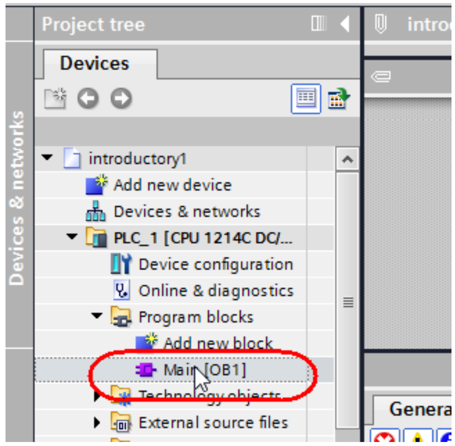


The Program Basics
There are two ways to enter the programming area.

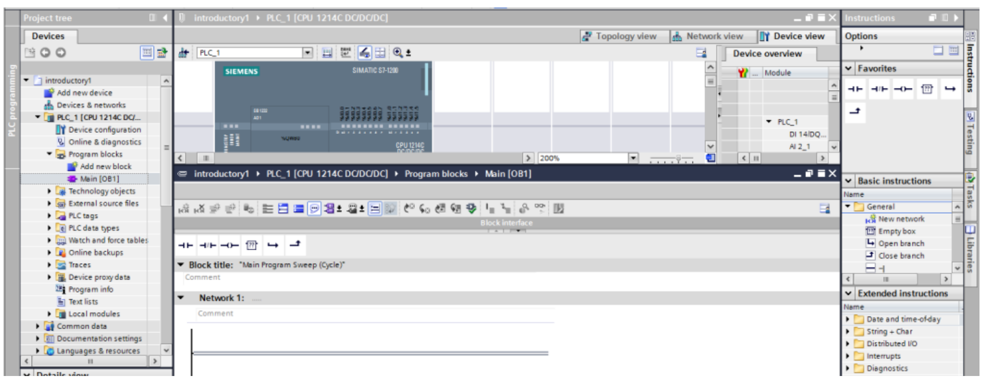
The first way is to select PLC programming and Main in the portal view.



The other way is to select the Main organizational block in the programming blocks area of the project tree in the project view.



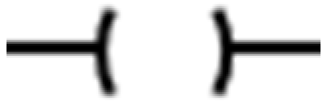
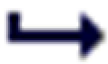
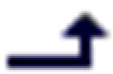
Either method will open the Program blocks area. A quick examination of the screen will show the Instructions in the task area of the screen on the right. The center in the work area has the ladder diagram area beginning with network 1 which will be the first rung on the ladder.



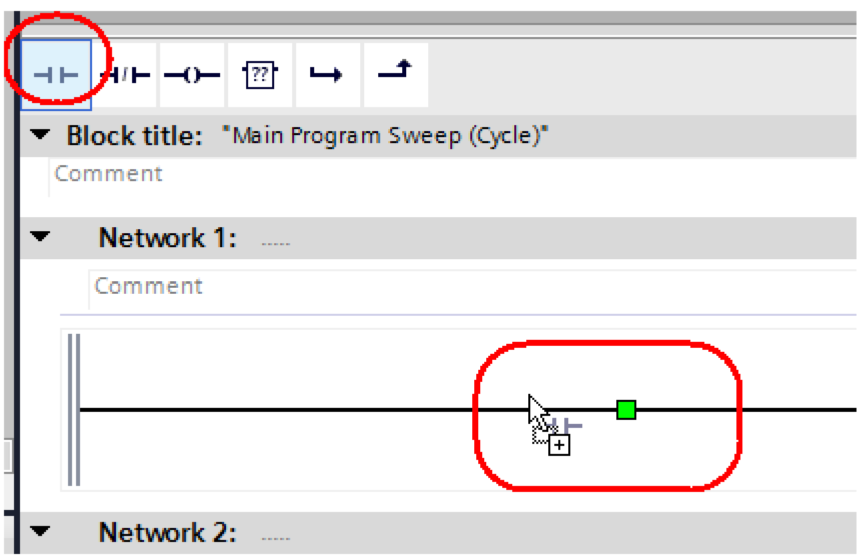
Ladder Logic

Each symbol has a meaning. If you recognize these basic ones you will see why they are included in the favorites area.

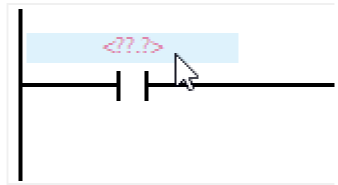
	This is a normally open input. This will wait for the input to go high. If this input is a switch it would be a normally open switch. It will wait for a mechanical action before proceeding.
	This input is a normally closed input. This will conduct and will stop conducting if the input goes high. If this input is a switch it will behave as a normally closed switch and will stop conduction when the input goes high.

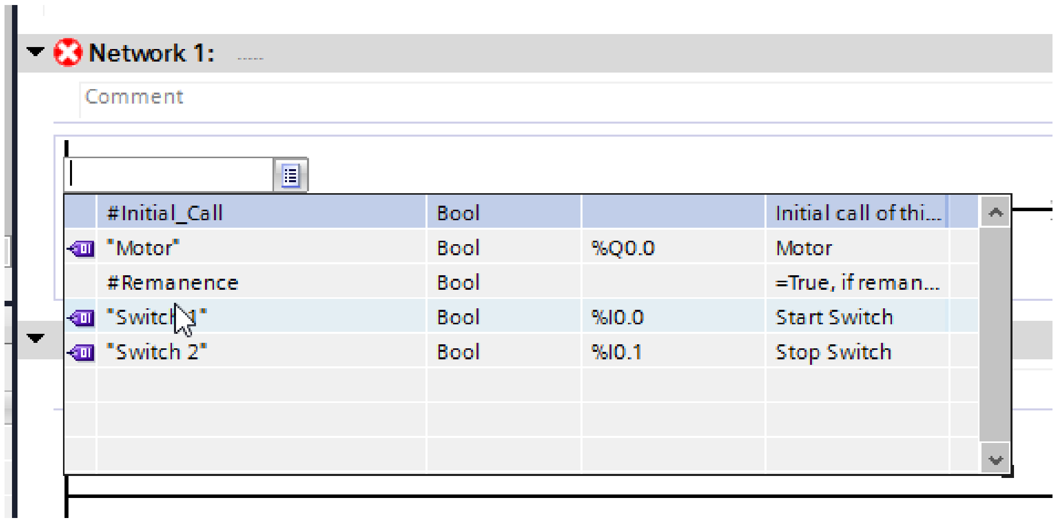
	This is a normally inactive output. It will energize when the rung logic is complete.
	This is a normally active output. It will de-energize when the rung logic is complete.
	This element opens a branch allowing more than one path for logic
	This element closes a branch forcing logic into a single path.

Create the first rung on the ladder by selecting a normally open input and dragging it to the first network. As you approach the rung of the network you will see a green highlight spot. Drop the normally open input there.

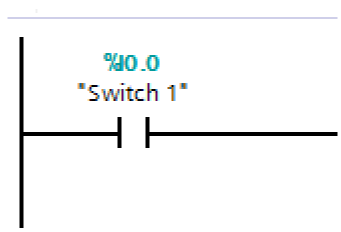


The program will recognize it as an input and move it to the left. Place your mouse on the red question marks. Once you click, select from the tag table what this input will be.

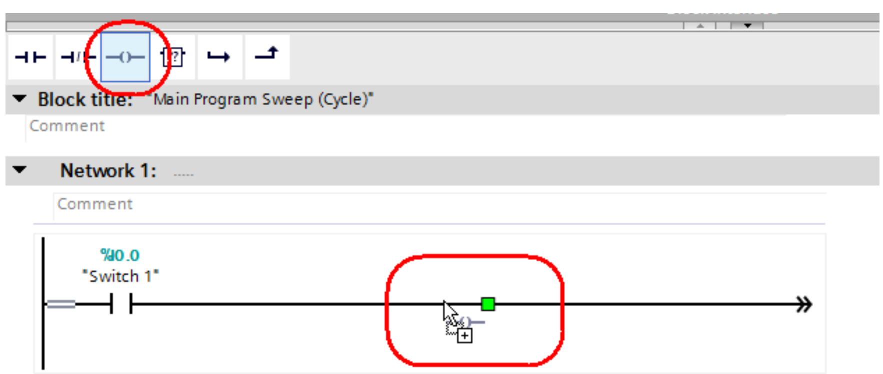




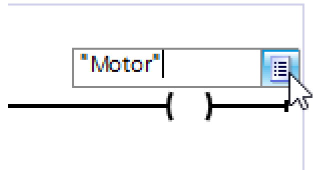
Select Switch 1 from the list. This will label the input and provide the address for this.



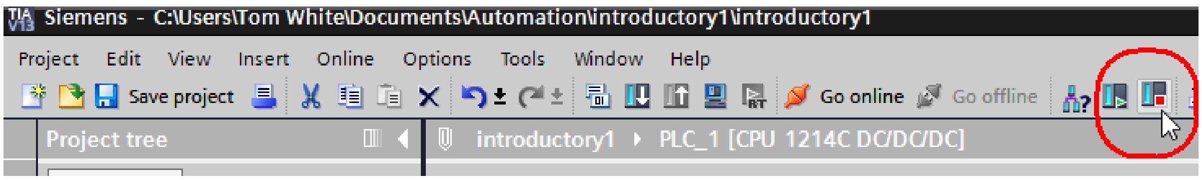
Drag a normally inactive output to network 1 and drop it on the green indicator.



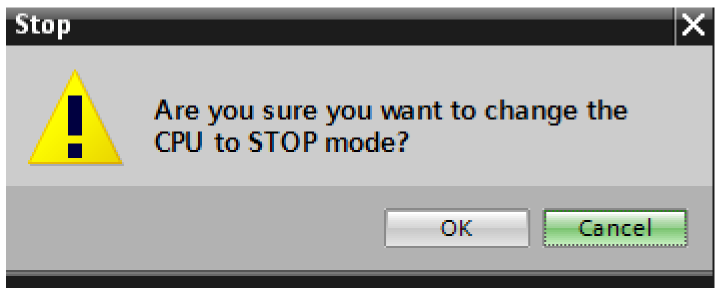
The program will move it to the right hand end of the rung. Set this one to motor.



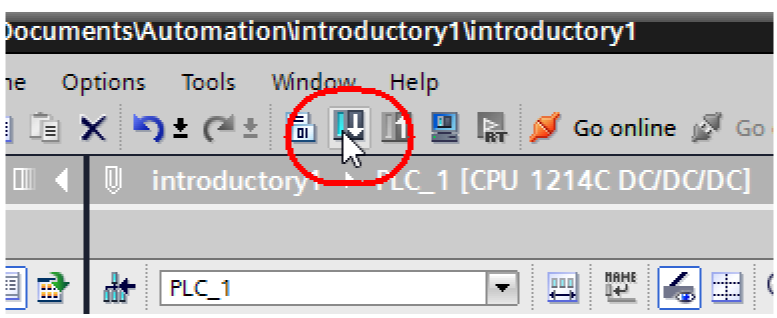
When input switch 1 closes output motor 1 will go from inactive to active.
At the top of the screen select the icon for Stop CPU. Loading a program is impossible while the CPU is running.



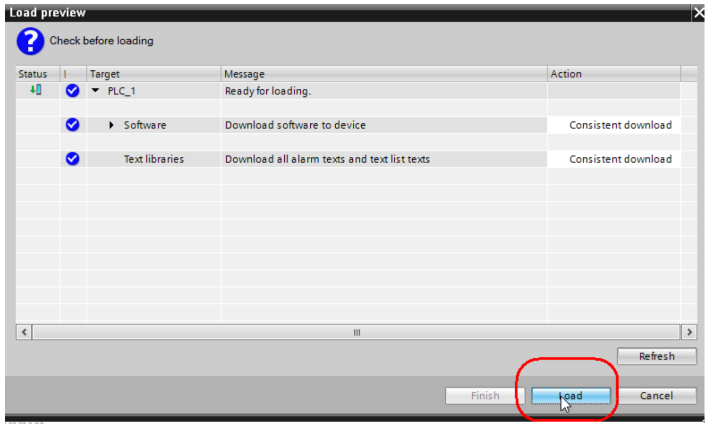
When prompted select OK



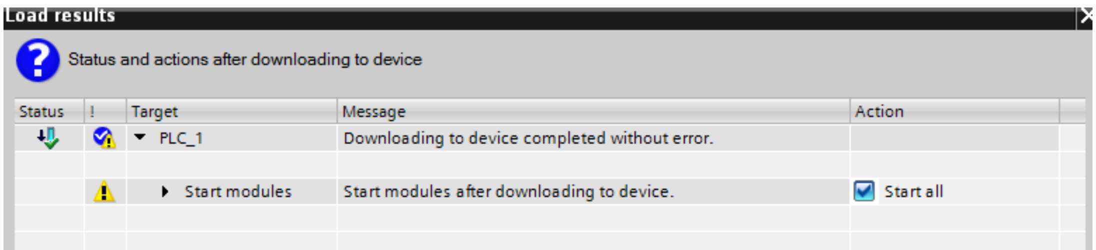
Select the icon for download to device.



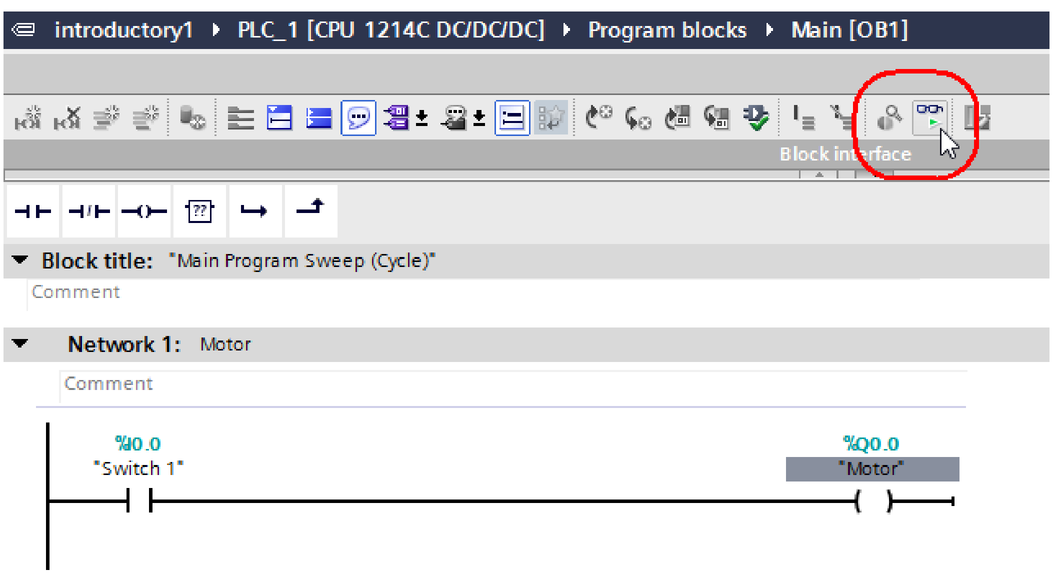
The program will compile the program and prepare to send it to the device. Select load at the bottom of the load preview window.



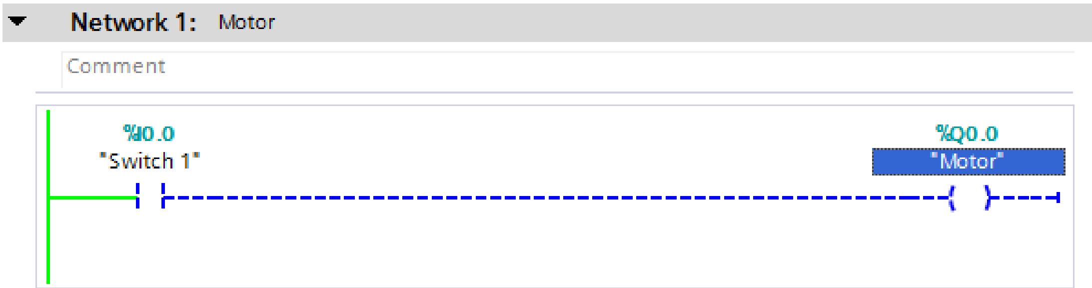
Check the Start all button and then click finish at the bottom of the load results window.



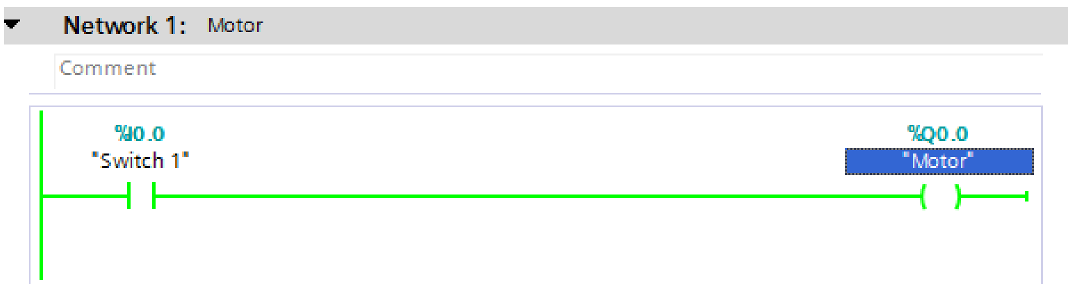
To see the effect of the program, click on the monitoring button to turn the monitoring on in the networking work area.



This will show you graphically what is happening in the PLC. In the example below you will see green from the rail to switch 1. At that point you see dashed blue to the output. That is showing that the program is waiting for the normally open input to close.



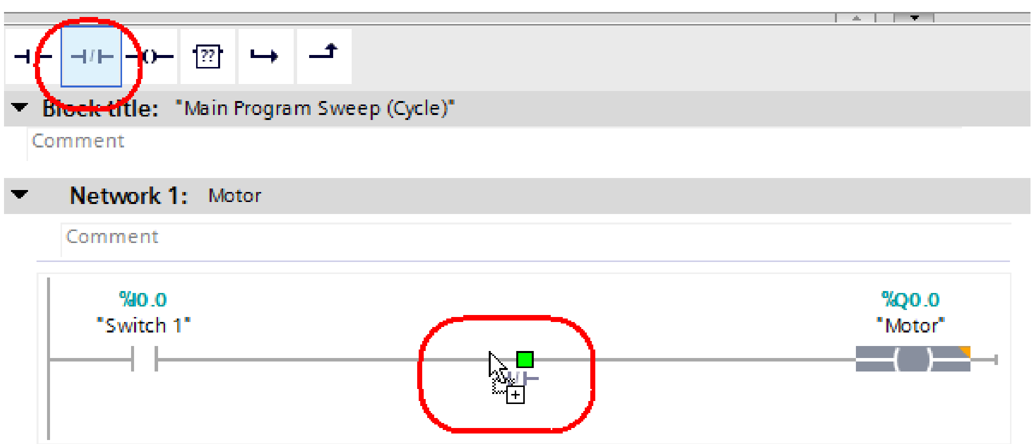
Warning: The motor will start on the next action. Press switch 1 and the dashed blue line should turn to green and the motor should turn on.



In this example the operator will have to keep the switch pressed in order to keep the motor running. This example will show how to edit the network to keep the motor running until the user closes the second switch turning the motor off.

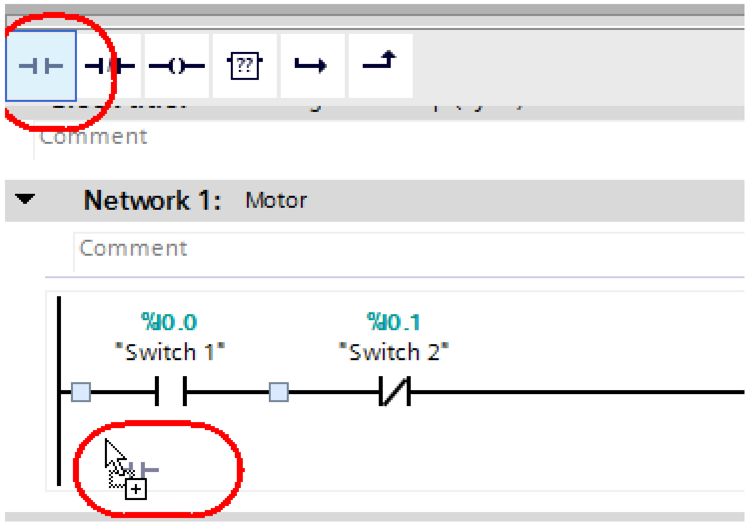
Begin by selecting the stop CPU icon. This will stop the running program.

Add a normally closed input by dragging it to the screen. Place it on the middle of the network.

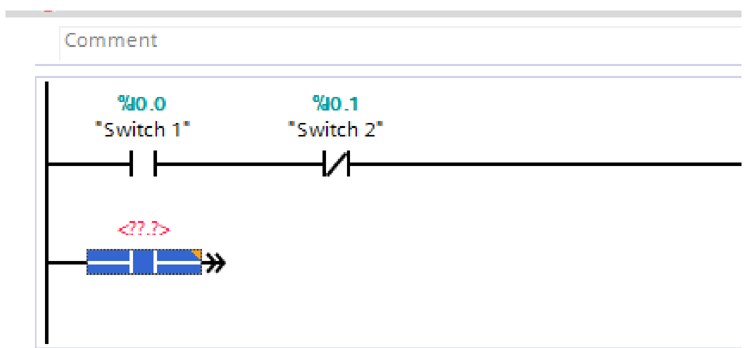


Assign switch 2 to this normally closed input. Now this will take care of turning the motor off. We want the motor to run. When we close switch 1 the motor turns on. We want to be able to keep it on until we press switch 2.

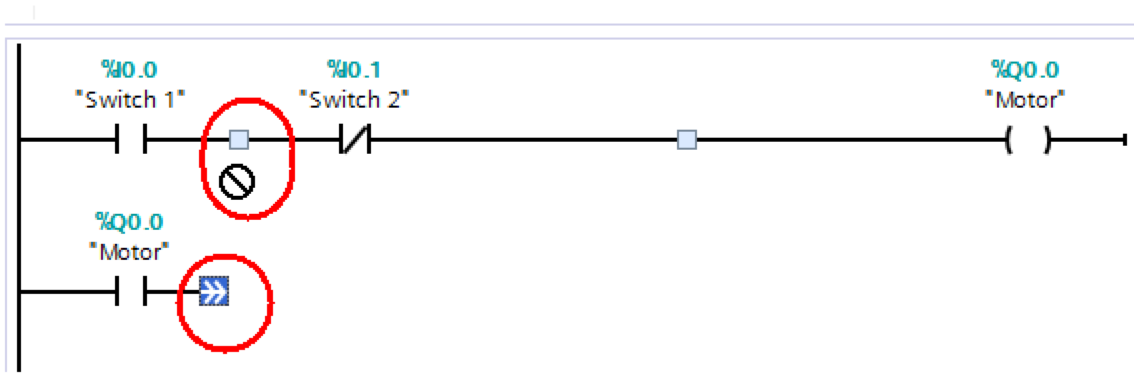
To accomplish this we add a normally open contact input. Drag it below the existing rung and let go.



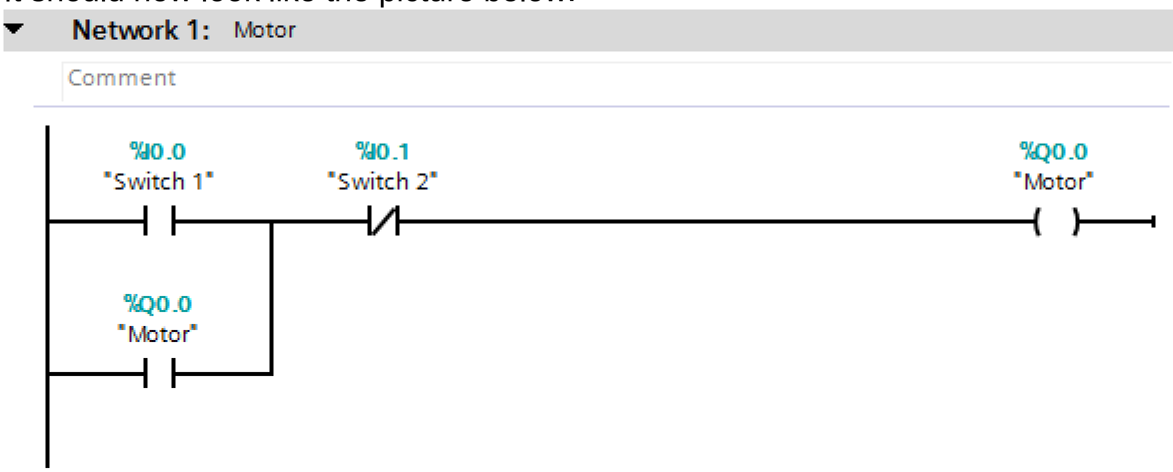
This creates a new branch coming from the rail.



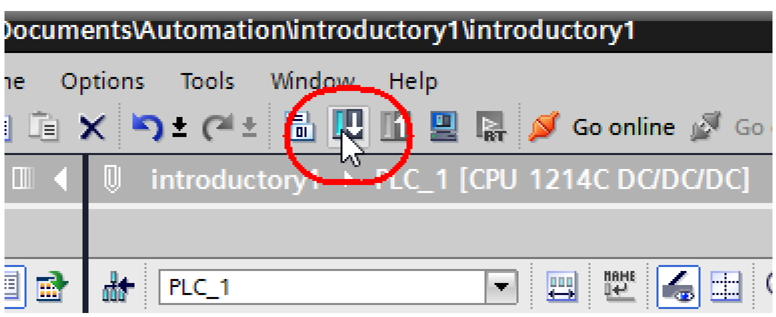
Assign this contact to the motor. When the motor is running this will provide the logic needed to keep the motor running. When we push switch 2 the connection will be broken and the motor will shut off and the contact assigned to motor will then open. Grab the double arrow at the end of the motor contact input and drag it upward. It will provide you with contact points to select. Select the contact point right after switch 1.



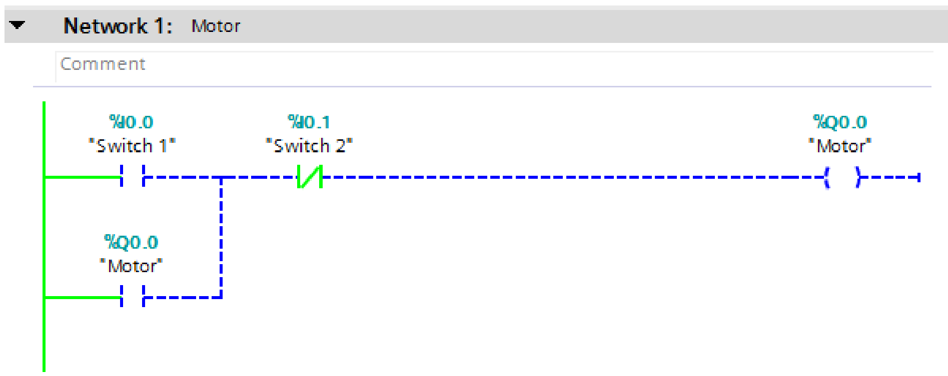
It should now look like the picture below.



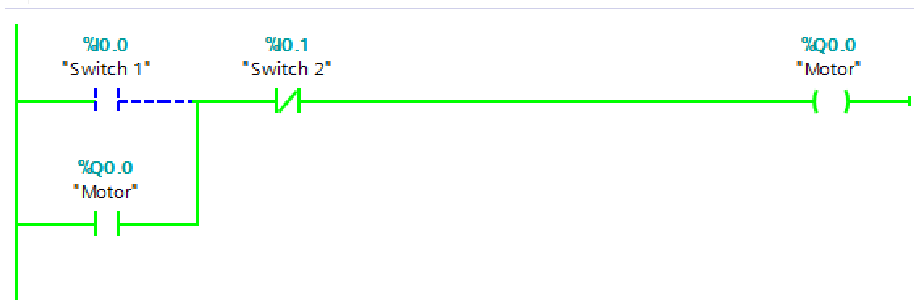
Select the icon for download to device. Download the latest version of the program to the CPU. Select the option to overwrite the program.



Change the CPU to run mode. Since the monitoring feature was turned on earlier, it should still be active. The ladder diagram will now show that it is waiting for either switch 1 or the motor contact to conduct before it will energize the output.



Press switch 1 to turn the motor on. What changes do you observe from the first one?



To stop the motor, press switch 2. Stop the CPU. Save a copy of your program.

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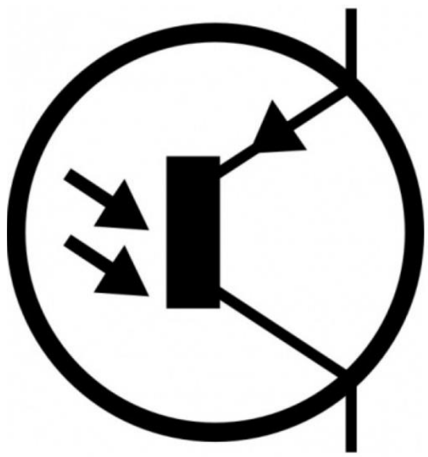
Counters

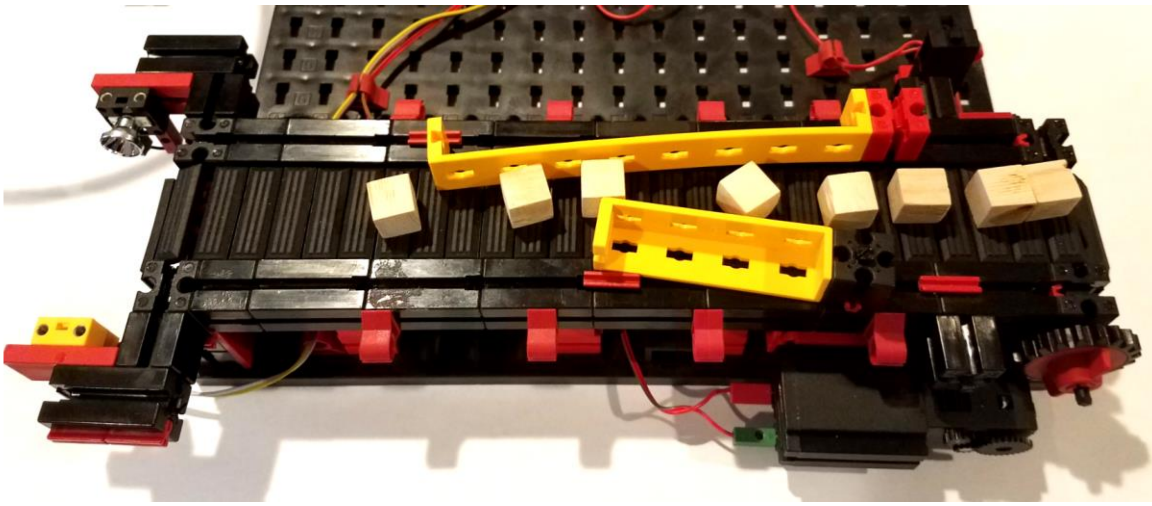
A counter is a term for a device which can monitor a process and can keep track of and display the number of times a particular event has occurred. We are using the photo transistor in combination with a lamp to monitor the number of times the beam has been broken. There are numerous applications of a counter built this way. The number of people passing through a doorway would be one example. A rotary optical encoder on a motor is another way a counter might be used. In this example we will use the counter to assure the number of items in a bag is what it is supposed to be.

Switches are installed in circuits to control the flow of electrons through the circuit. The phototransistor is setup as a fast acting semiconductor switch. Without light it is a normally open switch. When light strikes the device it begins to conduct and will continue to conduct until light is no longer there. The schematic for a phototransistor is shown below.



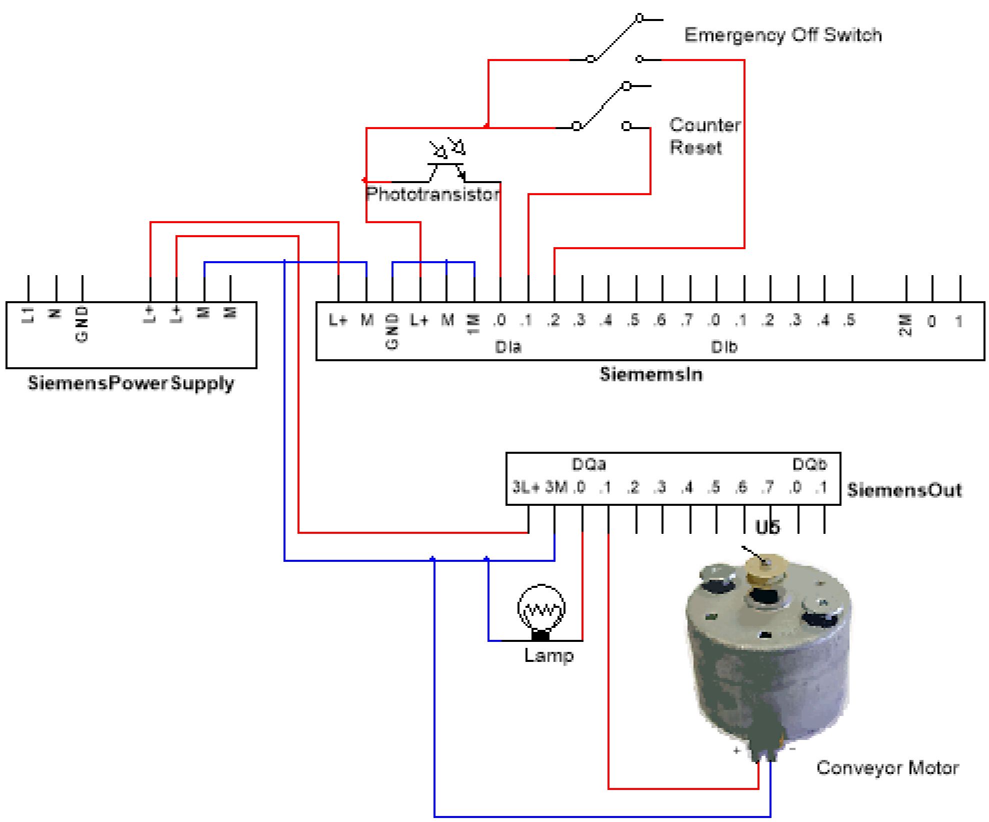
Conveyor Belt

The structure is made from Fischertechnik components found in the mySTEM™ Do Engineering Starter kit. Instructions for creating the kit can be found at https://drive.google.com/open?id=0B_7sFhPxnoaXU1hrRzI4SmM3VlE. The assembled system is shown below. In this example the photo transistor is mounted on one end of the conveyor belt. The lamp is opposite. The reset switch is placed at the far end in this picture but can be placed anywhere convenient.



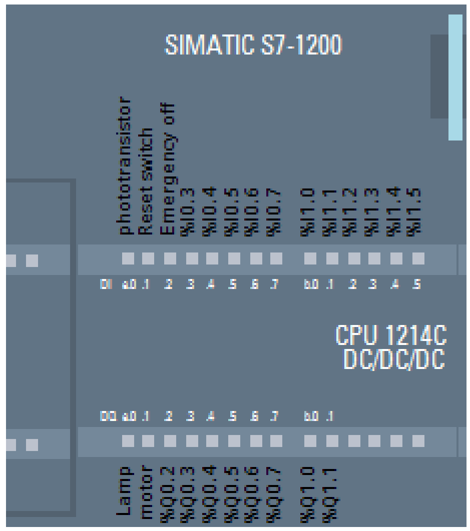
Wiring

The schematic below indicates the wiring for the conveyor. It is important to note the red spot on the phototransistor connects to the L+ and the other side connects to the 0 input. It is a polarized device. The lamp is connected to output 0 and the conveyor motor connected to output 1. The counter reset switch is wired to the I1 input and the Emergency cutoff switch to the I2 input.

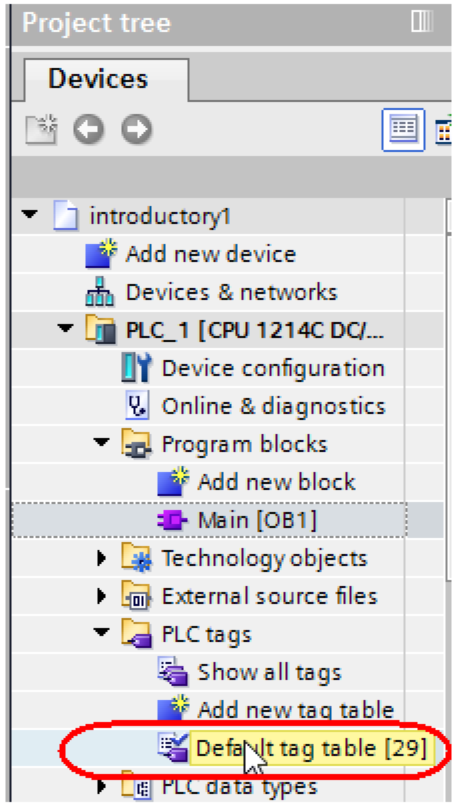


PLC Default Tag table

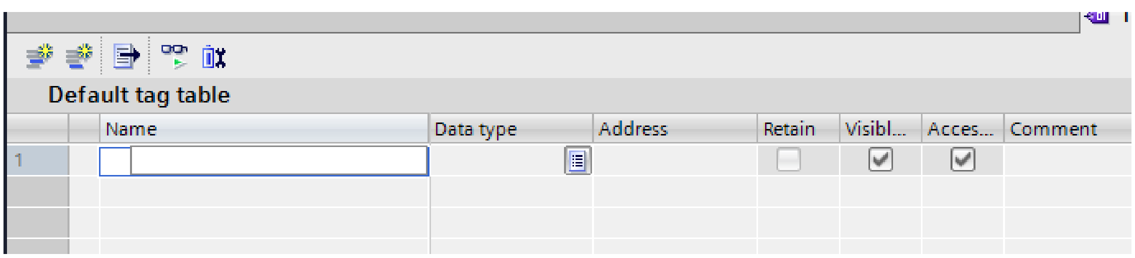
Configure a device for the program similar to the process used before. Once the hardware is connected, the PLC needs to know what is connected and the pins it will use for communication. The picture below is the current view of the PLC.



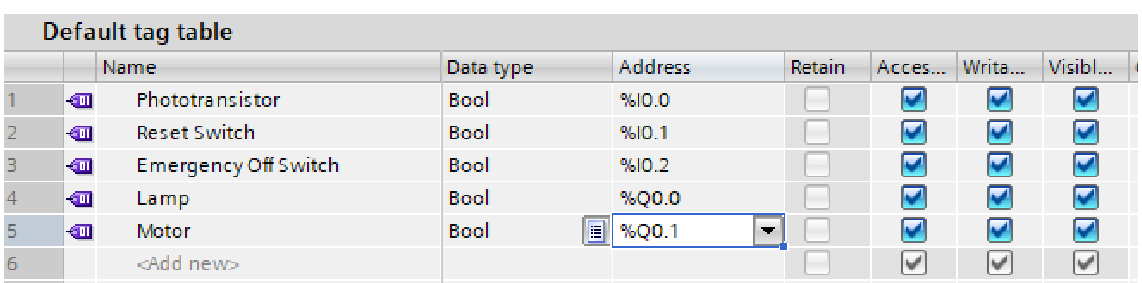
The tag table contains addresses and symbolic constants and provides information about the each pin. Expand the PLC Tags folder in the project tree. Select the default tag table.



This will open up the tag table.



Click in the name section of line one. Then fill in the table similar to the one below.

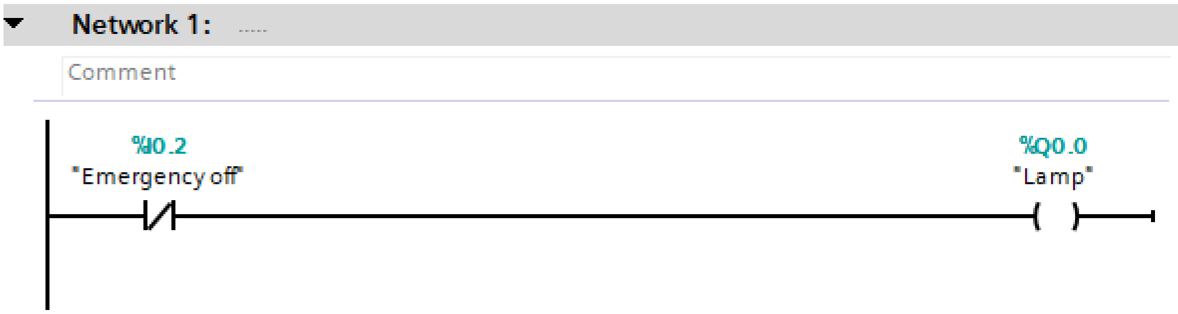


Default tag table

	Name	Data type	Address	Retain	Acces...	Writa...	Visibl...
1	Phototransistor	Bool	%I0.0	☐	☑	☑	☑
2	Reset Switch	Bool	%I0.1	☐	☑	☑	☑
3	Emergency Off Switch	Bool	%I0.2	☐	☑	☑	☑
4	Lamp	Bool	%Q0.0	☐	☑	☑	☑
5	Motor	Bool	%Q0.1	☐	☑	☑	☑
6	<Add new>			☐	☑	☑	☑

Program

For the application for the counter we will need the lamp for the counter on all the time unless we select the emergency off switch. To take care of this, the first network will consist of the emergency off switch using a normally closed contact and the Lamp output.

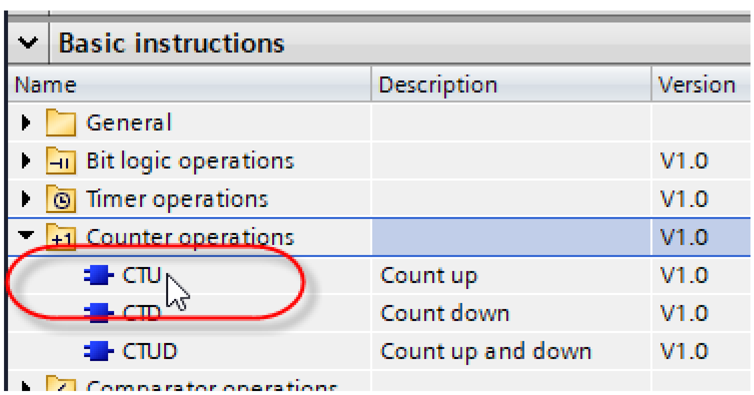


This will enable the lamp to be on continuously unless the emergency off switch is depressed.

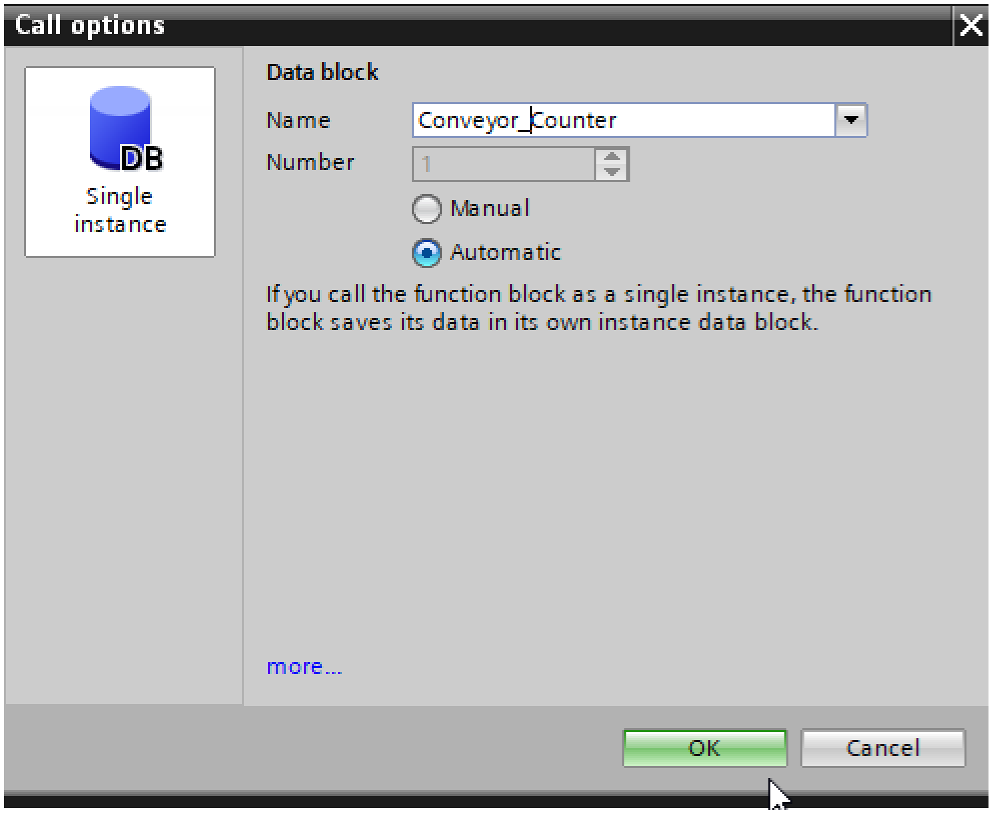
We want to count the objects coming off the conveyor belt and passing between the light and sensor. This changes the state of the phototransistor and will increment the counter.

Start a new network.

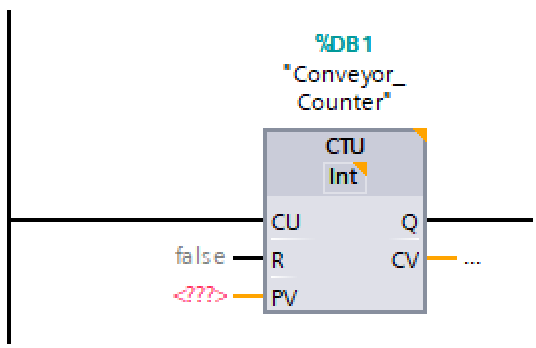
From the basic instructions menu, select the count up from the counter operations section.



This will bring up the call options. Either accept the default name of the counter or change it to suit your program. Set it to automatic and select OK

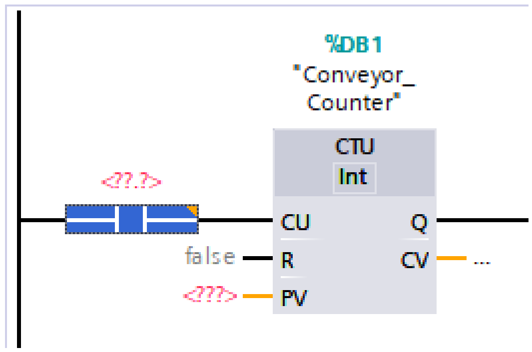


Selecting OK will reveal the counter block on the network.

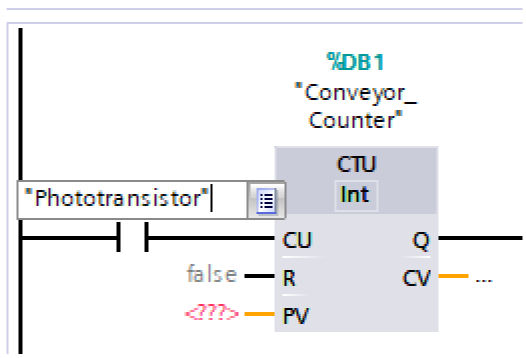


The block has an input (CU) which will cause the counter to count up 1 each time the input goes high. The PV input is where the count is set. Q will go high when the count reaches the PV value. CV is the current value of the count, which also shows up at the top of the block when it is running. R will resent the counter to 0 when that terminal goes high.

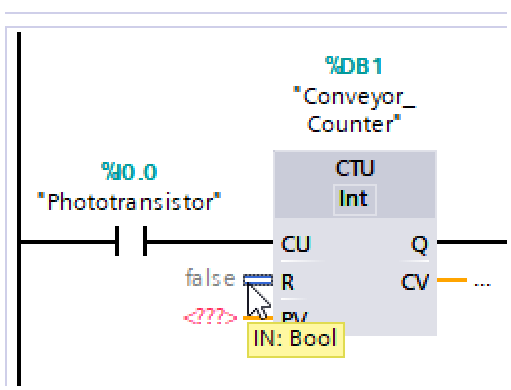
We want the counter to increment when a block falls in front of the phototransistor. Place a normally open contact on the line to the CU terminal.



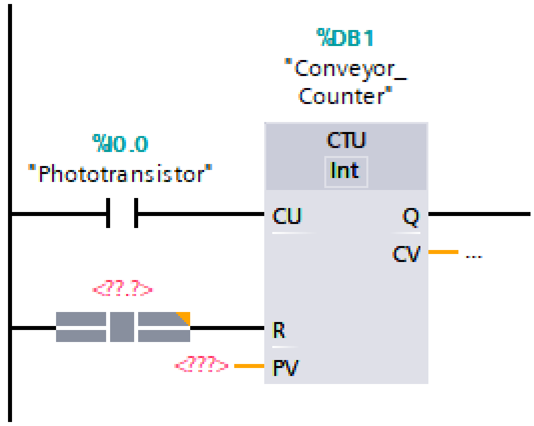
Set the value of the contact to phototransistor.



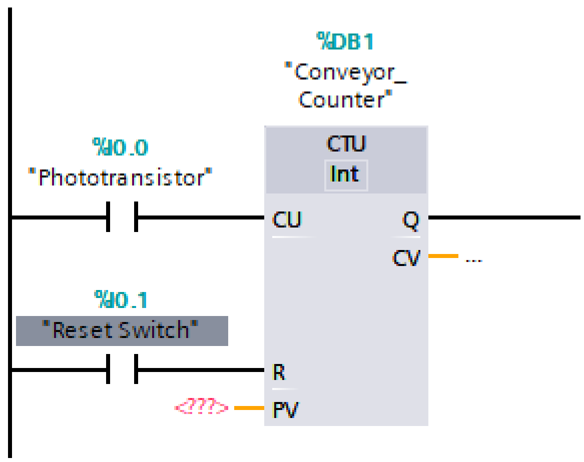
Place a normally open contact to reset the counter. To do this highlight the R terminal by clicking on it.



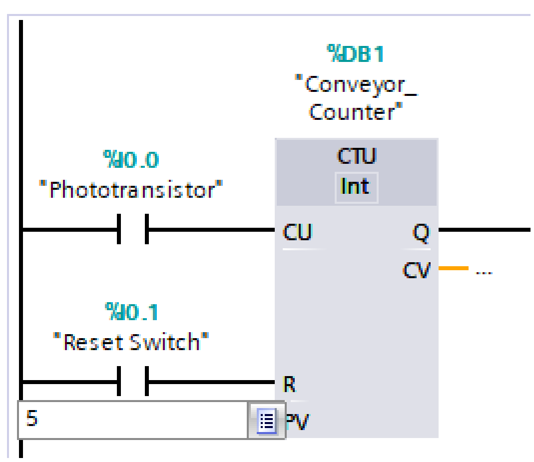
Then select an open contact and it will automatically place the contact in the correct place.



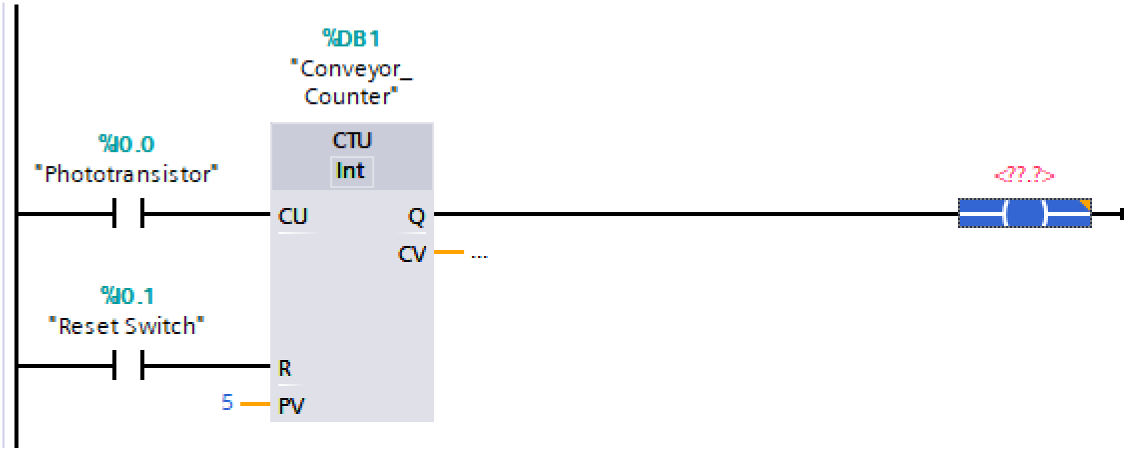
Assign the contact to the reset switch.



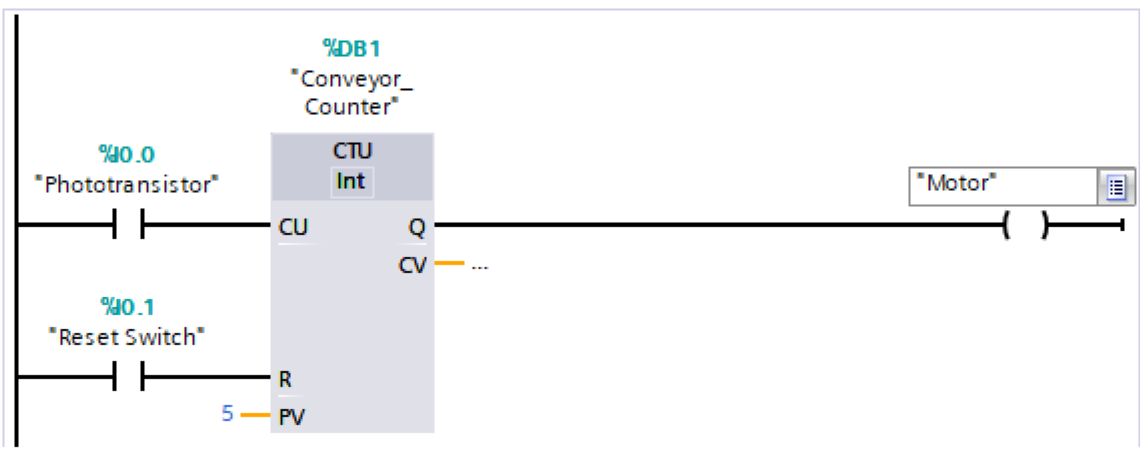
Begin with a value of 5 by double clicking on the ??? next to PV.



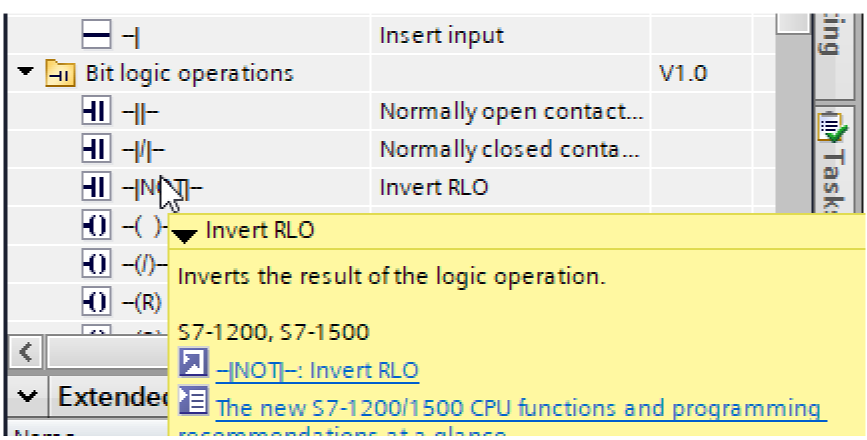
The problem calls for the conveyor to run until we reach a count of 5 now. Place an assignment on the line out from the Q terminal.



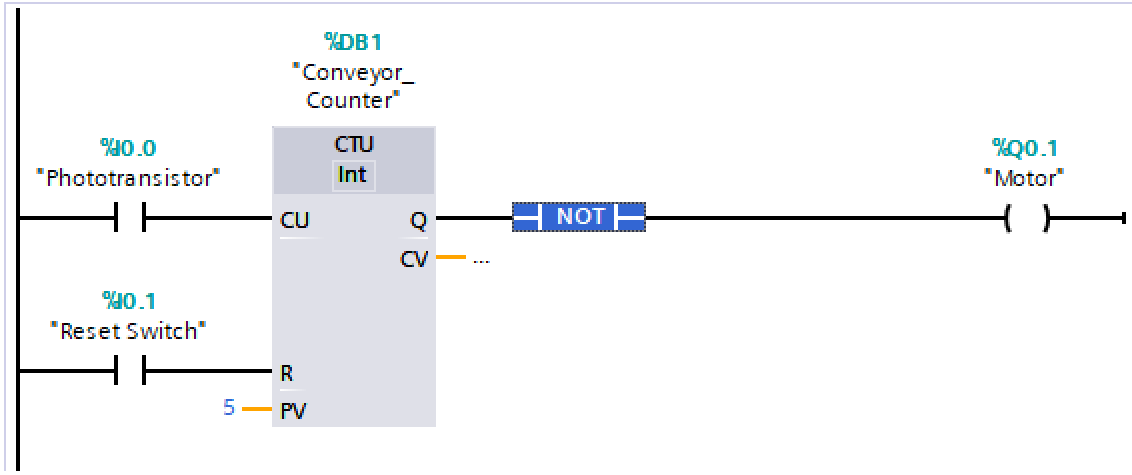
Assign it to the motor.



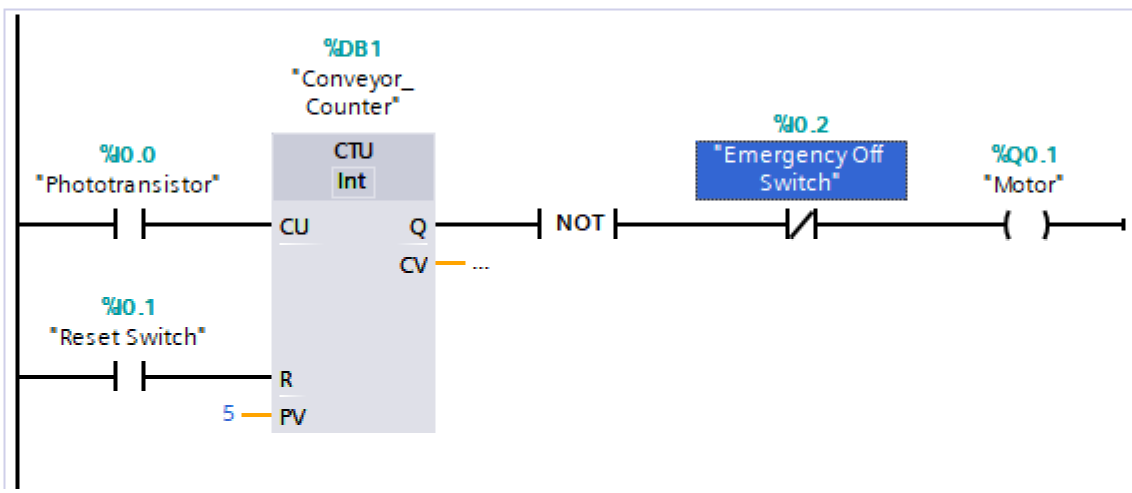
At this point the conveyor will not turn on until the count reaches 5. We want the motor to run until the count reaches 5 and then shut off. It is the exact opposite of the existing logic. To correct this, place a Not from the Bit logic operations menu. The Not is a Boolean expression that changes logic.



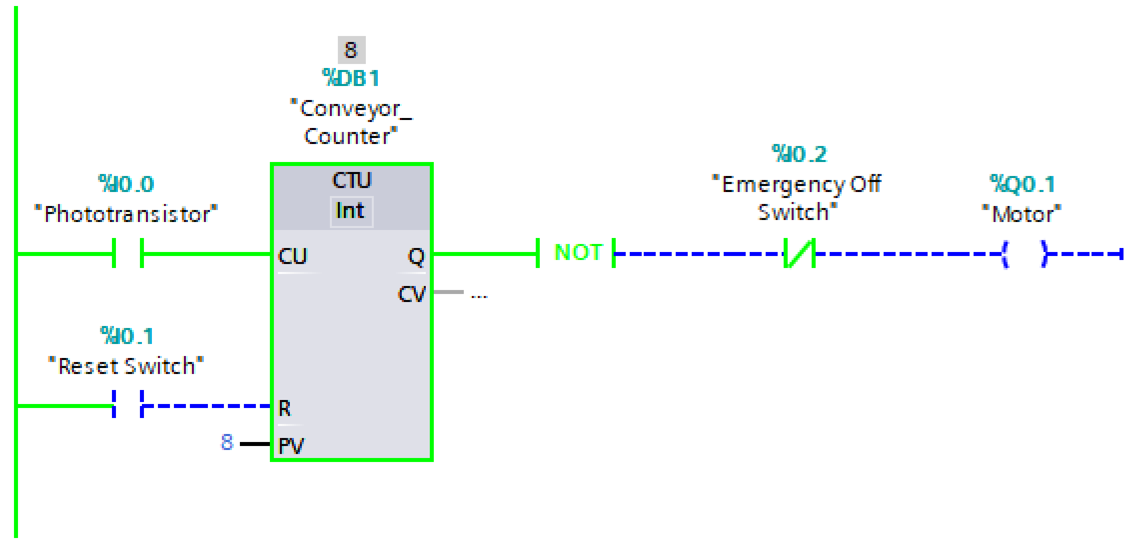
When the Q terminal is low the not will change it to a logic high. When Q goes high then the not changes it to a logic low.



Finalize the programming with the emergency off switch programmed to a normally closed contact after the not which will disable the motor when pressed.



Download the program to the PLC. Run the program to be sure it does what is expected. Stop the program and change the count and see how the conveyor behaves.



Be sure your emergency stop button works.

Save the program.

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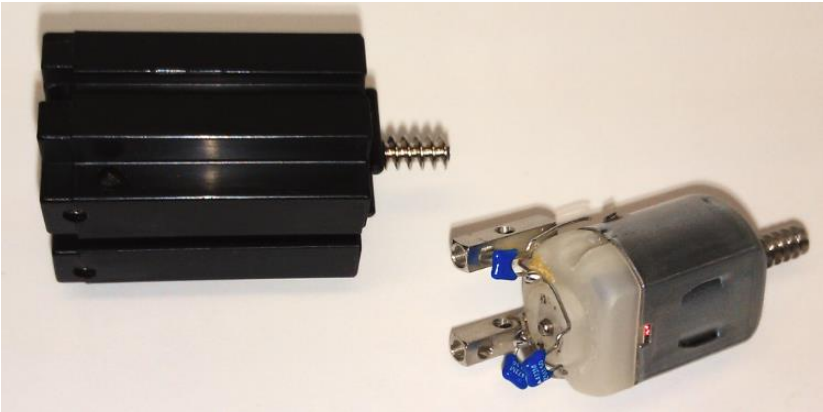
Motor Reversing

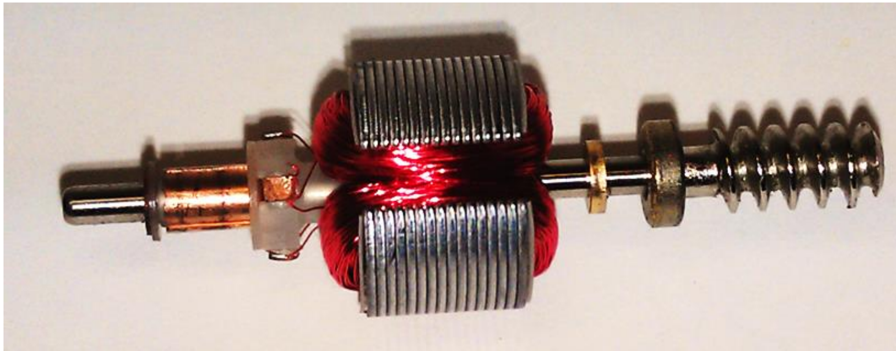
Theory
The Fischertechnik™ motor included with the kit is a DC motor inserted into a case with slots and electrical connections built in. This allows the motor to be connected to hundreds of different components used in the design of cyber-mechanical devices.

The picture below shows the motor both in and outside of the case.

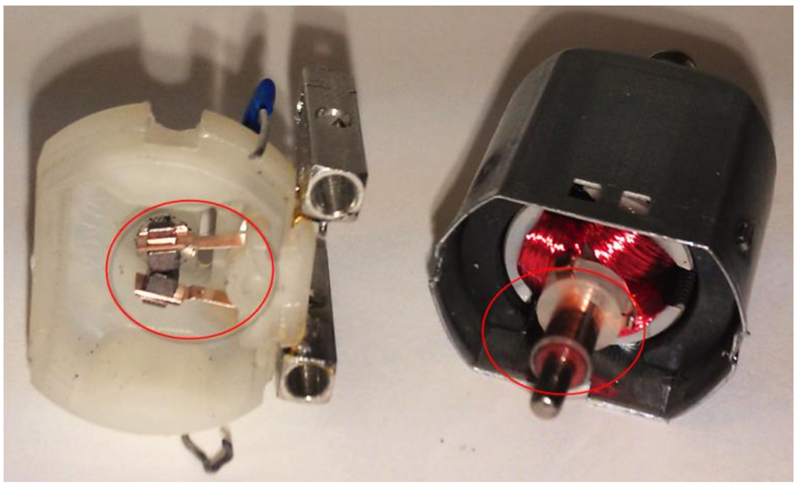


The motor itself consists of two permanent magnets in a case which establishes a magnetic field between them.

Inside the magnetic field we place a shaft wound with wire that is free to rotate. This shaft is called an armature. Electrical current passing through the wire of the armature causes a creation of a magnetic field. The wire is wound around a series of segmented plates of silicon steel to concentrate the magnetic fields.



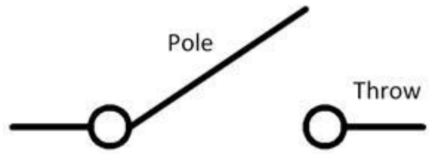
The electrical current passes through brushes which are the two copper pieces in the red circle on the left. These brushes contact the commutators on the armature, in the red circle on the right, causing the armature to rotate in the magnetic field.



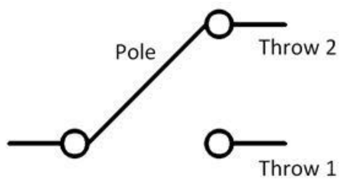
This setup allows a motor to run in two directions depending on the electrical polarity.

Switches
Switches are installed in circuits to control the flow of electrons through the circuit. They are categorized by the way they are actuated, by the number of poles and throws they have, and their normal position. The actuator is the mechanical method that causes the switch to open and close. Common types include momentary, toggle, slide, rocker etc. A normally open switch is one where the circuit is open in its normal position and the actuator has to be triggered in order to close the circuit and allow current to flow. A normally closed switch is one where the current can flow unless the actuator causes the switch to open blocking the current flow.

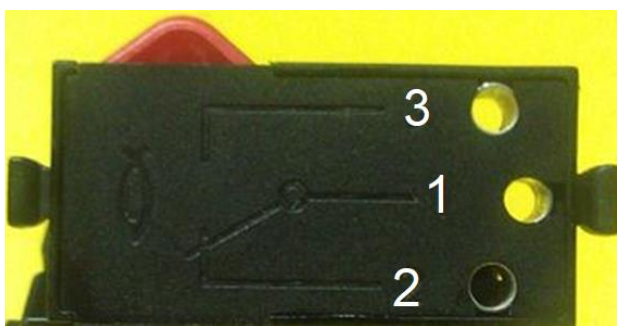
Poles provide the path for electrons. Throws control the circuits. The schematic below represents a single pole single throw switch (SPST). It provides a single path for electrons and controls one circuit.



The basic Fischertechnik switch is a single pole double throw switch. It has a single pole for electrons but two different paths. The switch is a single pole double throw (SPDT) and has three terminals. The schematic is shown below.

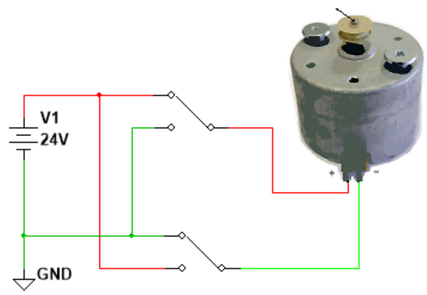


The picture below shows the actual Fischertechnik switch. It is a momentary switch which means depressing the actuator causes a temporary changing of the path. As soon as the user lets go, it reverts to its original position.

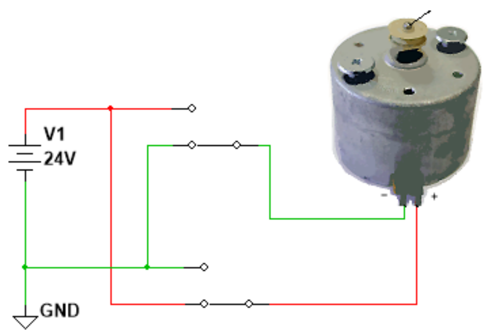


With the cover removed, the internal components are visible. The number 1 connection is the middle contact. See below, that it is in contact with the contact with the number 2 connection making the 1 & 2 normally closed and the 1 &3 normally open. When the button is pushed the connection between 1 and 2 is opened and the connection between 1 and 3 is closed. This is a temporary connection as the spring will return the switch to its normal position as soon as the pressure is released.

To change the direction of the motor, the polarity of the electrical power being supplied to the motor must be reversed. Examine the picture below. In one position the positive is supplied to the left terminal and the ground is connected to the right.



When the switch is thrown that will change the polarity to the motor and it should run in the opposite direction.



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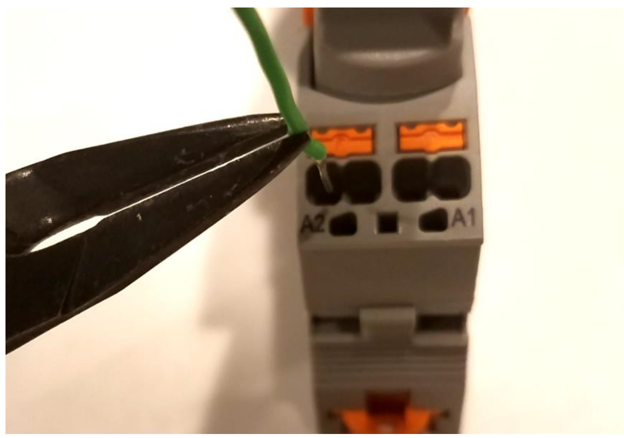
Relay

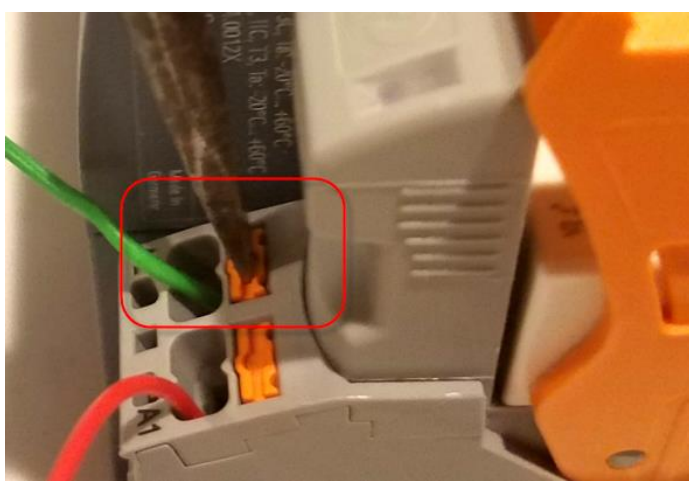
Relays are an electromechanical switch which is activated by current traveling through a magnetic coil causing the poles of the switch to change. You have used a switch to turn on a motor in learning the basics of ladder logic. In this example we will be using a Double Pole Double Throw (DPDT) relay which will allow us to reverse the polarity to the motor. The picture below is a 24V DPDT semiconductor relay.

This relay fits in a case so it can be placed on a DIN rail along with your PLC.

The relay uses push in terminals. Simply push the wire into the fitting. Some people use needle nose pliers to push thin wires into the slot.

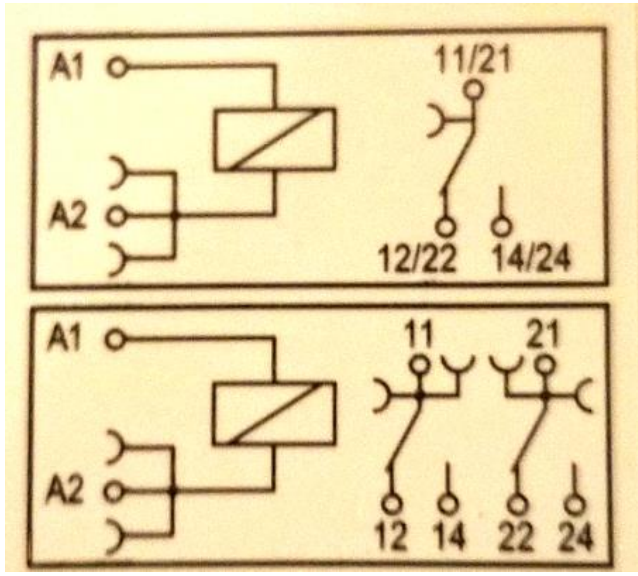


To remove a wire use a screw driver to press the orange tab above the wire. Once the orange tab is pushed in the wire is released and it can be removed easily.



The terminals on the relay are labeled on the side of the relay case.

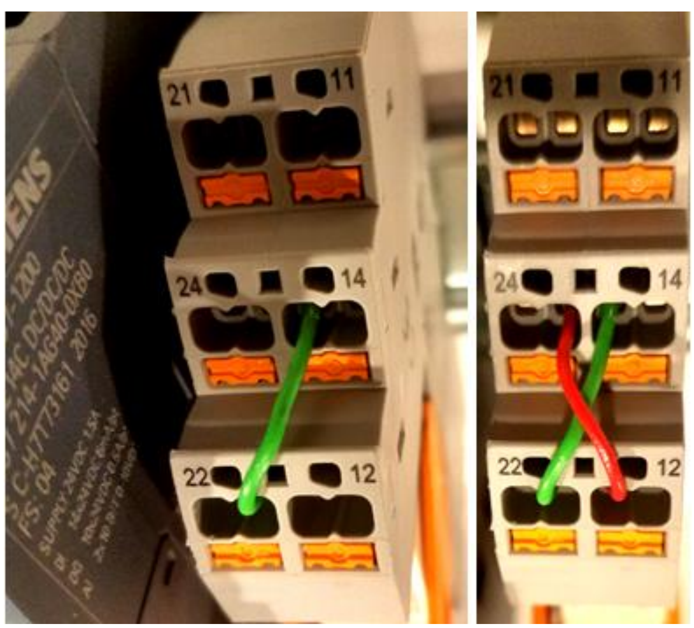
Wiring



The schematic shows the two terminals that control the positioning of the poles of the switch are A1 (+) and A2 (GND).

The two SPDT switches are labeled with 11 and 21 being the common poles. 12(22) and 14(24) provide the two throws to the poles.

The motor will be connected to terminals 11/21. To provide the two paths so we can reverse the current flow will require us to wire 14 and 22 together and 12 and 24. See the picture below.



Depending on what position the relay is in either 14 or 22 are in use but never at the same time.

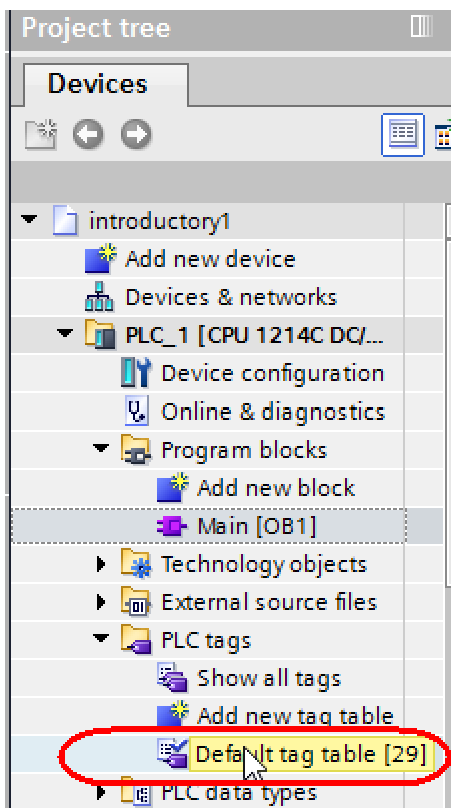
When we want to turn on the motor we need to wire the motor output connection (Q0.0) to the 12 and 24 connection. 14 and 22 are connected to the common (M) connection.

When we want to reverse the motor we will use the Q0.1 output and connect that to the A1 terminal on the relay. The A2 terminal is connected to the M(earth ground) terminal.

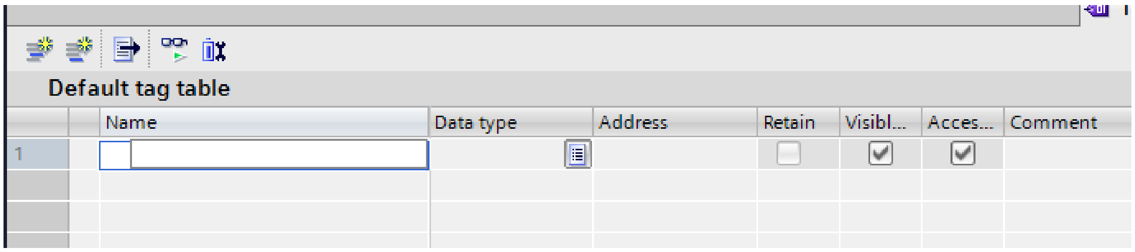
The motor will be wired to the 11 and 21 connections. If the motor turns the wrong way, reverse the wires on the motor.

Programming
Begin a new project and configure a device as done previously. Open the tag table.

The tag table contains addresses and symbolic constants and provides information about each pin. Expand the PLC Tags folder in the project tree. Select the Default tag table.



This will open up the tag table.



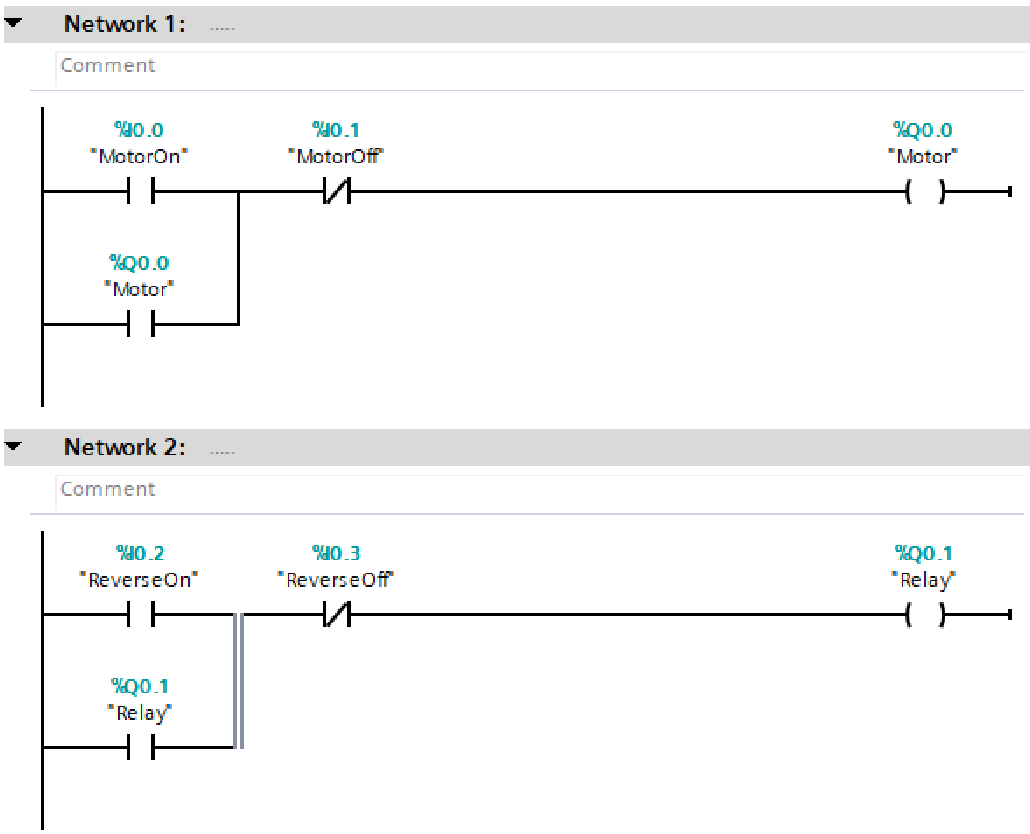
Click in the name section of line one and begin entering the data so your table looks like the one here.

Default tag table

Name	Data type	Address	Retain
Motor	Bool	%Q0.0	
Relay	Bool	%Q0.1	
MotorOn	Bool	%I0.0	
MotorOff	Bool	%I0.1	
ReverseOn	Bool	%I0.2	
ReverseOff	Bool	%I0.3	

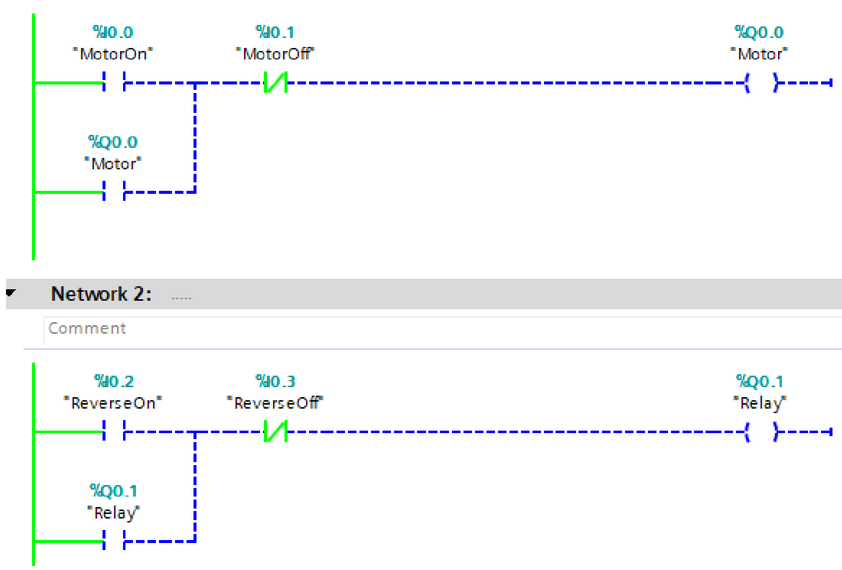
In this instance we have the motor assigned to Q0.0 and the relay to Q0.1

Open the Main (OB1) program block area. Create the following two networks.

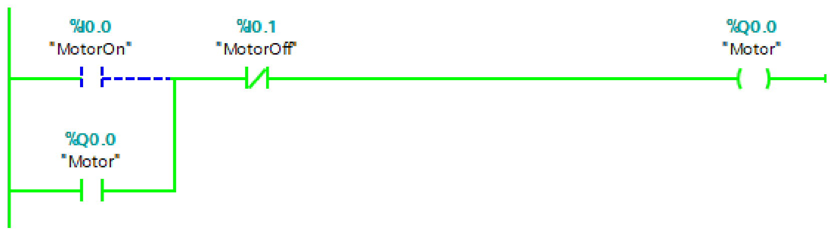


Download the program to the PLC. Turn the monitoring on.

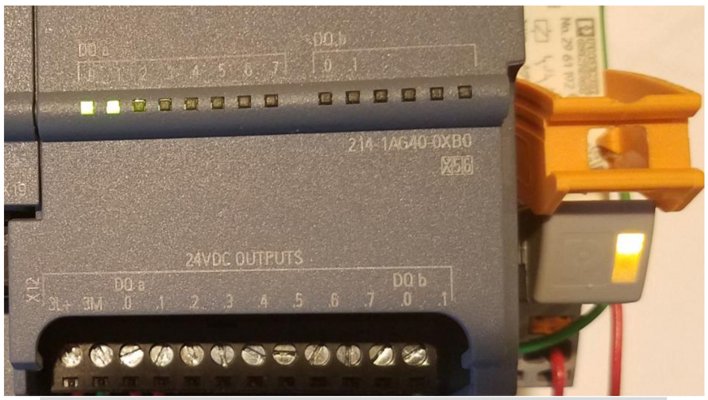
The screen should resemble the one in the picture below.

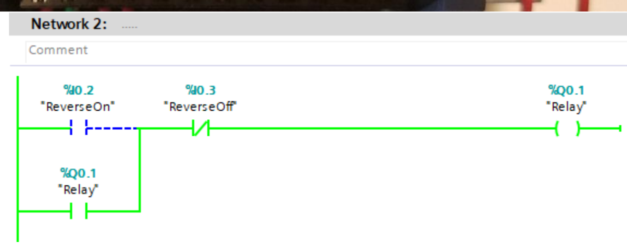


Press the motor on switch. The motor should begin turning and the monitoring should show that it is running.



Now depress the reverse switch. The second network should energize the relay and the motor should change directions. Also the light on the relay should be illuminated now.





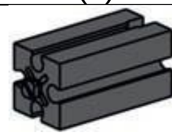
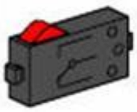
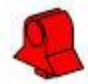
It should be possible to reverse the motor at any time just by selecting the “ReverseOn” or “ReverseOff” switches.

Back

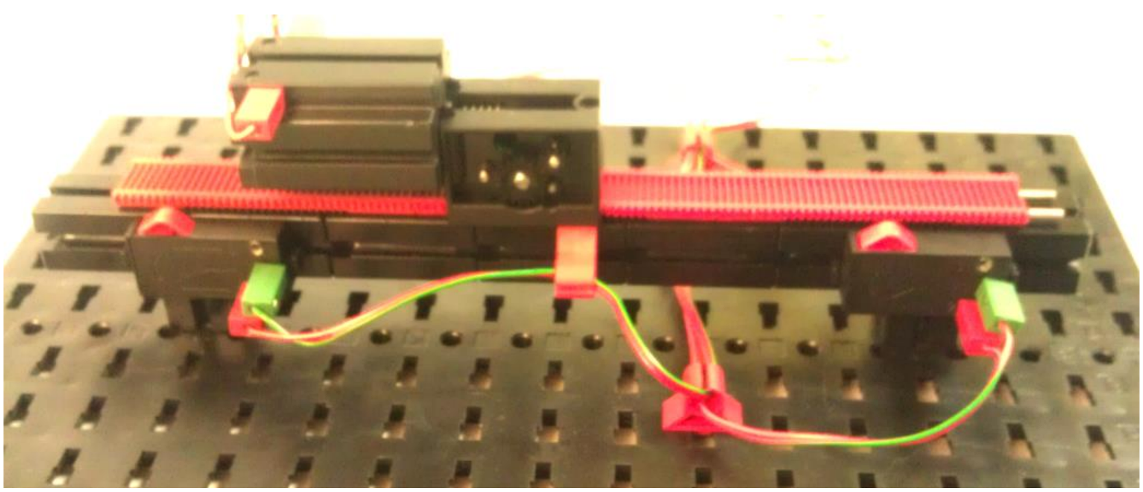
Closed Loop Programming:

Basic systems consist of an input, a process, and an output. These simple systems are called open loop systems because the system cannot interact with the world. For example the clothes washer has no idea if the clothes are clean or not. The cycle runs for a time and then stops. For most of our needs simple systems are not enough or are energy wasters. Closed loop systems add feedback to the system from sensors to continuously monitor and regulate the system. Street lights have a sensor to turn themselves on when it gets dark and off again when it becomes light. In programming we design loops to monitor sensors to allow control of systems.

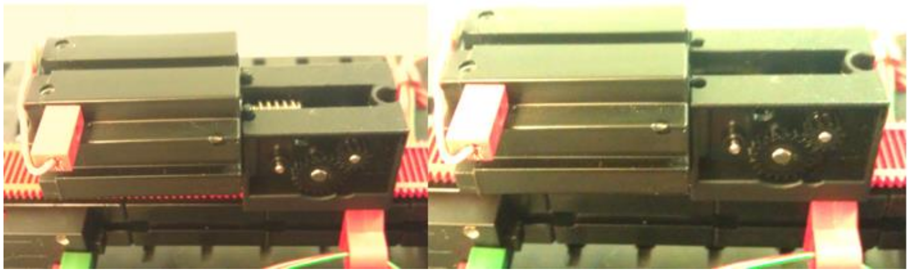
This exercise utilizes parts found in the Do Engineering Basic Kit available from Studica.

 Rack and Pinion 60 (3)	 Motor Rack Gearbox (1)	 Flat Plug Red (6)
 Building block 15 with 2 pins (2)	 Building Block 30 (8)	 Flat Plug Green (6)
 Mini-Switch (2)	 S Motor (1)	 Cable Clamp (5)
 Base Plate (1)		

The components are assembled as shown below. There are seven of the building block 30s that allow the rack gears to be aligned in a row. The two 15 mm blocks with the two pins hold the assembly up in the air. Electrical wiring should be organized in any model you construct. The cable clamps allow the wire to be supported and out of the path of the motor. Be sure to leave enough wire so the motor and gear box can travel freely from end to end of the rack gear. In the picture below you can see the switches set up at each end of the rack gear. These are the ReverseOn and ReverseOff switches. Run the same program and the motor should travel back and forth between the two switches.



The gear box will lock upon the rack gear when the motor is engaged. Pull the motor up slightly to release the gear before moving the assembly by hand. The picture below shows the motor in both positions. On the left you can see the worm gear on the motor as it is not engaged with the gears. On the right the motor worm gear is all the way down and the assembly should not move unless you power the motor. Damage will result when the motor and gearbox are forced.

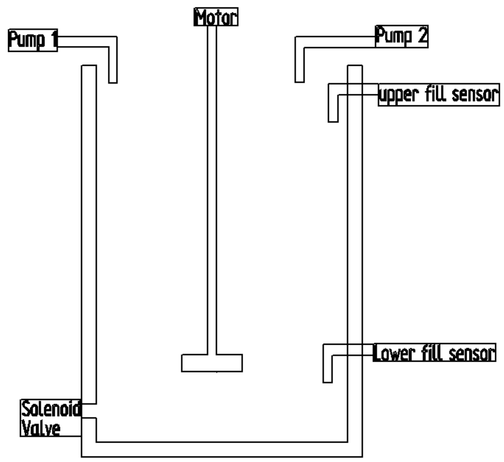


Back

Timers

In this next exercise we will add some new instructions to build programs to perform some different functions. We will be using a flip flop and timer to control action in the mixing tank.

Similar to the last example begin a new program. Define the hardware. The name given this example is mixer.



Action Needed

In this case we desire to mix two different components in a tank. When the lower fill sensor observes no fluid in the tank it delivers a signal that begins to fill the tank. The two pumps each deliver fluid to the tank until the level reaches the upper fill sensor. When the upper fill sensor observes fluid it should turn off the pumps. Once the pumps are off the mixer motor should engage for 20 seconds to assure proper mixing. Once the mixer finishes the solenoid valve should open and remain open until the tank drains exposing the lower fill sensor which shuts off the solenoid valve and begins the cycle again.

The Tag Table

Mixing Tank ▸ PLC_1 [CPU 1214C DC/DC/DC] ▸ PLC tags ▸ Default tag table [38]

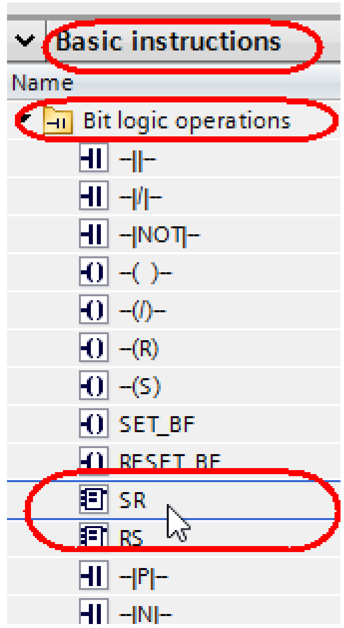
Default tag table

	Name	Data type	Address	Retain	Acces...	Writa...	Visibl...
1	Lower level switch	Bool	%I0.0	☐	☑	☑	☑
2	Upper level switch	Bool	%I0.1	☐	☑	☑	☑
3	All stop switch	Bool	%I0.2	☐	☑	☑	☑
4	Pump 1 Hot	Bool	%Q0.0	☐	☑	☑	☑
5	Pump 2 Cold	Bool	%Q0.1	☐	☑	☑	☑
6	Mixer Motor	Bool	%Q0.2	☐	☑	☑	☑
7	Solenoid Valve	Bool	%Q0.3	☐	☑	☑	☑
8	Fill level Monitor	Bool	%M0.0	☐	☑	☑	☑
9	Valve control	Bool	%M0.1	☐	☑	☑	☑

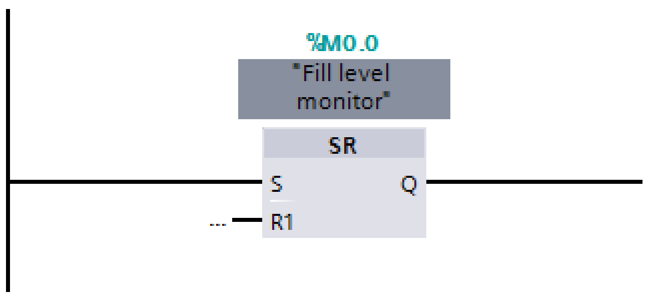
The Program
This program will consist of 3 separate networks that will talk to each other. Open the main operational block.

FlipFlop
The first network will contain a SR flip flop. The SR (Set Reset) flip flop is an electronic circuit that outputs a Boolean signal depending on the input. It can have only one output at a time.

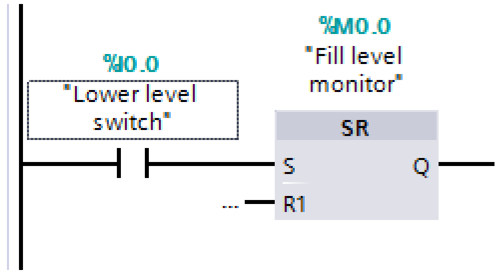
Find the SR flip flop in the Basic instructions tab in the instructions area on the right side of the screen. Expand the Bit logic operations folder.



Place the SR flip flop in the center of the network. Assign the Fill level monitor to the flip flop. This monitor has the tag %M0.0 meaning it is a bit assignment in the 0 position. In other words it delivers a Boolean signal.

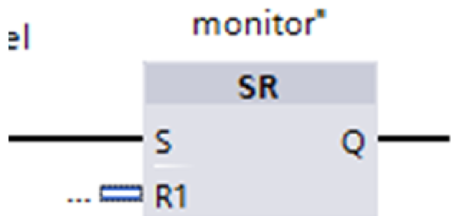


The output (Q) will depend on the states of the two inputs. If both the S (set) and R1 (reset) inputs are low (0) then the output (Q) is low. If S is high (1) and the R1 input is low (0) then the output (Q) will be high (1). Since input R1 takes precedence if R1 is high the output of the SR Flip Flop will be turned off. In this example we need to add some contacts to adjust the logic. Add a contact to the S (set) input. This will be the low level sensor. The lower level switch will only deliver an output when uncovered. When the set reset flip flop sees the logic high it will turn on the output and leave it on until the reset contact goes high. Once the pumps turn on they will run until the reset pin delivers high logic.

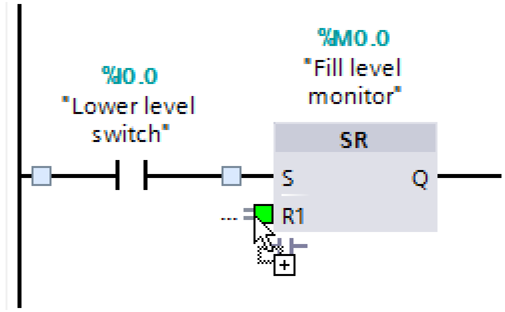


The pump should turn off when the tank is full. That would be the upper level switch.

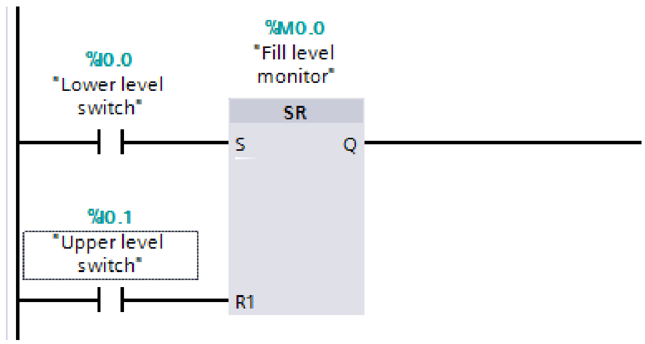
Highlight the R1 terminal by clicking on it. It should look like the image below.



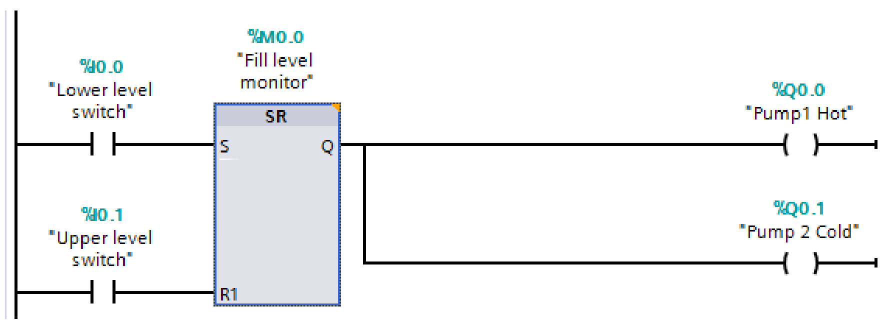
Then drag a normally open contact to R1 and it will show the green square.



Let go of the contact and it will complete the connection for you. Assign the upper level switch to the contact.



Add outputs for both pumps. In this case you will use the open branch from the favorites menu.

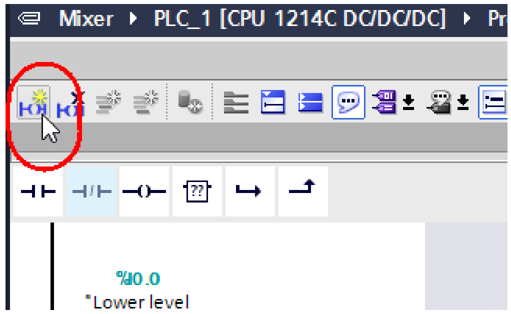


Once the pumps turn off, the description informs us the mixer should now run for 20 seconds to thoroughly mix the fluid in the tank.

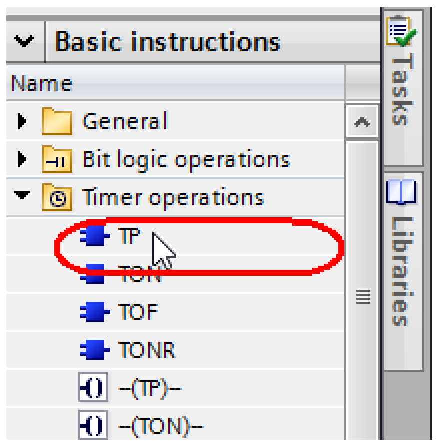
Timer

The timer controls the mixer motor. It will turn on the output for a set amount of time and then turn it off. Dishwashers and clothes washers use this same approach while they are running. The timer allows them to function for a set time and then it shuts the machine down.

Begin a new network by selecting the icon for insert network.

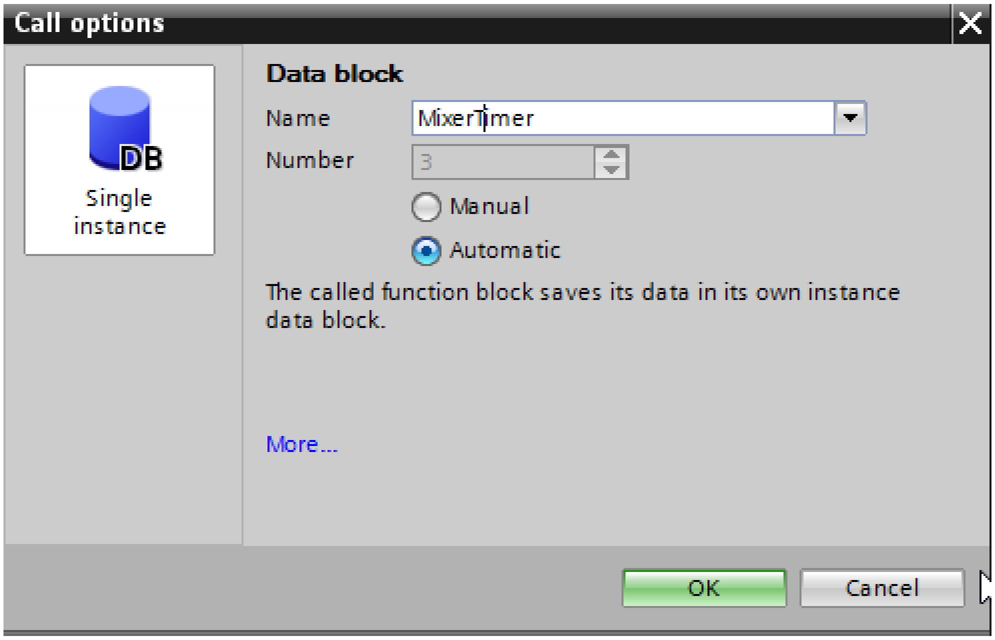


Select the TP (Timed Pulse) timer from the timer operations folder in the basic instructions in the Instructions area on the left side of the screen.

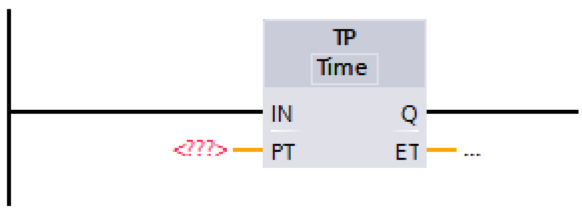


Place this block in the new network.

It will open up the call options dialog box. This is a single instance timer. Experts generally name blocks so they can look back and see what they are doing. Default names can be confusing.

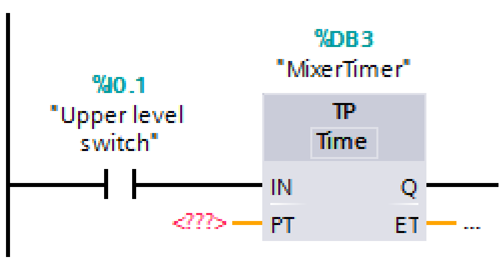


Click OK and place the block on the network.

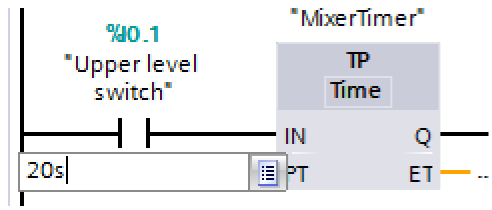


The timer block has an input (IN) that will trigger the countdown. It has an output (Q). The PT pin (Pulse Time) is where the programmer specifies the time and the ET pin (Elapsed Time) displays the current value while it counts.

Insert a contact on the IN leg. Since we don't want the mixer to begin until the tank is full we can use the upper level switch to trigger the timer. Once the level reaches the upper level switch the pumps are moved to the off state by the flip flop in the previous network.



Enter the 20 seconds for the pulse time by double clicking on the red question marks. Type the number 20s which stands for 20 seconds. There is no space between the 20 and the s. The s is lower case.



Add a normally inactive output to control the mixer motor.

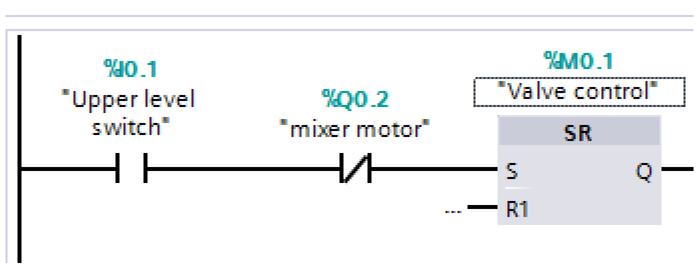
Drain Valve Logic

The last network needed for this program is the control for the drain valve. The logic can be tricky because we need to put conditions on when the output can turn on. According to the problem we need to turn on the valve when the tank is completely mixed. This means the upper level switch should tell us the tank is full, but we don't want to drain the tank until the mixing is finished. This is a logic AND situation. When we create a network where two things must happen together they are in series. Control must pass through one set of contacts and then the other.

This example uses a second SR flip flop. Create another new network.

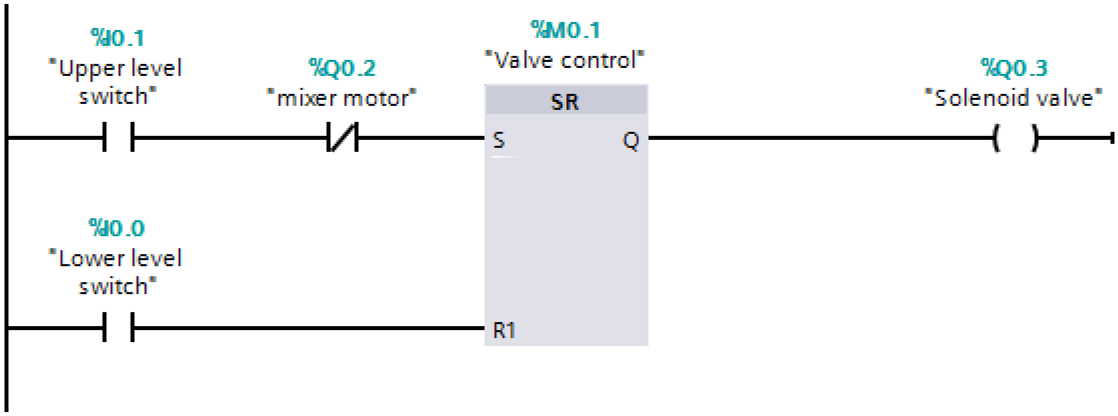
Place an SR flip flop on the network.

Place two contacts leading to the Set terminal. The first will be a normally open contact tied to the upper level switch. The logic will not advance until the switch detects the fluid in the tank. The second is a normally closed contact. This one monitors the mixer motor. When the motor is running the contacts open and no logic is passed to the set of the flip flop.



Reset controls when the valve turns off. In this example we want to close the valve when the level drops so the lower level switch goes high. This will turn off the output of the flip flop.

Add an inactive output to turn the solenoid on and off.



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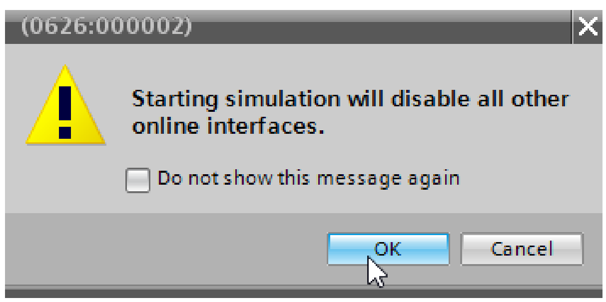
Running a Simulation

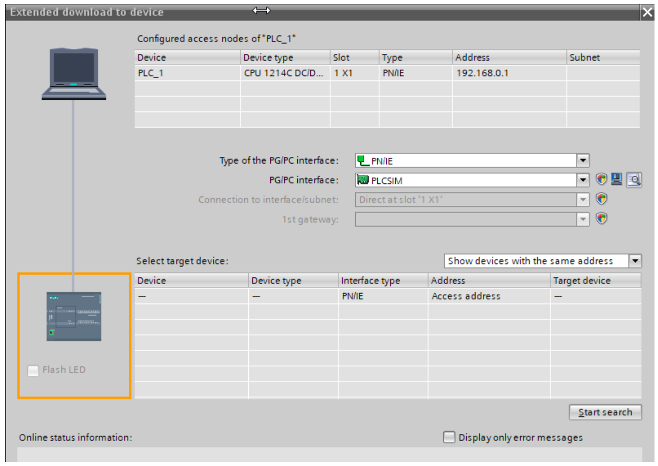
There are times when you want to see if your logic is working before you connect the hardware. Any large system is prone to mistakes in planning and simulations prevent damage and allow for faster development.

Go to the online pull down menu and select the option for simulation. Select start

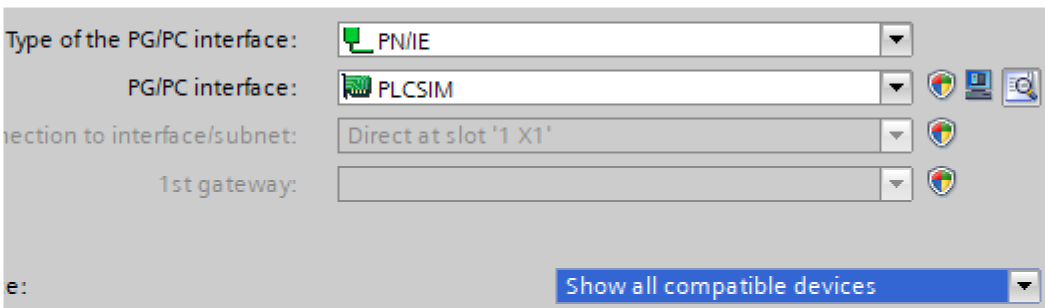
A warning will appear. Select OK



See a dialog box for “extended download to device.

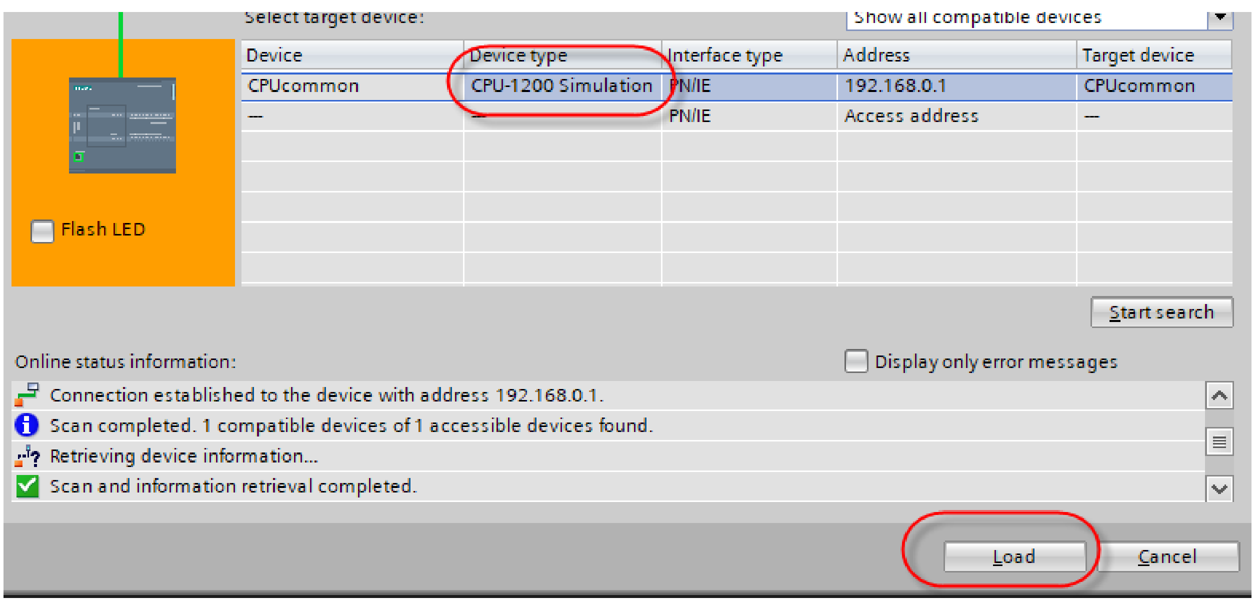


Be sure to set the type of the PG/PC interface to PN/IE and set the PG/PC Interface to PLCSIM and show all compatible devices.



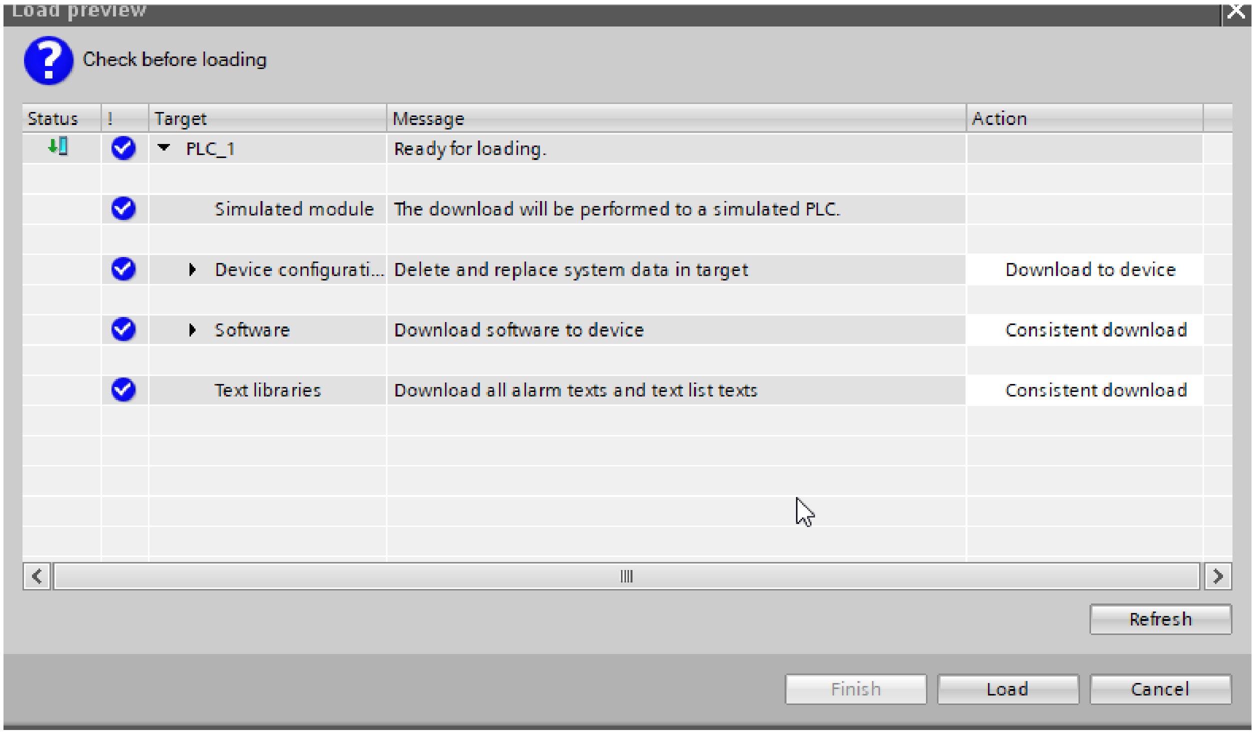
Select Start search.

See the results with the CPU-1200 Simulation showing up as the device type.

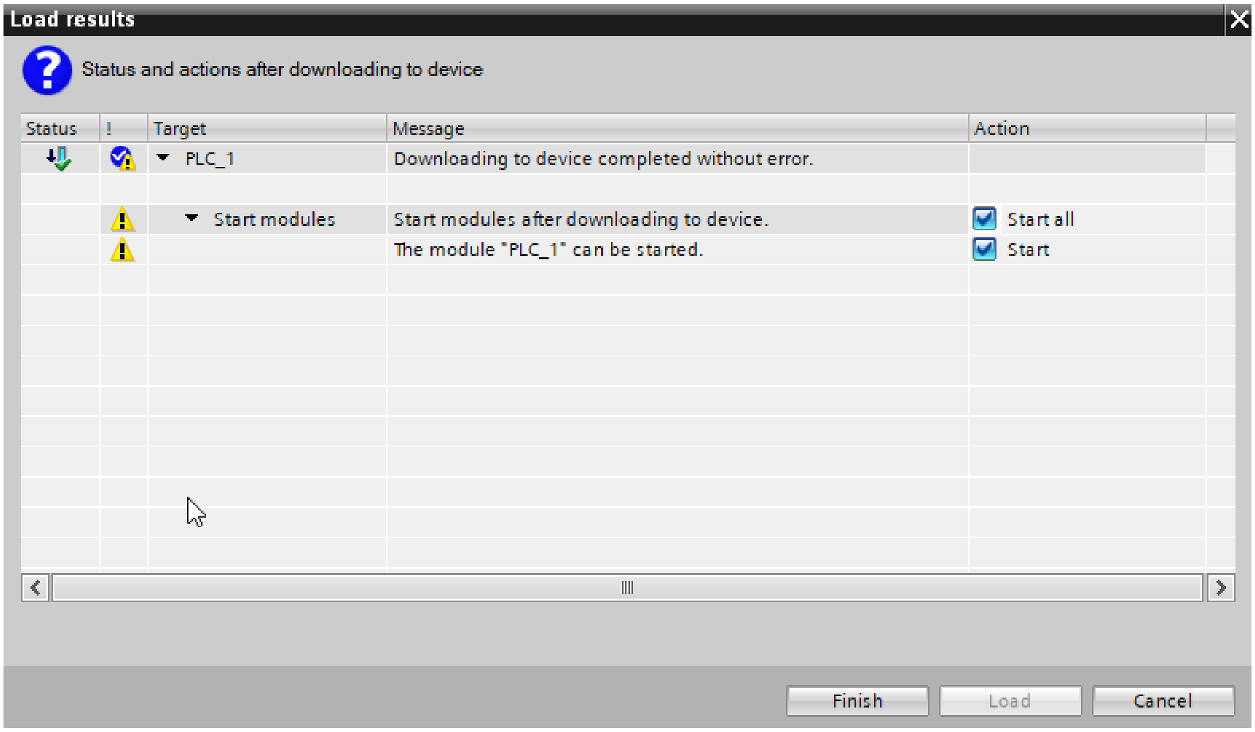


Select Load.

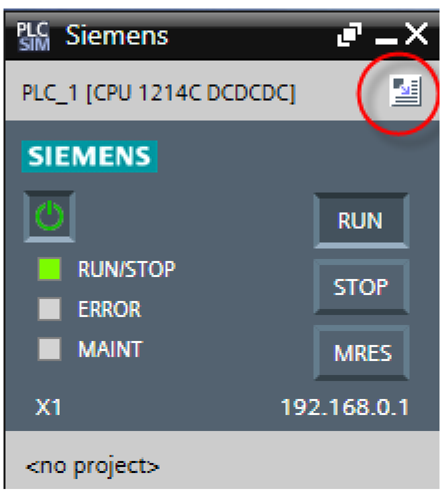
The load preview box opens. Select Load.



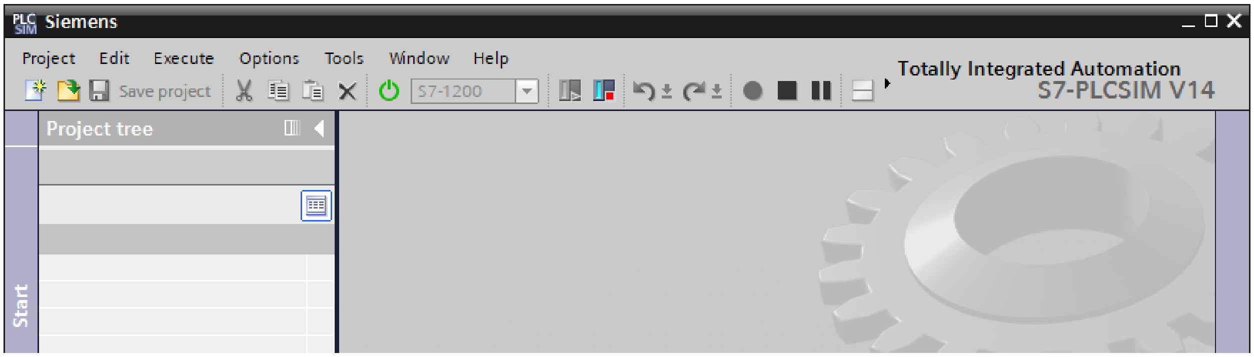
When the load results box opens, select the Start all and then select finish.



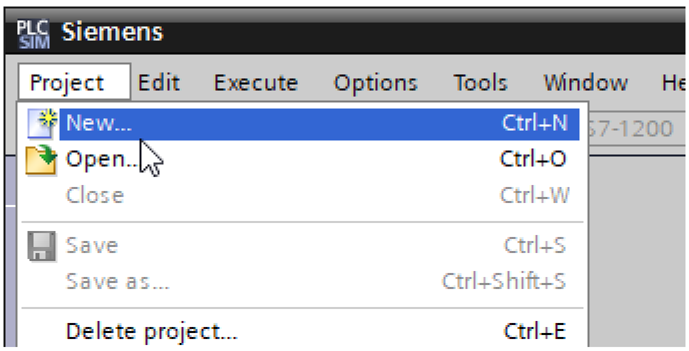
The S7-PLCSIM which is the simulation program should be open. It might be a compact view. If that is the case select the icon in the red circle below.



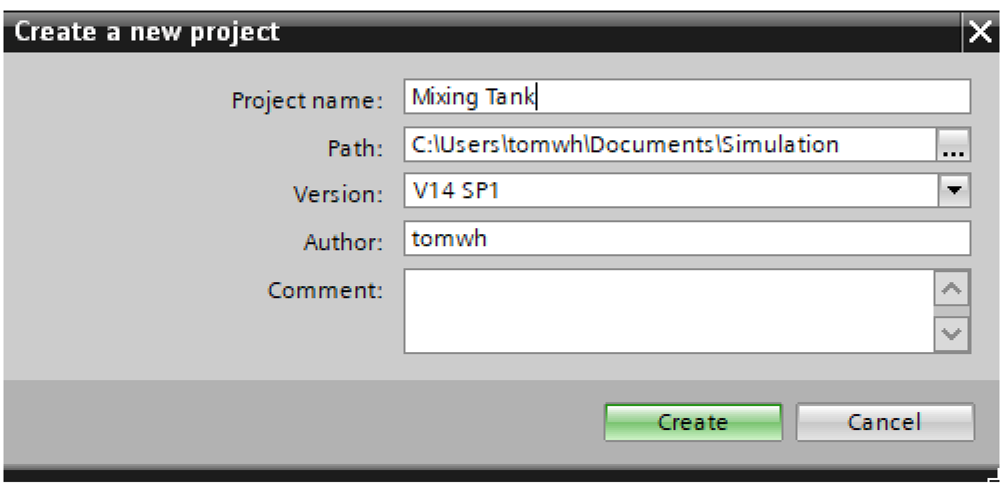
This will open the project view.



The first step is to select new project from the project pull down menu.

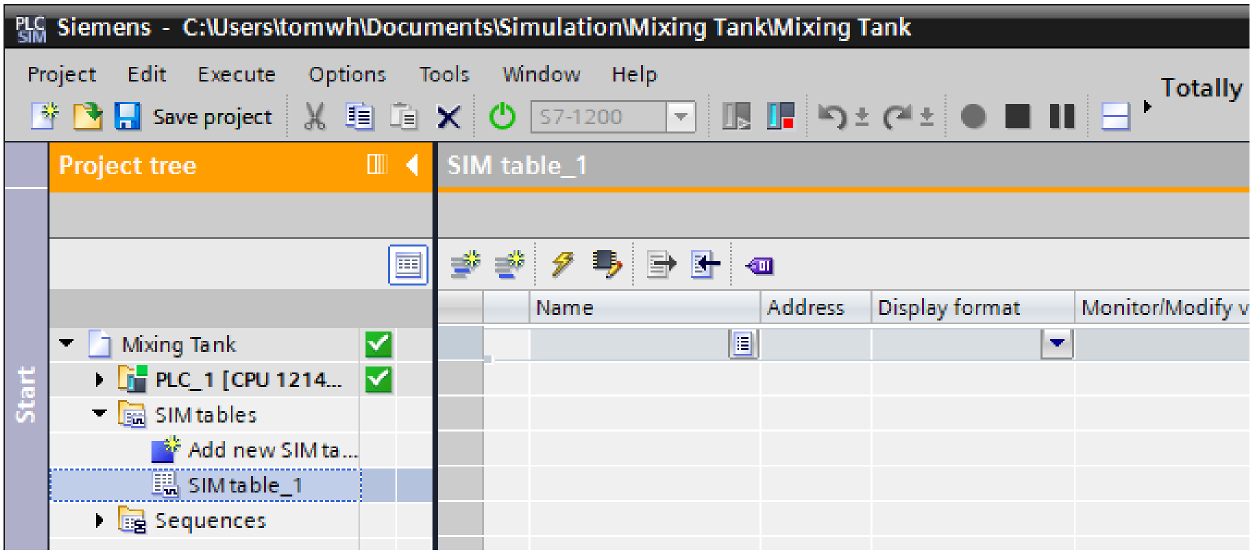


In the dialog box give this project the same name as your existing file with your program blocks. Select Create.



It will take a while to load.

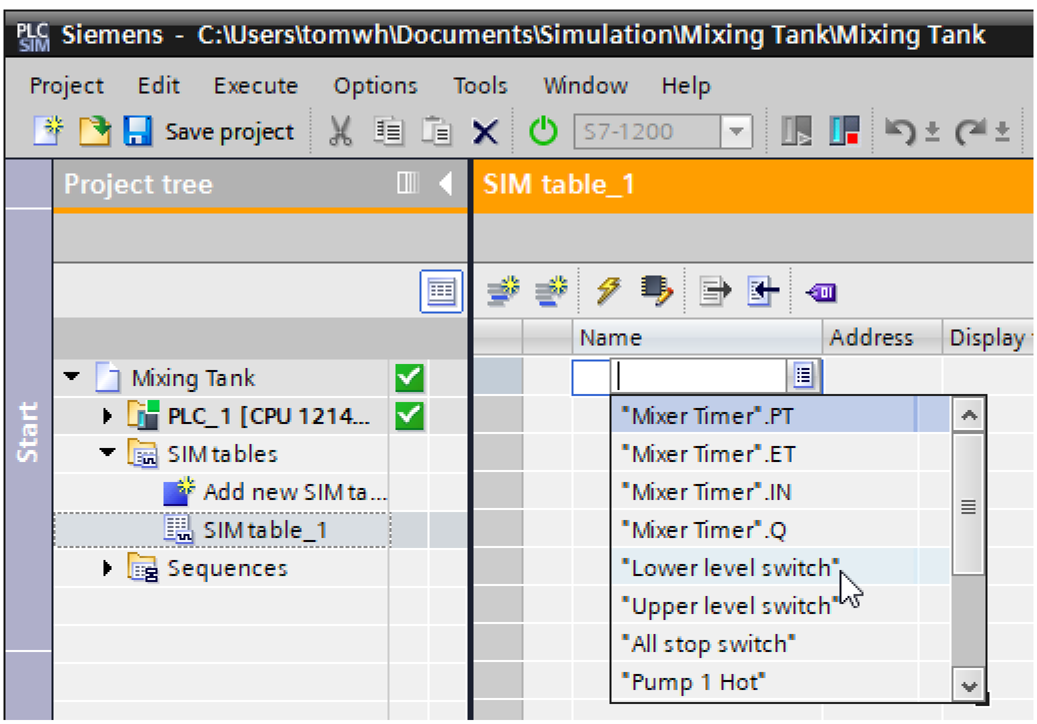
SIM Table
In the simulation window expand the PLC and SIM tables sections to locate the SIM table.



The SIM table allows us to import inputs or outputs into the simulation to control the simulation.

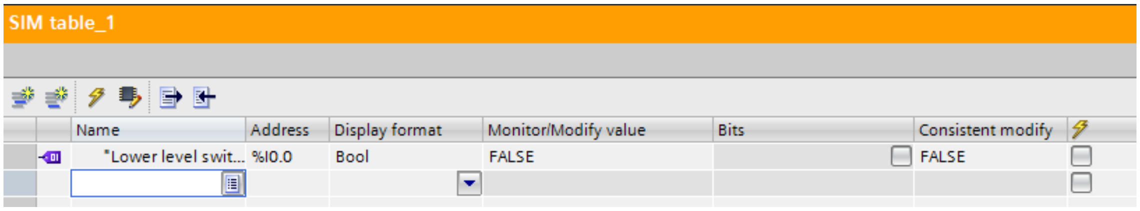
In this case we will need the lower and upper fill sensors.

Begin on the SIM table and click on the space in the name area.

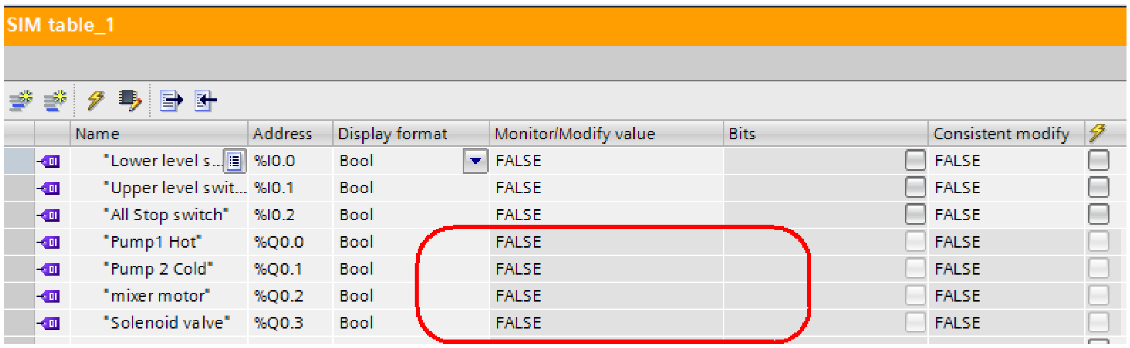


Select the lower level switch from the options.

When you click on line 2 the rest of the information will populate automatically.



Continue placing the various tags we used to set up the program.



Inputs we can control with a check. Outputs we can observe what is happening. If you look carefully in the circled area you can see there is a different fill color for the outputs.

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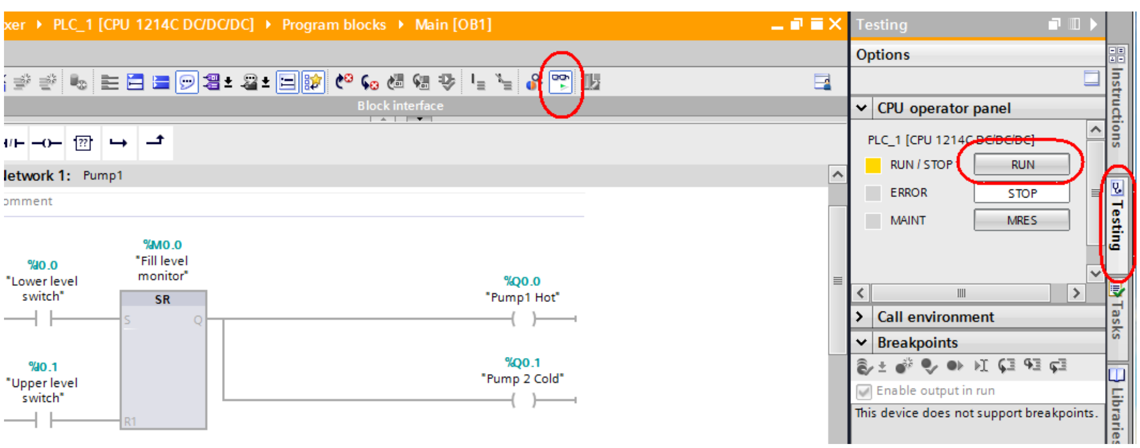
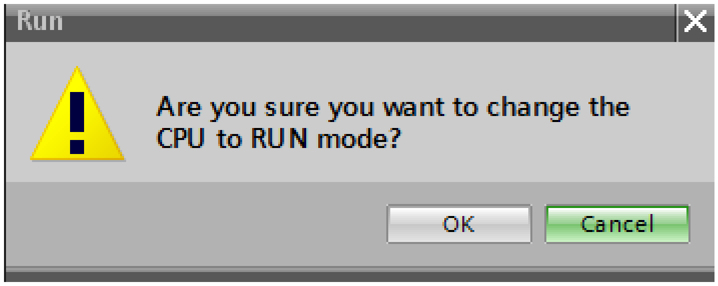
Using the SIM Table

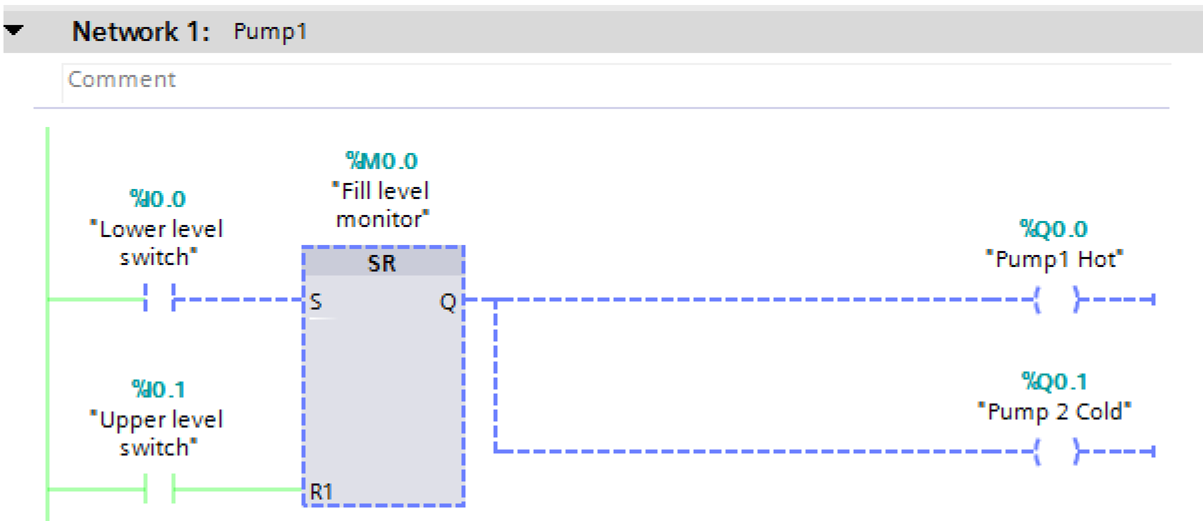
You are now ready to simulate the project. Click in the ladder logic diagram on the main program screen. Turn the program monitoring on. On the right hand side of the screen select testing to show the CPU operator panel.



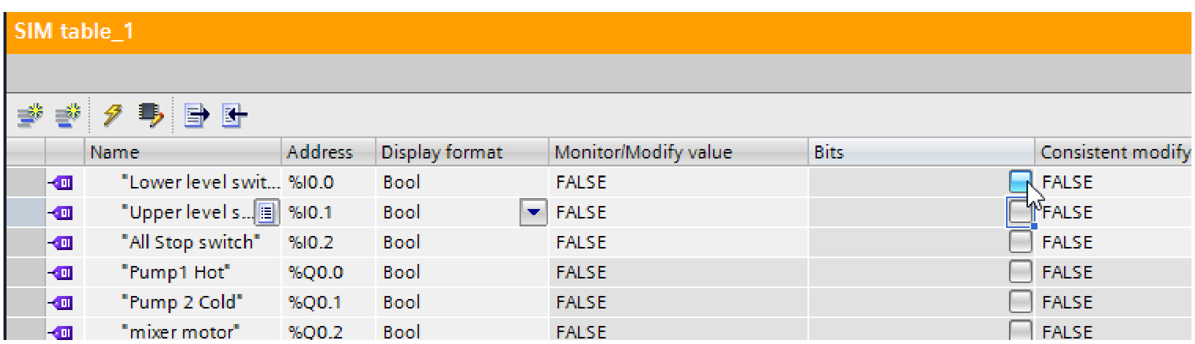
Select the run button to engage the simulation. Answer OK to the prompt.



See the first network waiting for the lower level switch to close and begin the program.



On your SIM table just finished, click the check box in the bits column for the lower level switch.

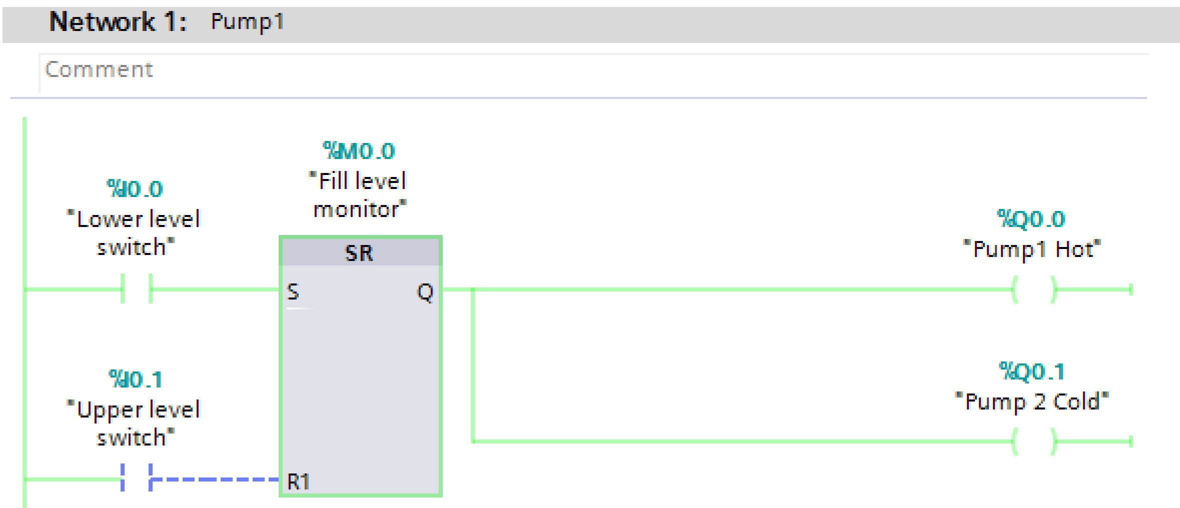


Observe that the monitor shows the lower level switch to now be true. The two pumps are also showing they are operational.

SIM table_1

Name	Address	Display format	Monitor/Modify value	Bits	Consistent modify
"Lower level s...	%I0.0	Bool	TRUE	[x]	FALSE
"Upper level swit...	%I0.1	Bool	FALSE	[ ]	FALSE
"All Stop switch"	%I0.2	Bool	FALSE	[ ]	FALSE
"Pump1 Hot"	%Q0.0	Bool	TRUE	[x]	FALSE
"Pump 2 Cold"	%Q0.1	Bool	TRUE	[x]	FALSE
"mixer motor"	%Q0.2	Bool	FALSE	[ ]	FALSE
"Solenoid valve"	%Q0.3	Bool	FALSE	[ ]	FALSE

Looking at the logic diagram and see the logic has turned the pumps on.

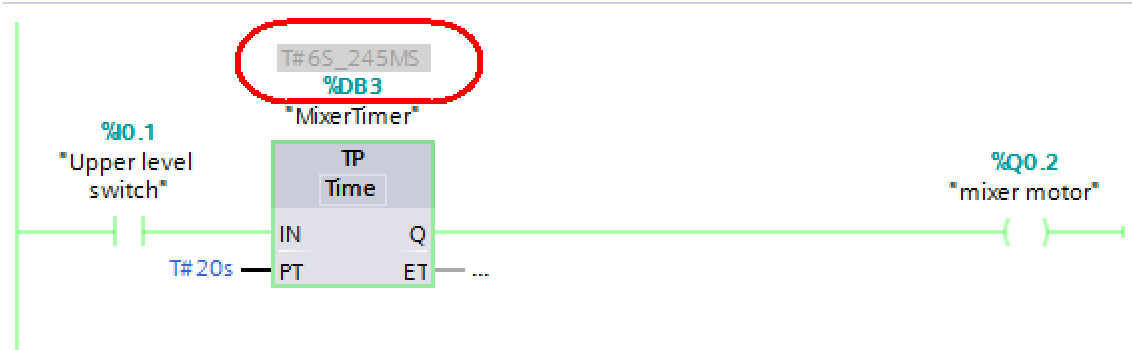


Remember, the program will turn on the mixer once the filling is finished. Uncheck the lower level switch check box on the SIM table. Check the Upper level switch bit box.

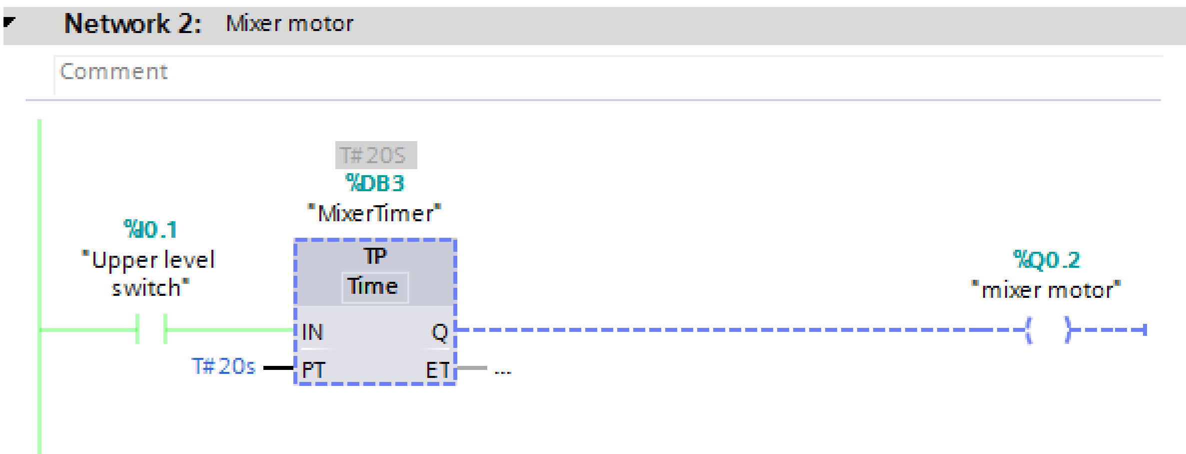
SIM table_1

Name	Address	Display format	Monitor/Modify value	Bits	Consistent modify
"Lower level swit...	%I0.0	Bool	FALSE	[ ]	FALSE
"Upper level s...	%I0.1	Bool	TRUE	[x]	FALSE
"All Stop switch"	%I0.2	Bool	FALSE	[ ]	FALSE
"Pump1 Hot"	%Q0.0	Bool	FALSE	[ ]	FALSE
"Pump 2 Cold"	%Q0.1	Bool	FALSE	[ ]	FALSE
"mixer motor"	%Q0.2	Bool	TRUE	[x]	FALSE
"Solenoid valve"	%Q0.3	Bool	FALSE	[ ]	FALSE

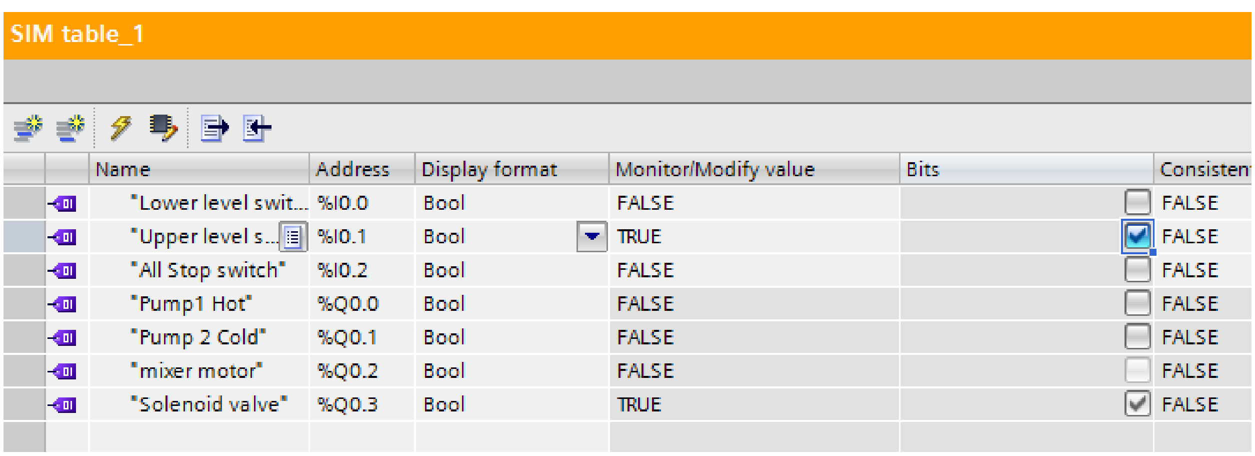
The pumps should turn off and the mixer motor turn on. Looking at the second network, see the timer counting.



Once the timer reaches 20 seconds the mixer should turn off.



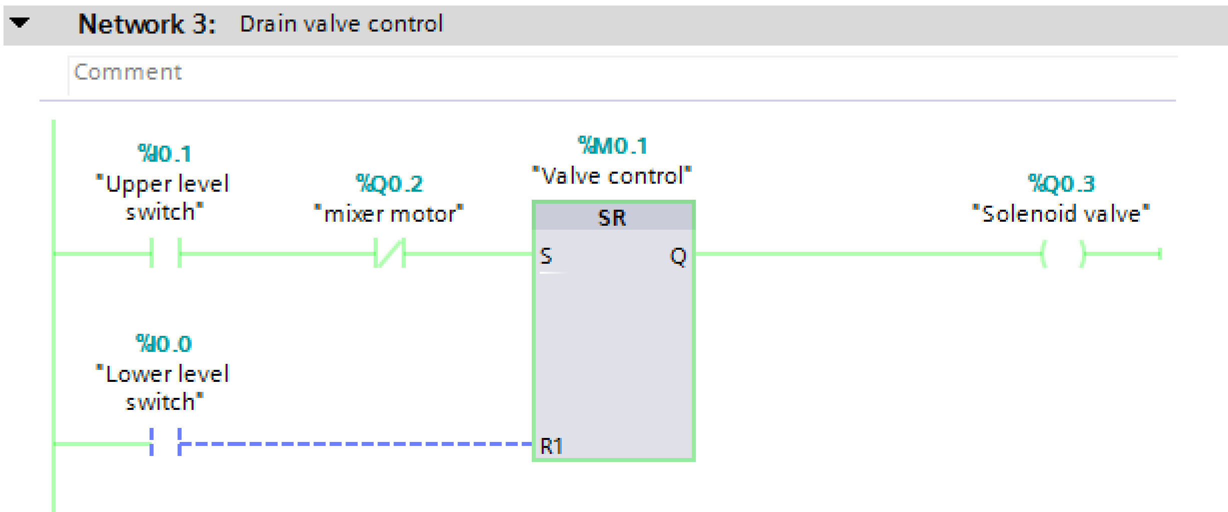
On the SIM table, see the solenoid has now turned on since the logic has been met.



SIM table_1

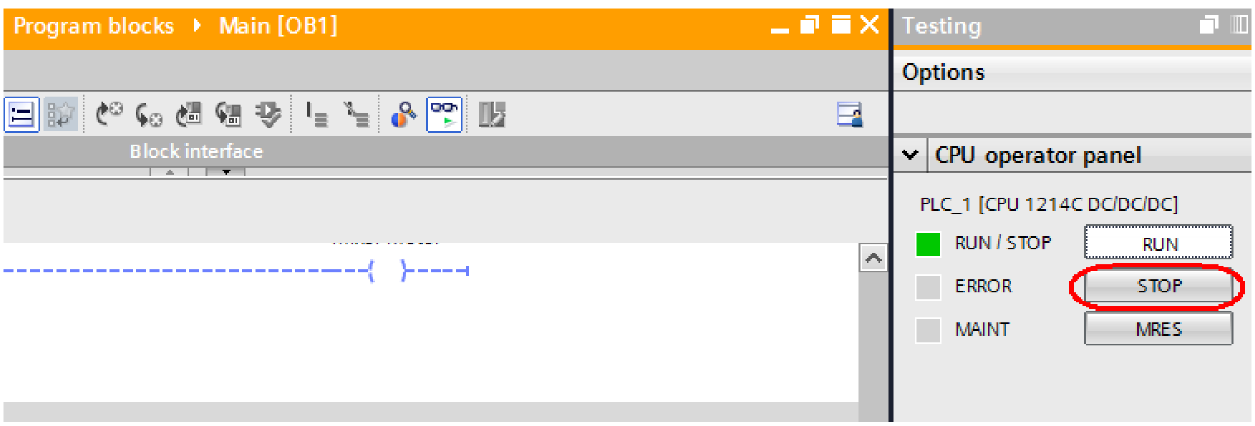
Name	Address	Display format	Monitor/Modify value	Bits	Consisten
"Lower level swit...	%I0.0	Bool	FALSE		FALSE
"Upper level s...	%I0.1	Bool	TRUE		FALSE
"All Stop switch"	%I0.2	Bool	FALSE		FALSE
"Pump1 Hot"	%Q0.0	Bool	FALSE		FALSE
"Pump 2 Cold"	%Q0.1	Bool	FALSE		FALSE
"mixer motor"	%Q0.2	Bool	FALSE		FALSE
"Solenoid valve"	%Q0.3	Bool	TRUE		FALSE

The ladder logic diagram is now showing that the solenoid controlled drain valve is now open.



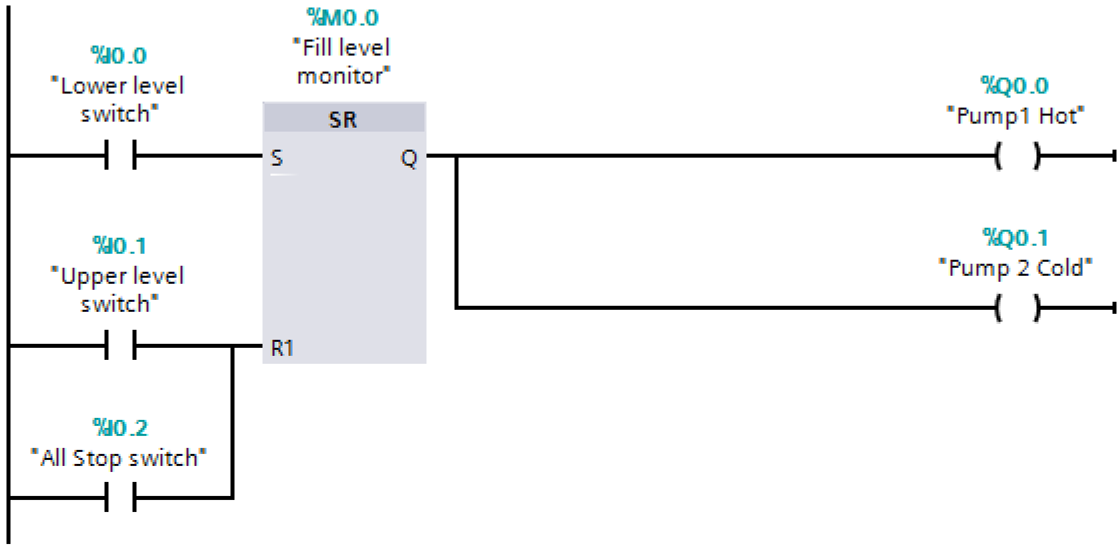
When returning to the SIM table and unchecking the upper level switch and checking the lower level, the process will repeat itself.

When satisfied with the results, click the Stop button in the testing window to end the simulation.

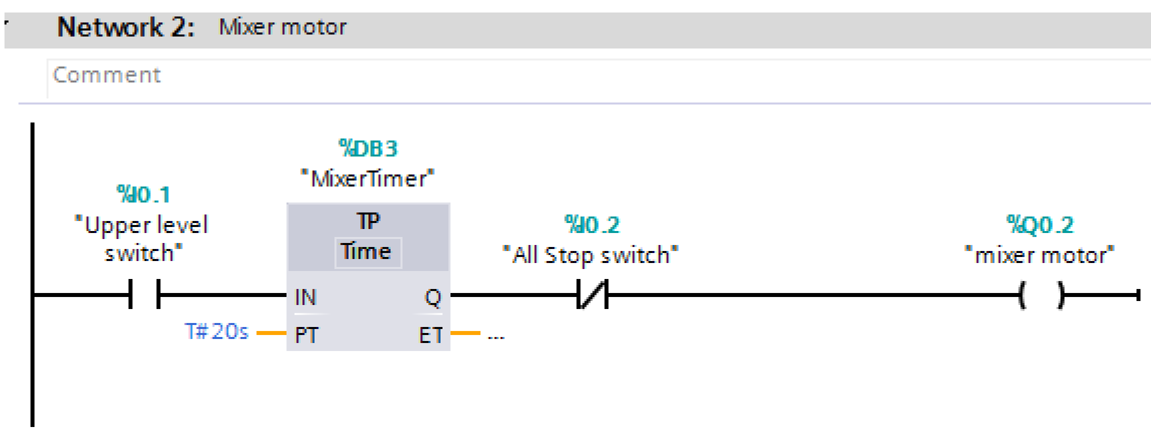


The last component of the program we need is to allow for the emergency stop switch which will stop all functioning of the program.

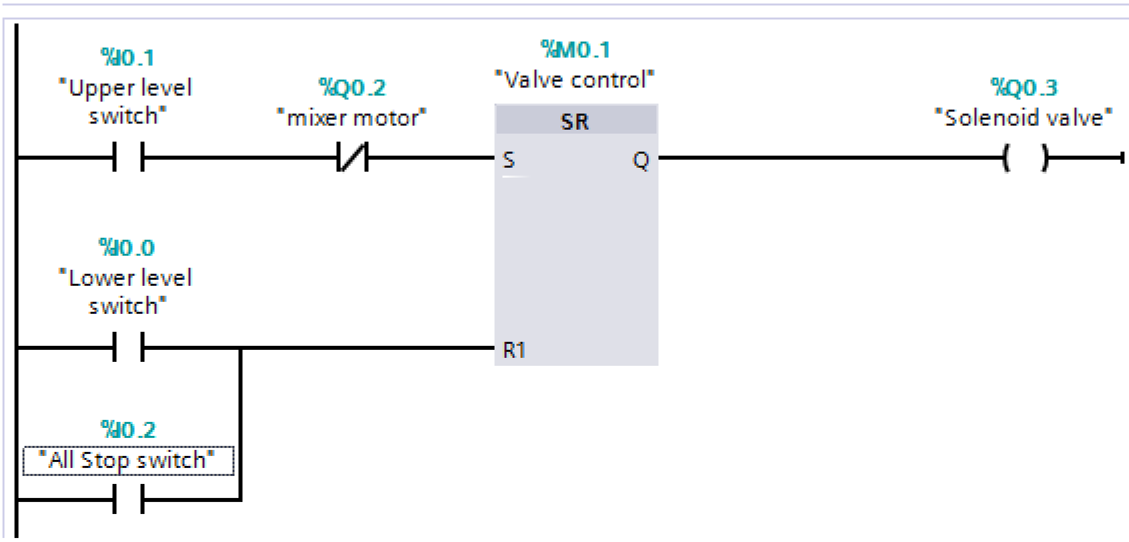
Since we have three networks, we need to decide how to stop each. In the first network the pumps are on until the upper level switch engages. We need to provide a piece of OR logic. When the tank is full OR we hit the emergency stop, we want the pumps to stop.



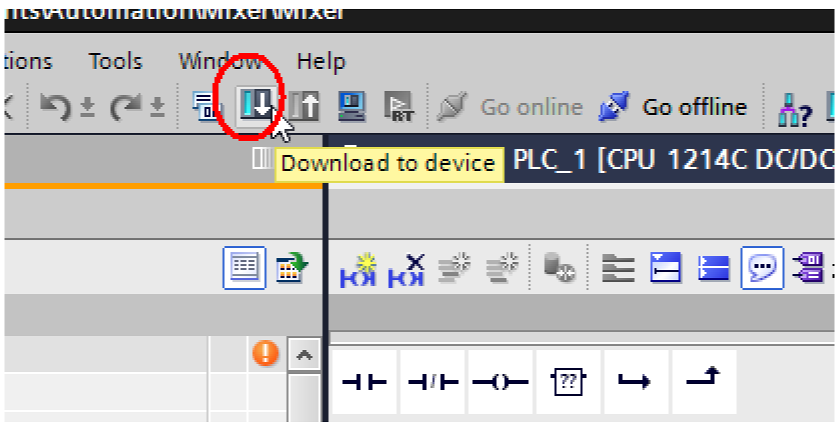
In the second network the mixer will run if the timer is running. In this case we will add AND logic. Only if the timer is running AND the stop button is not pushed will the mixer run.



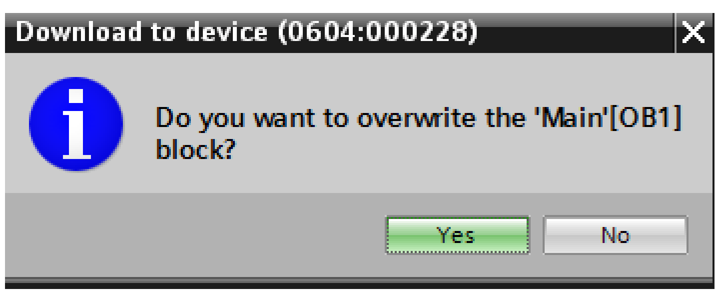
In the third network the solenoid valve will open if the upper level switch is on and the mixer motor is off. It will run until the lower level switch is active or someone hits the stop switch. This is OR logic again.



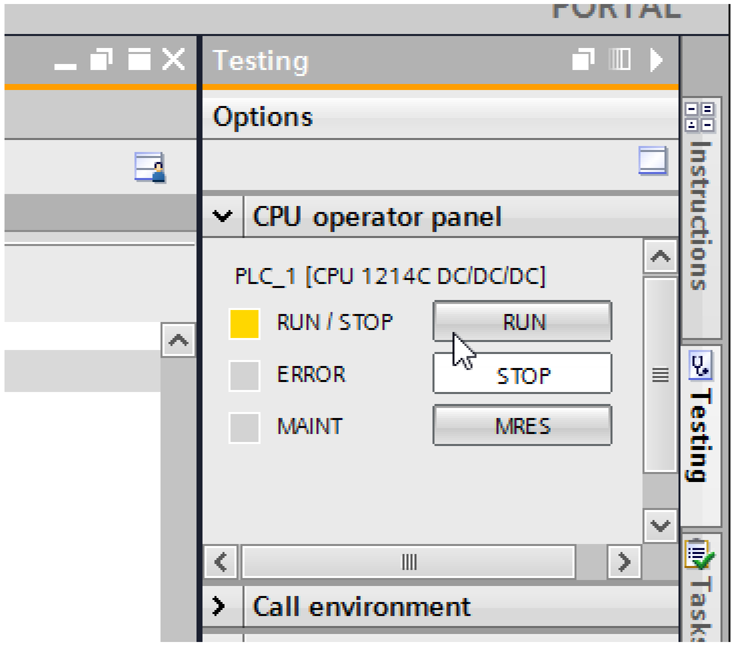
Now it is time to see if the stop switches work the way we desire. Select the icon for download to device.



The prompt will check if you are sure you want to overwrite the program.



Select Yes. Once the program downloads to the device select run from the Testing Operator panel.



This time during your simulation be sure you can stop each network with the all stop button.

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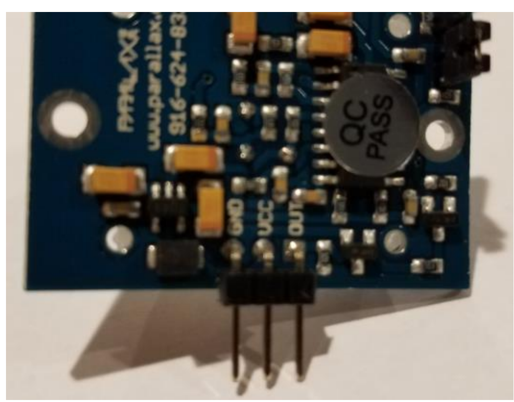
PIR Sensor-Motion Detector

The PIR (Passive InfraRed) sensor measures the infrared light radiating from things in front of the sensor. Their most common use is in motion detectors. When objects move the infrared shifts and the sensor which has multiple slots can see the “image” shift from slot to slot hitting the various receptors behind it. While Passive is in its name it is only passive because it is not sending signals out only receiving them. It is an active sensor because it has processing circuitry.

This is a digital sensor. The circuitry senses when movement occurs in front of it. This will wire into the PLC with the use of a relay.

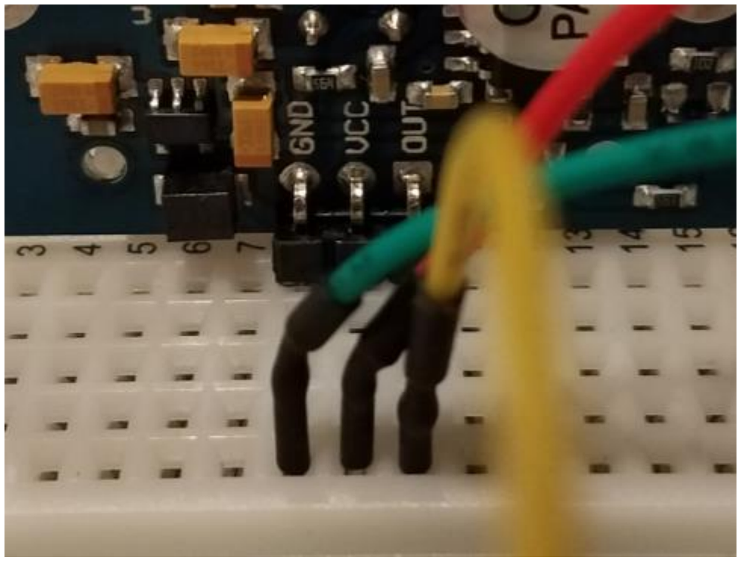
To function you need to connect a power source. On the back of the sensor you will see three pins. They are labeled GND, VCC and OUT.



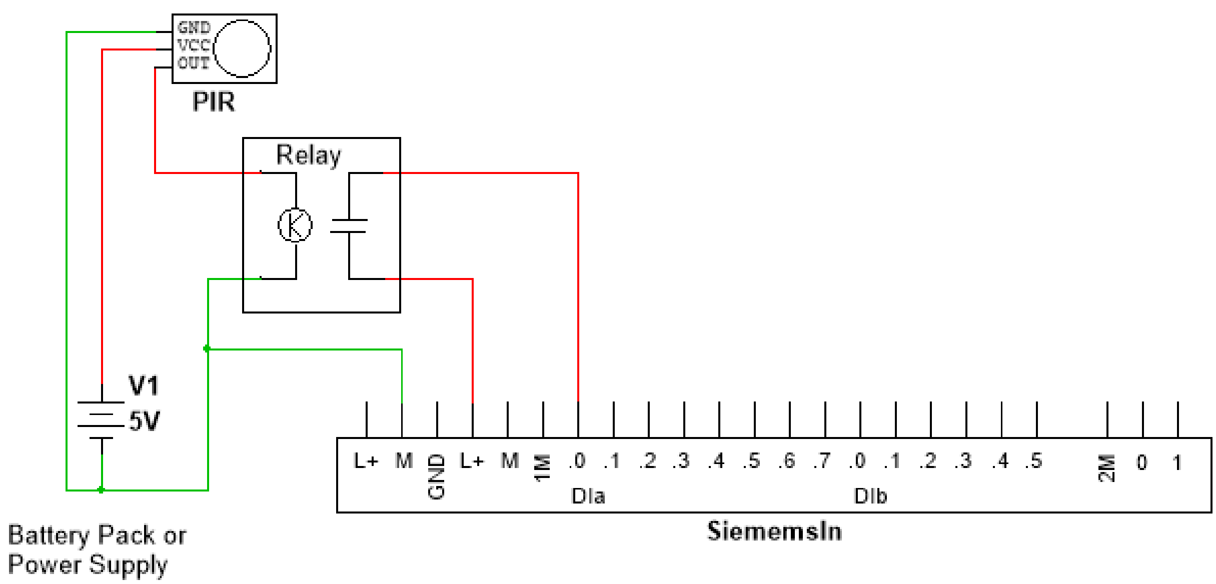
The ground is connected to ground, VCC is connected to +5V. Out is the signal which is a digital signal. The signal goes high when the sensor detects something moving in front of it. This 5V signal is not enough to trigger the input on the PLC but it is enough to trigger a relay which can act like a switch when connected to the PLC.

Connecting the PIR sensor

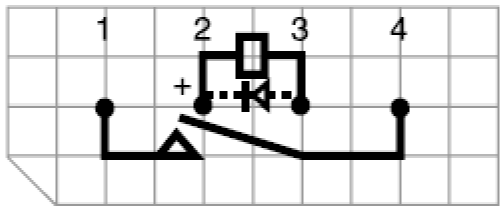
The sensor can be inserted into a bread board or connected through long wires that supply the connections to the relay on the breadboard. The picture below shows the color coding of the wires connecting to the pins.



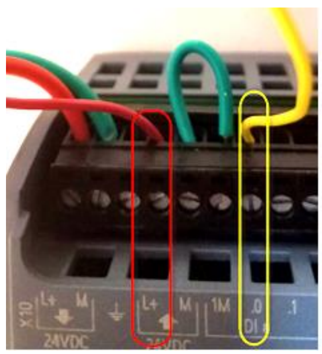
A power supply or batteries will supply 5V for the VCC. The Ground is connected to the power supply ground pin and an M terminal of the PLC. The signal is taken to the relay. This signal can cause the relay to trigger. A wire brings the 24 V from an L+ from the PLC to the relay. The other side of the relay connects to one of the input terminals. See the wiring diagram below.

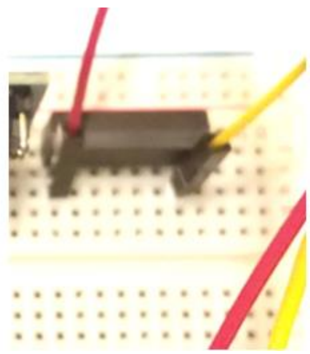


The relay is configured so the contacts are the outside pins and the coil is controlled by the pins in the middle. The picture below is from the data sheet.

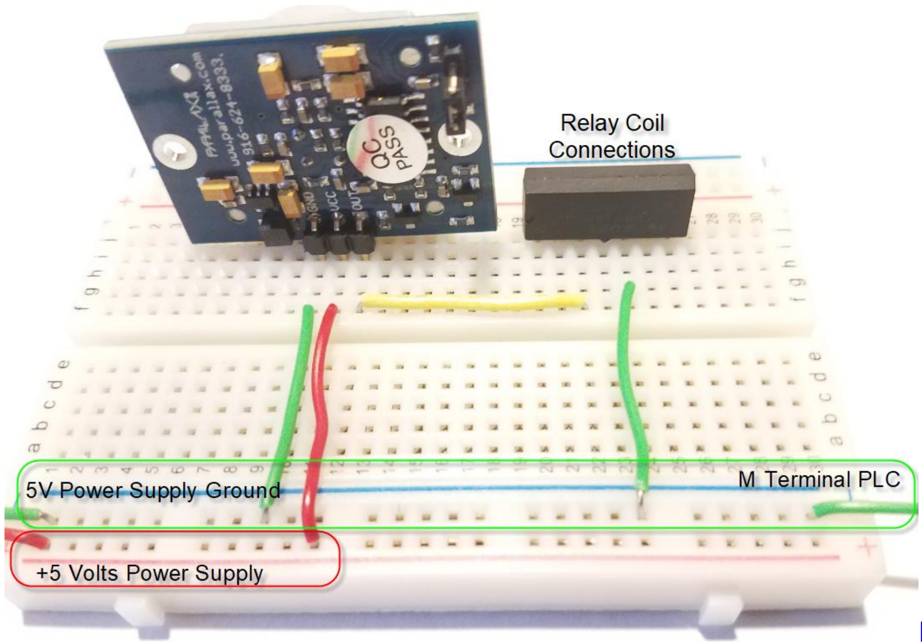


Pin 4 will be connected to the I0.0 input of the PLC. Pin 1 is connected to the L+ connector. In this way it is hooked up like the push button switches.





To trigger the relay we add the signal from the PIR sensor to Pin 2 of the relay and connect pin 3 to ground. Note only the ground connects to the M terminal on the <u>PLC Not the +5V</u>


Relay Coil
Connections
5V Power Supply Ground
M Terminal PLC
+5 Volts Power Supply

Back

Logic and Decision Making

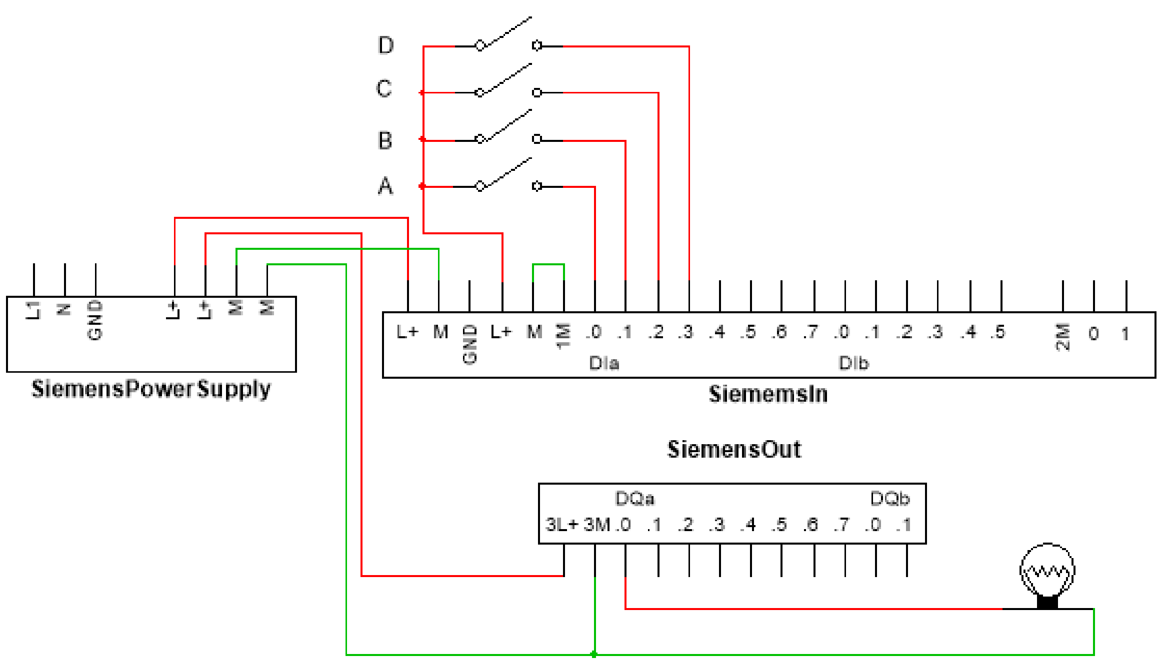
Most of us think of switches as being on or off. Programmers think of switches being in two states. Those states could be high and low or if done mathematically as 1 and 0.

Logic allows us to take inputs from sensors and make decisions based on these inputs. In the exercise above, an output directly tied to a switch was created. What follows will allow us to derive an output from a combination of inputs. For these exercises it is necessary to have the programming pallet visible.

For an excellent explanation of logic and Boolean algebra see the “All About Circuits” Website. http://www.allaboutcircuits.com/vol_4/chpt_7/1.html

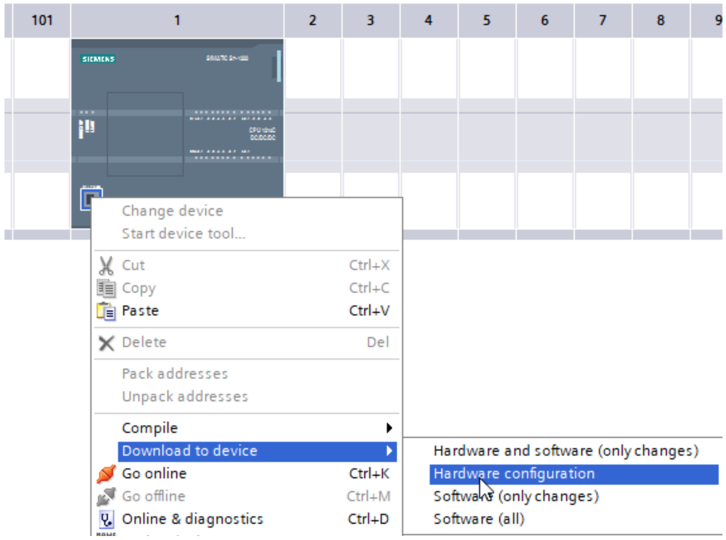
This activity will use switches and a lamp wired to the PLC. You will create ladder logic diagrams and record what happens.

Setup
Use the schematic below to wire the PLC.



Open the TIA Portal and begin a new project.

Place the Device. Once the device is placed select the download to device with the hardware configuration.



Let the program find the device and finish downloading the hardware setup.

Open the default tag table and place the following in the table.

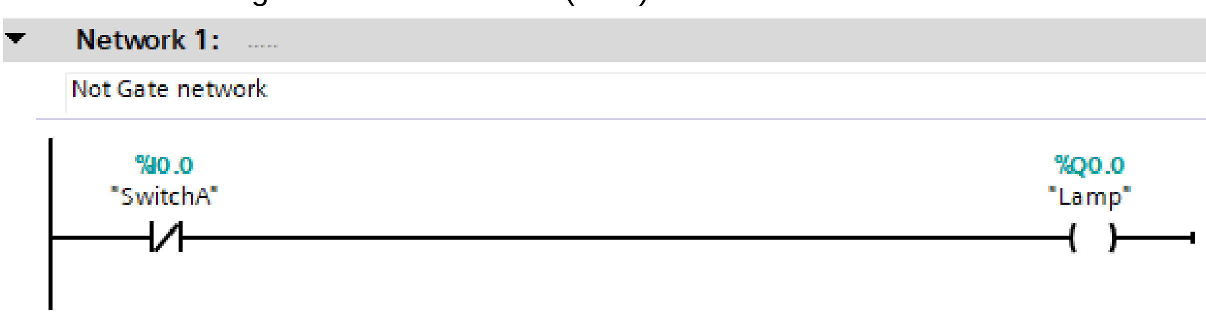
1		Lamp	Bool	%Q0.0
2		clamp	Bool	%Q0.1
3		SwitchA	Bool	%I0.0
4		SwitchB	Bool	%I0.1
5		SwitchC	Bool	%I0.2
6		SwitchD	Bool	%I0.3
7		Flip Flop	Bool	%M0.0

In the examples below you will add a single network to check out the answers. You will overwrite the network to see different logic.

The NOT Gate

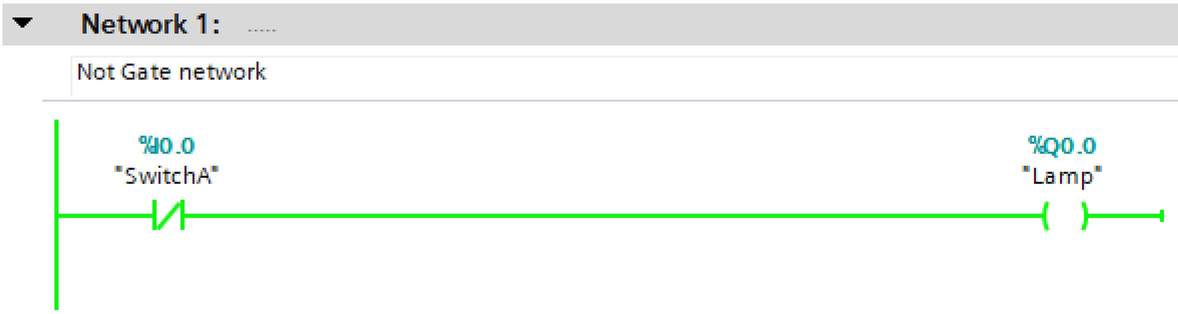
The not gate is the simplest of gates with only one input and one output. Sometimes these gates are called inverters.

Create the following network in the Main (OB1) and download to the device.



Turn on the Monitoring. Set the CPU in Run mode.

The Lamp should light immediately.

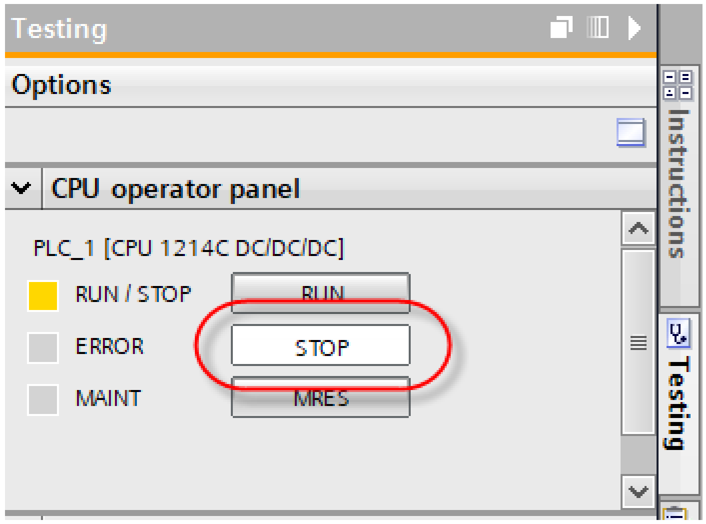


Truth Table:
When the program is running, record what you see in the chart below. When writing logic, the switches are represented by the letters A, B, C etc. The output is represented by the letter Y. Click on the SwitchA to toggle it from a 0 to a 1. If you see a 0 in the chart, it means the Switch should be off. Observe the Logic lamp. If the light is off, place a 0 in the logic column. If the light is on, place a 1 in the logic column.

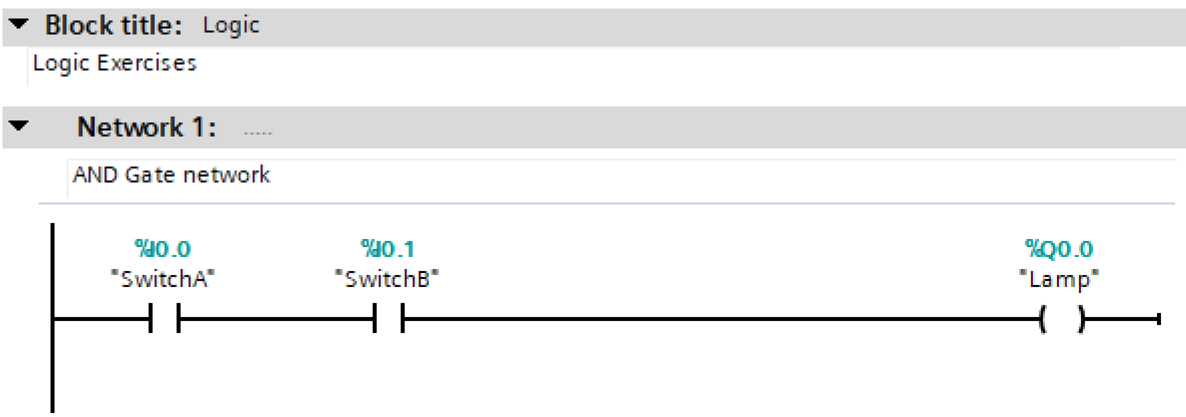
NOT	
A	Y
0	
1	

Boolean Expression:
A Boolean Expression is a mathematical expression detailing the relationship between the inputs and the outputs. It is written in the form of the Output equals the Input that caused the output. The Input in our example is called A. Since A has two states we call it A when the input is High and NOT A or A Not when the input is Low. We write NOT A by placing a bar over the letter. $(\bar{A})$
In our example the Output is called Y. From your Truth Table above you must determine the formula. Circle the correct one below and cross the other out. Ask yourself was the Y Lamp lit when A was pressed or not pressed.
$Y = A$
$Y = \bar{A}$

Place the CPU in the stop Mode and take the CPU offline.



AND Gate:
Change network 1 to resemble the network below.



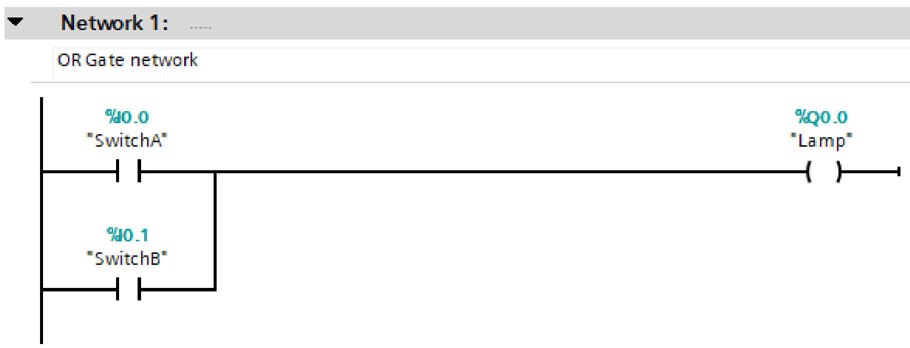
Download to the CPU. And place it on line. Start the CPU again. When the program is running, record what you see in the chart below. Click on the Switches to toggle the value from a 0 to a 1. (off to on). There are four possible combinations. If you see a 0 in the chart that means the switch should be off. Observe the Logic indicator. If the light is off place a 0 in the Y logic column. If Y is on, place a 1 in the Y logic column.

AND		
A	B	Y
0	0	
1	0	
0	1	
1	1	

Boolean Expression:
Since there are two inputs there are more possibilities for the Boolean expression. From your earlier research you found out that we are interested only in the value of the Inputs when the Output is high. Write the Boolean expression for the AND gate below.

Stop the CPU and take it off line.

OR Gate
Change network 1 to resemble the network below.

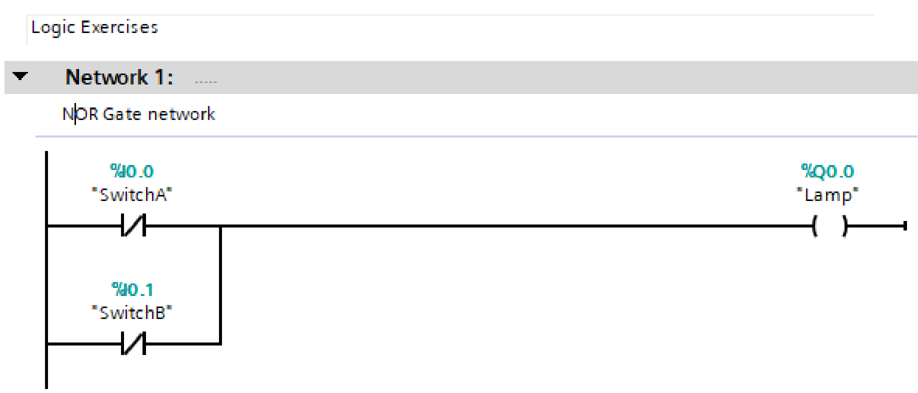


Download to the CPU and run the program. Repeat the process with the Switches and fill in the OR truth table and write the Boolean Expression for the OR Gate.

OR		
A	B	Y
0	0	
1	0	
0	1	
1	1	

Boolean Expression:

NOR Gate
This logic is called a NOT OR or NOR for short. Create the following network.

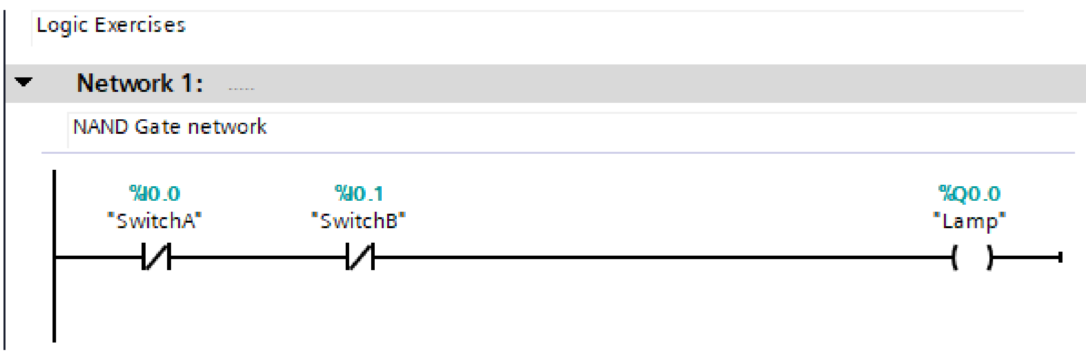


Repeat the test to discover the truth table. Record it below. Write the Boolean expression next to the Truth Table.

NOR		
A	B	Y
0	0	
1	0	
0	1	
1	1	

Boolean Expression

NAND Gate
This logic is called a NOT AND or NAND for short.

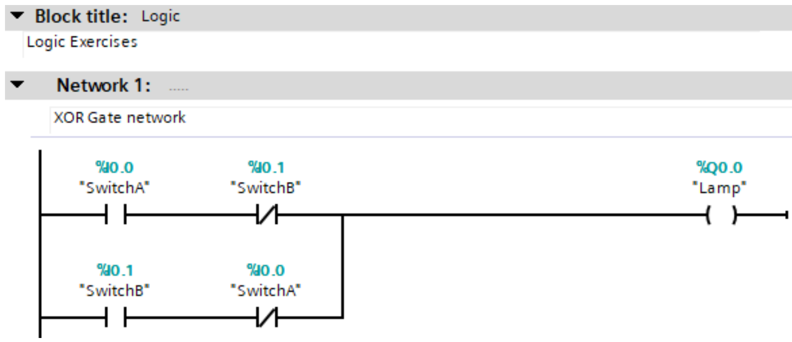


Repeat the test to discover the truth table. Record it below. Write the Boolean expression next to the Truth Table.

NAND		
A	B	Y
0	0	
1	0	
0	1	
1	1	

Boolean Expression

Exclusive OR Gate
This logic is called an Exclusive OR or XOR for short. Create the following network.



Repeat the test to discover the truth table. Record it below. Write the Boolean expression next to the Truth Table.
.

XOR		
A	B	Y
0	0	
1	0	
0	1	
1	1	

Boolean Expression

Back

Truth Table to Ladder Logic
As you begin to see logic as it relates to ladder logic you can begin to make a truth table for what you want to happen. They will help you simplify logic and define what you want to happen. Consider the following Truth Table

A	B	C	D	Y
1	1	1	1	0
1	1	1	0	0
1	1	0	1	1
1	1	0	0	0
1	0	1	1	0
1	0	1	0	0
1	0	0	1	0
1	0	0	0	0
0	1	1	1	0
0	1	1	0	0
0	1	0	1	0
0	1	0	0	1
0	0	1	1	0
0	0	1	0	0
0	0	0	1	0

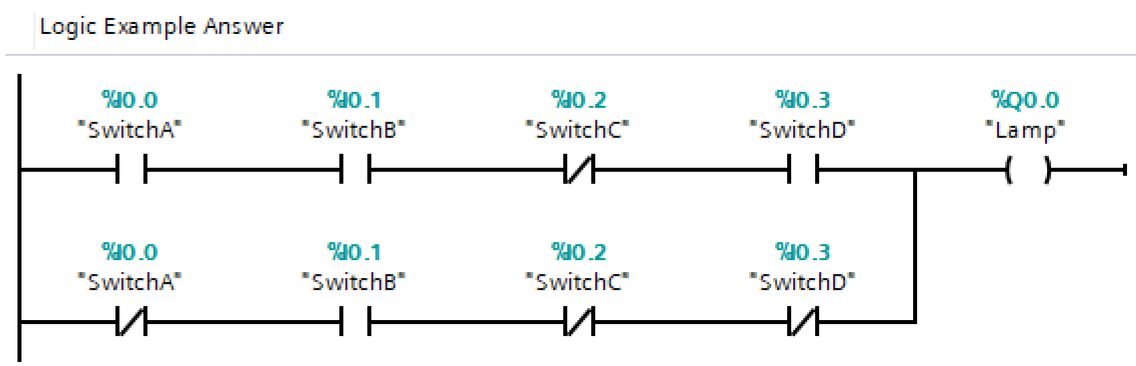
0	0	0	0	0

We could write an expression for each case. Since we are only interested in places where we want an output, we can eliminate anything where Y=0. Looking at the table, there are only two logic combinations where we want an output.

Those would be $AB\bar{C}D + \bar{A}B\overline{CD} = Y$.

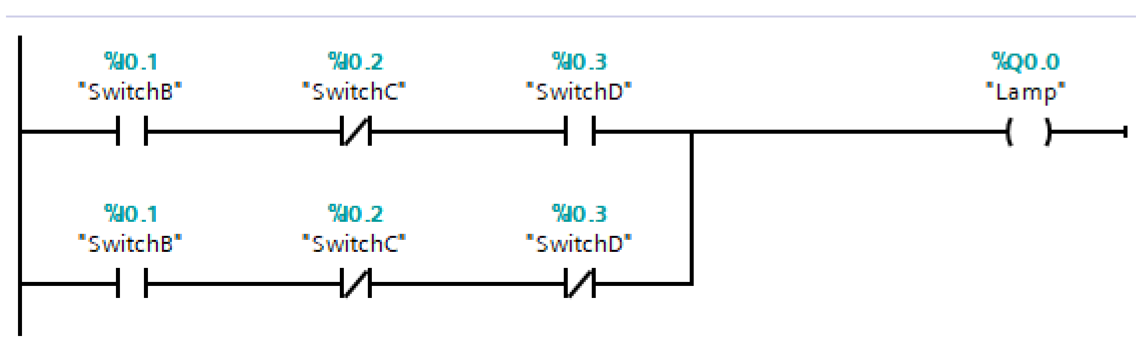
You would pronounce this as A and B and not C and D OR not A and B and not C and not D.

Write a network that would do that. Yours should look like the one below



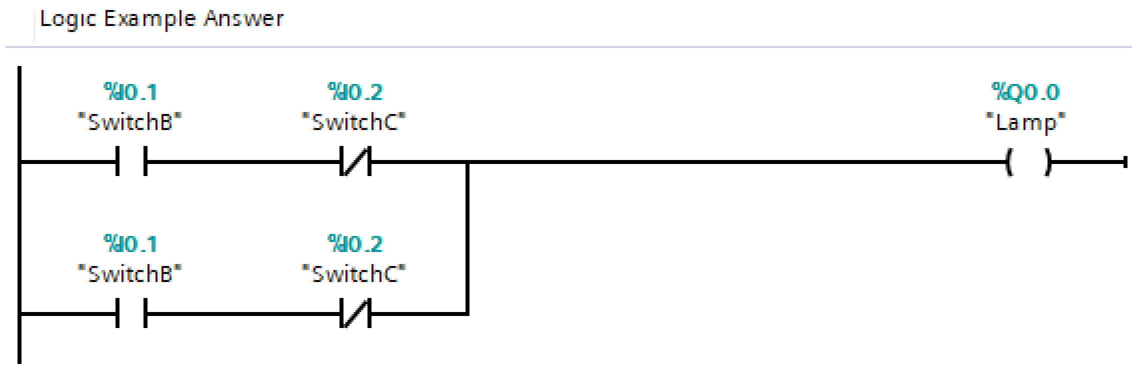
Download to the CPU. And place it on line. Start the CPU again.
Compare the results to the original truth table. When you are satisfied it matches the truth table take the CPU off line again.

We could further simplify the logic. If you look at the network you created, one branch has A while the other has not A. It doesn't make any difference if A is high or low. In logic we call this a Don't Care. We can simplify this by eliminating the A from the equation. Your new network should resemble the one below.

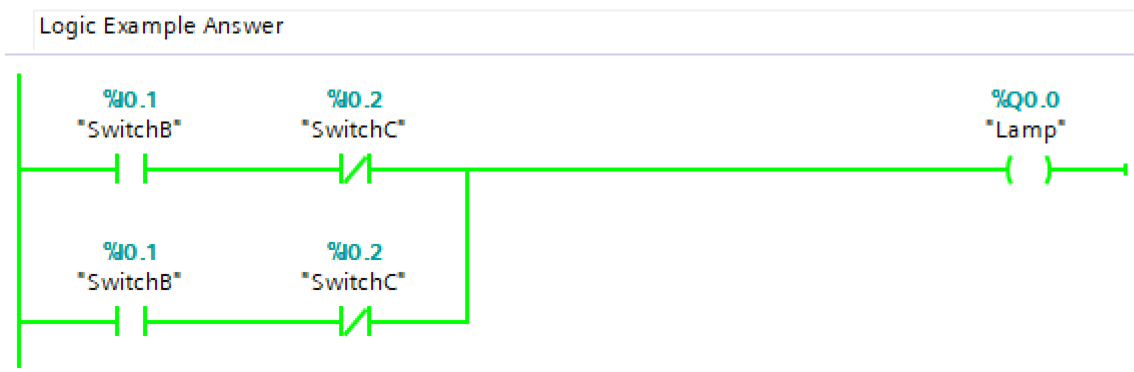


Test this one out. Do the outputs still match the truth table?

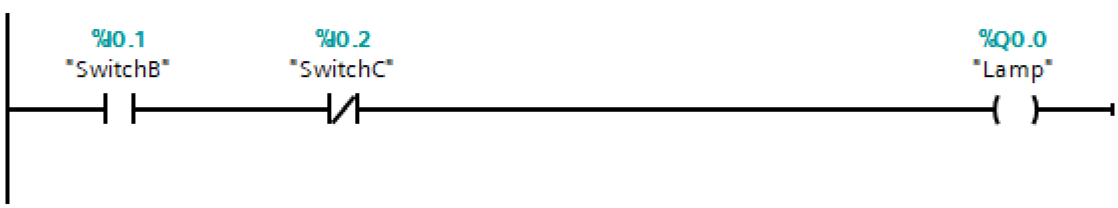
If you look at the network above, you see element D is also a Don't Care situation. Rewrite the network.



Does it still match the truth table?

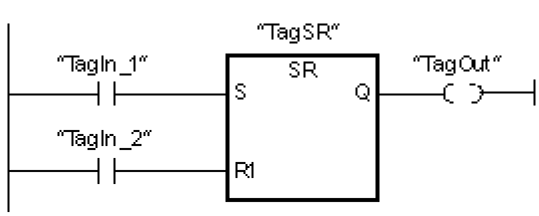


Since you can eliminate any term that is in a don't care situation we can say the new equation is $B\bar{C}$. So we can further simplify the network by removing the duplication.

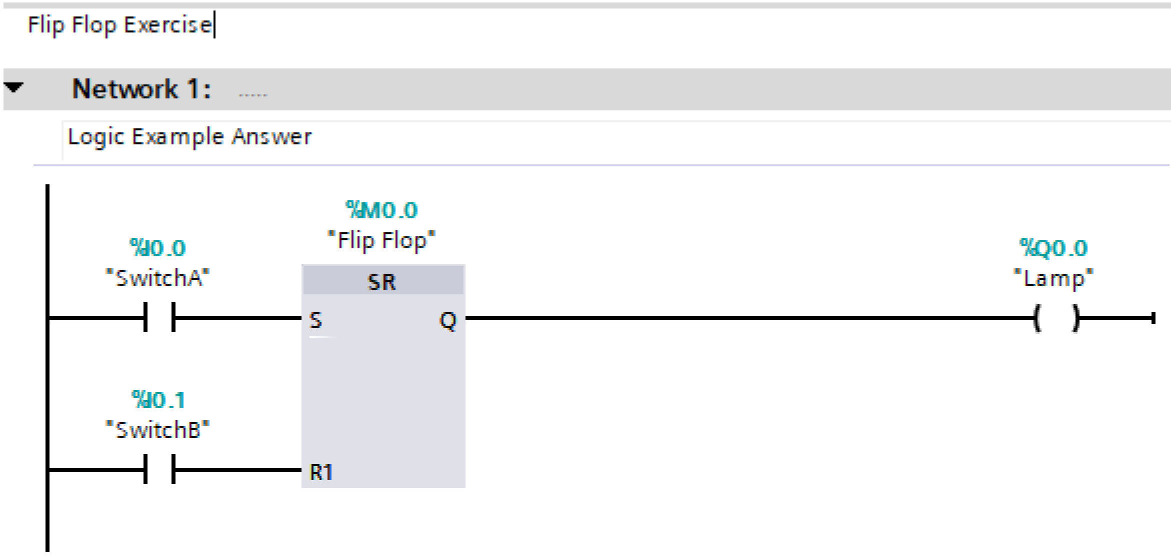


SR Flip Flop

You used an SR flip flop in an earlier exercise. If you look up the SR flip flop from the help information system you see the diagram



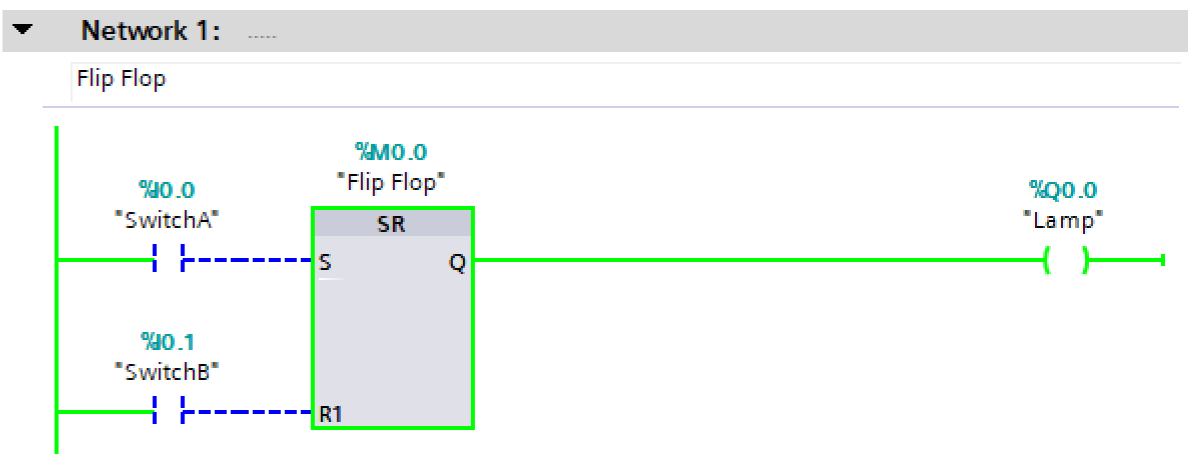
Tagin_1 and Tagin_2 are Boolean inputs. TagOut is an output. Create the following network.



Comparing the network to the help menu we see that SwitchA is the Set input and SwitchB is the Reset input. Lamp is our output. Download the network to the PLC and place it on line and run the program.

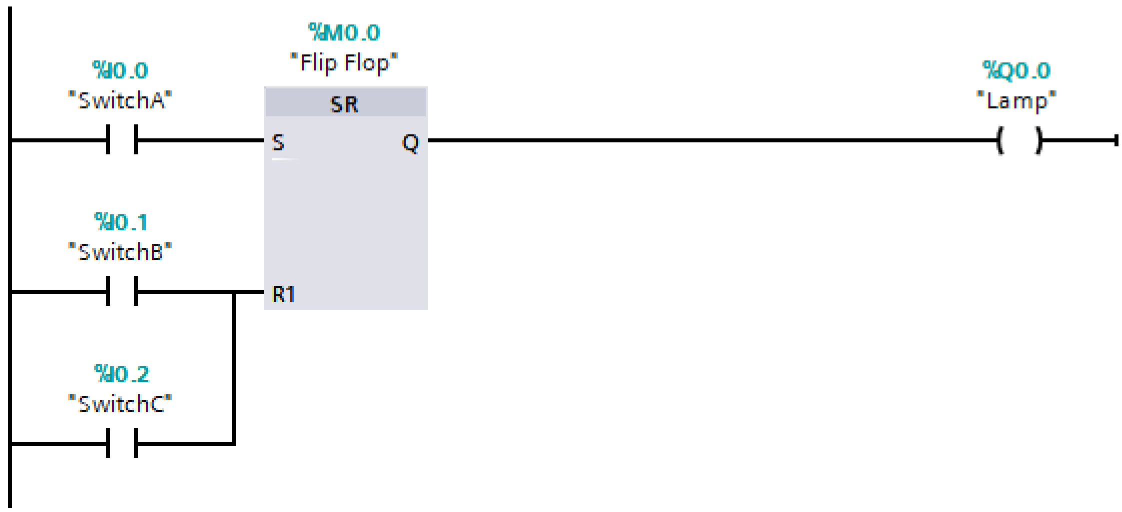
Press SwitchA and observe what happens.

Even after you let off of SwitchA the output keeps running.

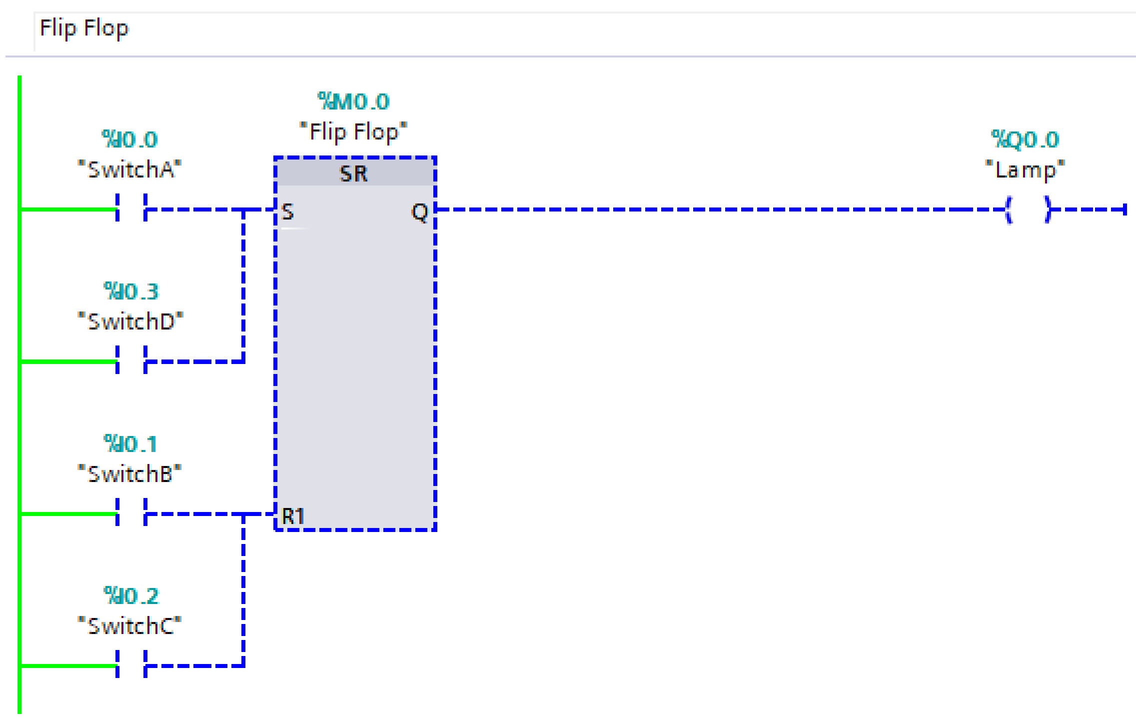


To shut the output down select Switch B.

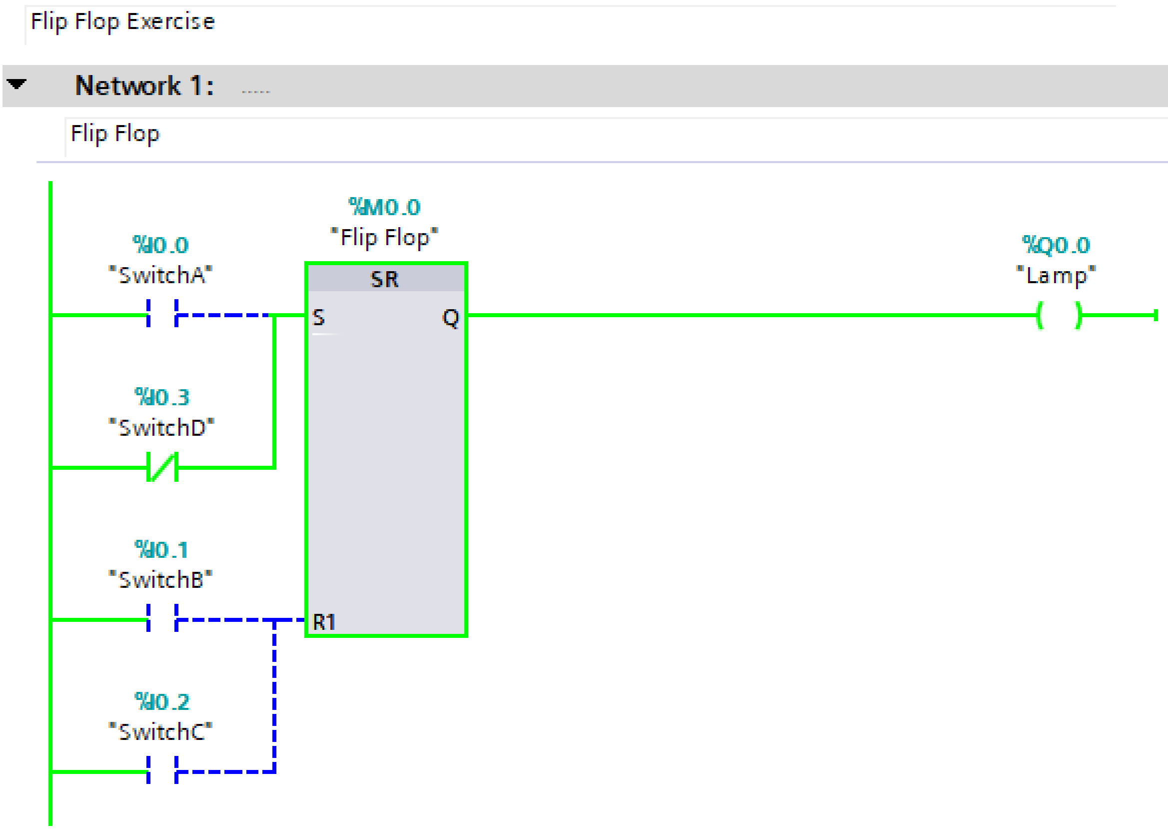
If you think about this as a conveyor control we would want the conveyor to run until we tell it to stop. There are several things that might cause it to stop. An Emergency switch would be one, but suppose there is a sensor that would cause the conveyor to stop in a certain position. Thinking in Boolean terms we want to stop the conveyor when the emergency switch OR the sensor switch went high. Create the following network.



Run the network and assure that either Switch B OR Switch C will reset the flip flop stopping the conveyor. In the next network we will add Switch D to the network. Switch D will represent a clamping system.



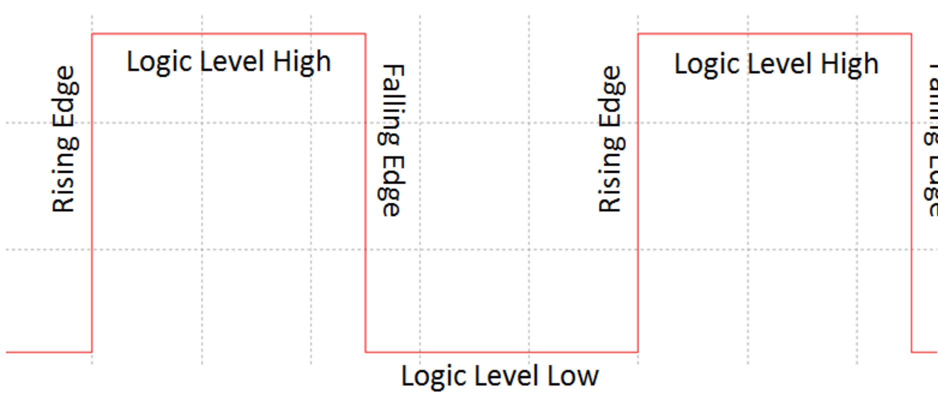
So now either Switch A or Switch D will turn the conveyor on and B or C will turn it off. If we only want the conveyor to begin when the clamping system releases but not while it is engaged we could try the logic not SwitchD.



Unfortunately the conveyor will now always run. In this case we are looking at the wrong piece to trigger the logic.

Back

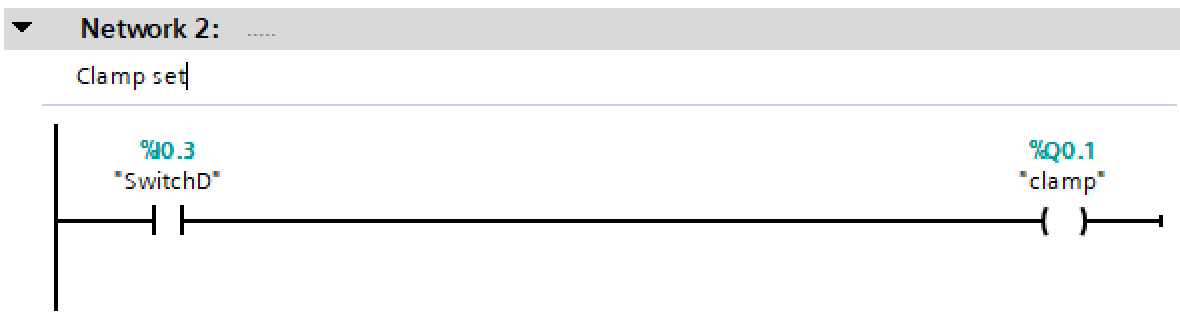
Edge Triggered vs. Level Triggered
Triggering is the process of making a branch of the program active when it receives the expected digital input. This means the program will perform a function once the trigger is activated. There are important differences in the effects of the triggering process. The first is level triggering. In level triggering the branch occurs when the desired level of input is present. This can be a logic high or low. Edge triggering the circuit becomes active when the triggering input goes from low to high or from high to low.



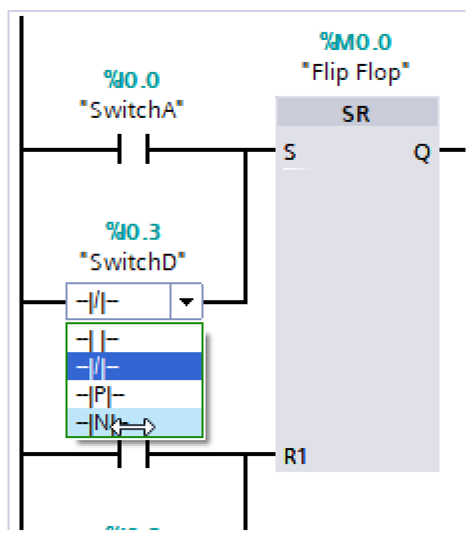
The picture above depicts the logic waveform from a switch as it changes states. The logic levels are Low (0) and High (1). The transitions between the levels are the edges of the waveform. The rising edge is going from Logic Level Low toward Logic Level High. The Falling Edge occurs when the logic transitions from High to Low.

Continuing on from the example above, imagine when the clamps set by SwitchD release. That is the point when we want to start the conveyor again.

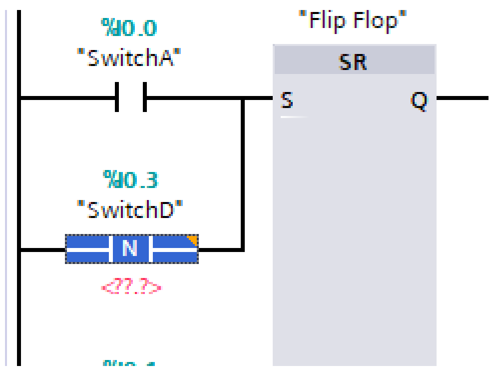
Add a second network. In this one, SwitchD is causing the clamps to lock.



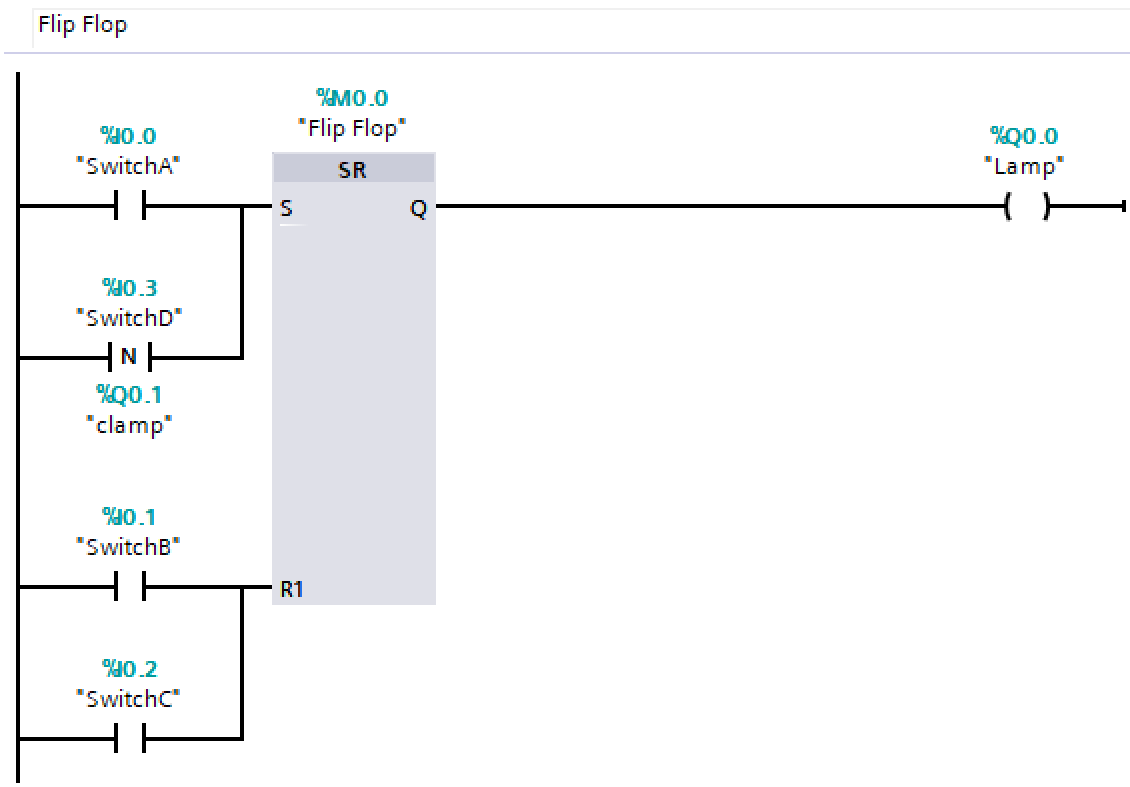
In the first network left click on SwitchD. You will see several choices. Select the choice for Negative (N) or falling edge.



Once it is created it wants to know the input Boolean location.



In this case Clamp is selected. It will only give us a signal when the clamp is released.



Download to the device. Run the program. Hit SwitchA to turn the conveyor. Select SwitchC to stop the conveyor in the correct position. Hold Switch D in for a few seconds to simulate the clamping system running. When you let go of SwitchD the conveyor motor should begin again. In this case the conveyor motor is represented by the lamp.

Back

Designing Programs for Problems

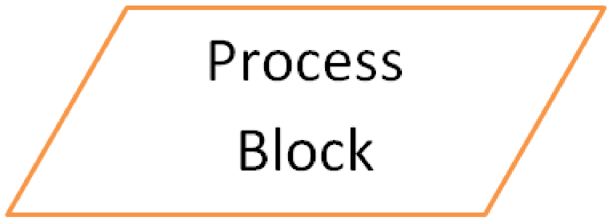
Once your programming tasks become more complicated, the planning for the creation of the logic and program flow is more difficult. It is important to begin with paper and pencil to record what you want to happen and when. Once that step is accomplished most people find graphic organizers are very helpful to see what should be happening. Below are two different ways you might find helpful. It should be noted there is no one correct or perfect way to solve problems. The following exercises are presented in order to help you organize your thinking.

Flow Charts

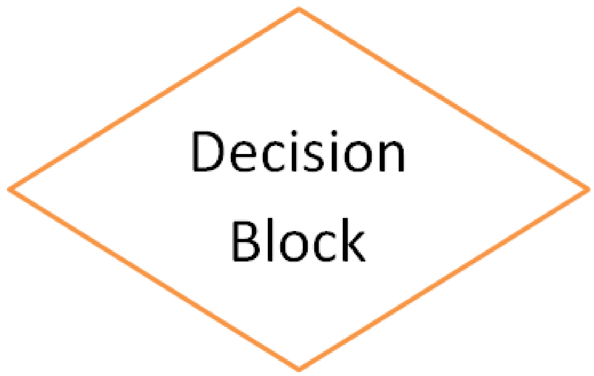
Flowcharts are a graphic representation of an algorithm, often used in the design phase of programming to work out the logical flow of a program. Flowcharts use simple geometric symbols and arrows to define relationships between elements. This visual representation of the flow of a process helps organize thinking. The program designer knows where decisions need to be made and can identify what processes are conducted and in what order. Flowcharts are also used in other design work to explain complex processes and as an aid in quality control. This activity will introduce you to flowchart symbols. Each symbol represents a program command.

While there are numerous symbols used by professional programmers this exercise will concentrate on the ones used most often. You should familiarize yourself with the basic shapes and what they represent.

The Terminator block is used to indicate the Start or End of a program.



The process block represents a Process that occurs. This might be turning a motor or lamp on, getting the value of a variable, or setting input or output pins.

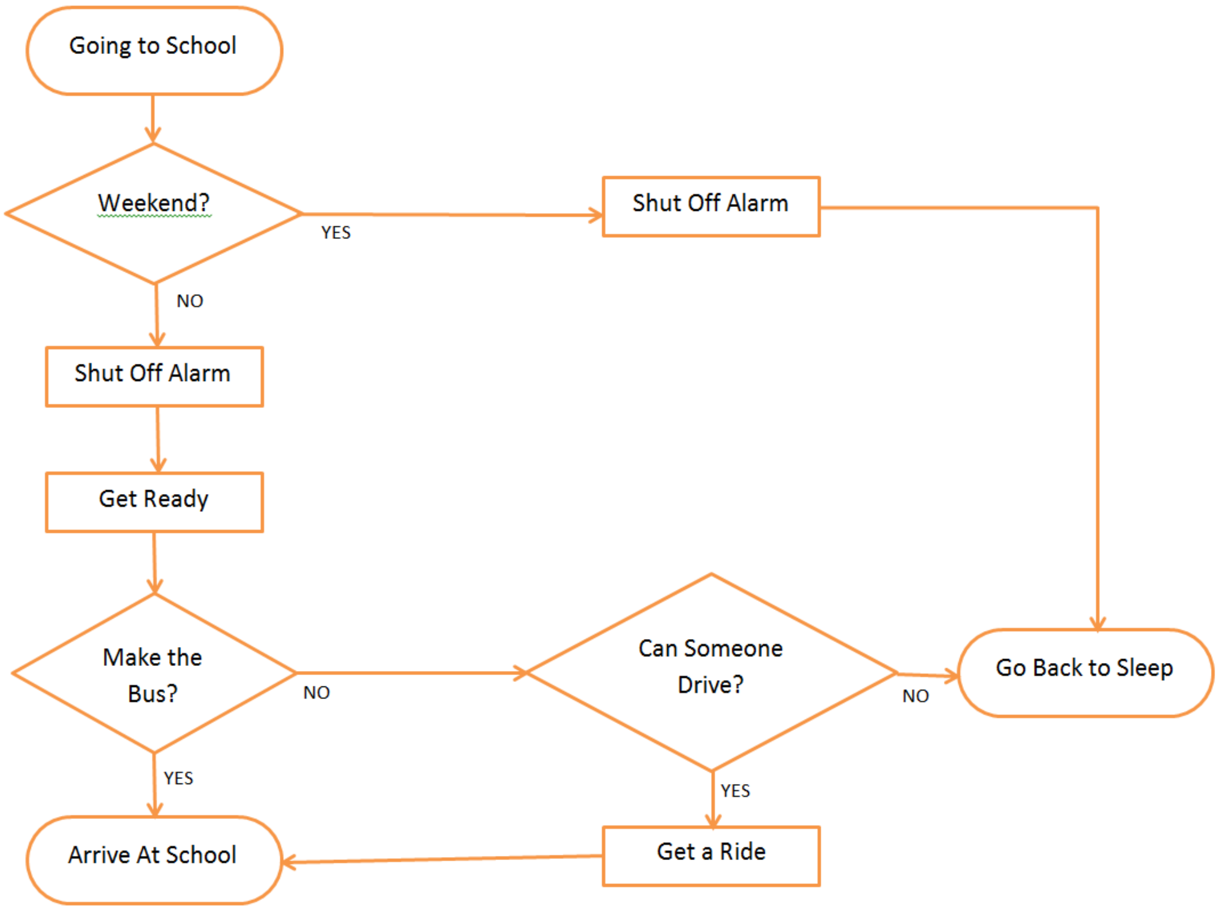


The Decision block is used to branch the program after comparing variables or checking the position of switches.

Data blocks are used to assign variables and to set parameters. This shape is also used for assigning inputs and outputs to variables as well as defining delays.

Blocks are connected by arrows called Flow Lines which show how the blocks connect together.

Review the flow chart that follows. Step through it to follow the logic it is depicting.



What is the eventual course of action if it is the weekend?
If it is not the weekend and you missed the bus what is your next action.

Conclusion:

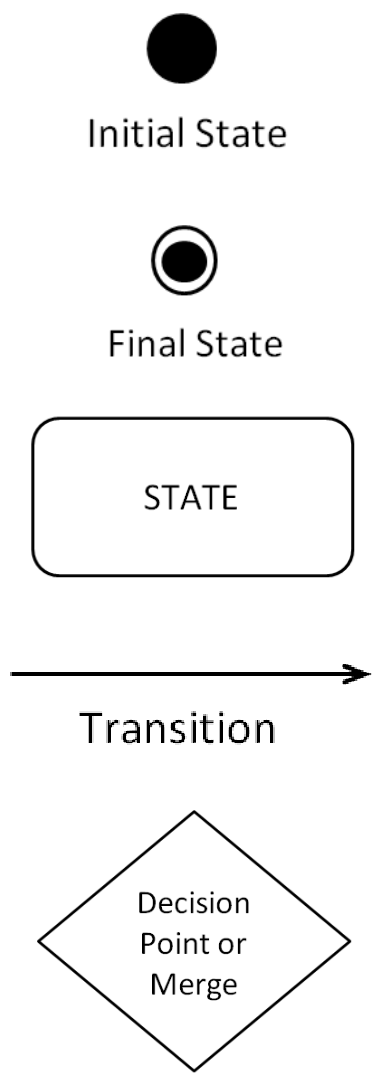
Using the information from the flowchart section above prepare a flow chart for each of the following problems and attach them to this sheet.

1. Create a flow chart for placing toothpaste on a toothbrush and then brushing your teeth for 45 seconds.
2. Create a flowchart for creating a peanut butter and jelly sandwich.
3. Create a flowchart for helping a three-year-old child put on their jacket.

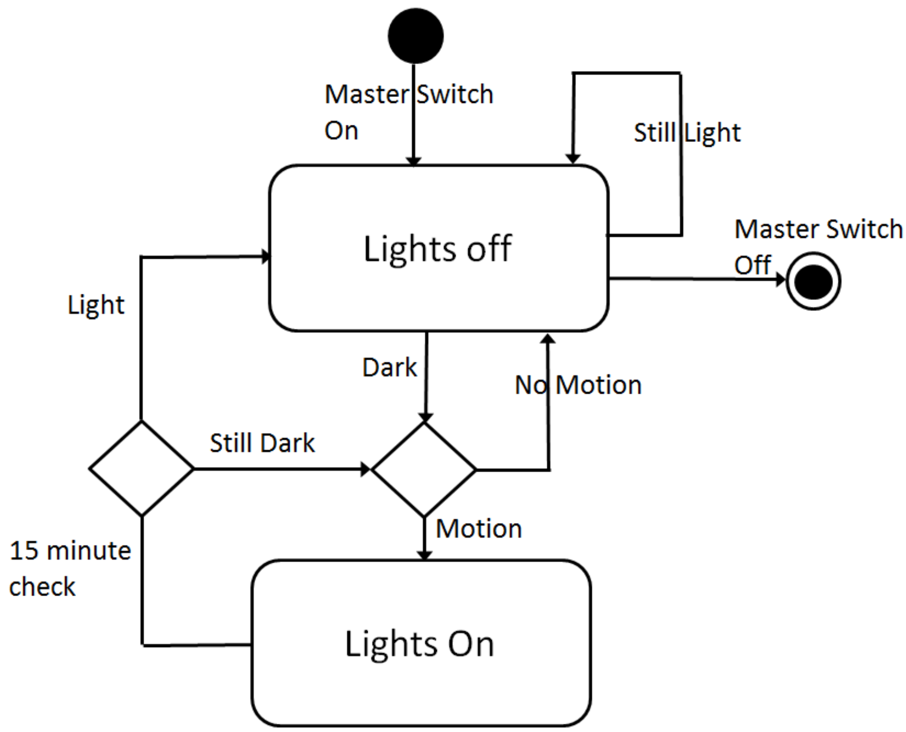
Back

State Machines
State Diagrams are graphic representations of how systems sequentially behave. They depict the flow of control using states and transitions. State Diagrams describe a system as a series of States which perform an activity or wait for an event to occur. The system can only exist in one state at a time. The system executes the current state until a change is initiated by a triggering event or condition that will cause a transition to another state. State machines are used to design programs and sequential logic circuits. Understanding how to draw state machines will help solve more complex programming problems. Since there are many ways to approach any problem state machines can define a system and allow the programmer to focus on transitions and guarding actions. This exercise will help you understand and create state machines to help you design programs to control models, robotics, and experiments.

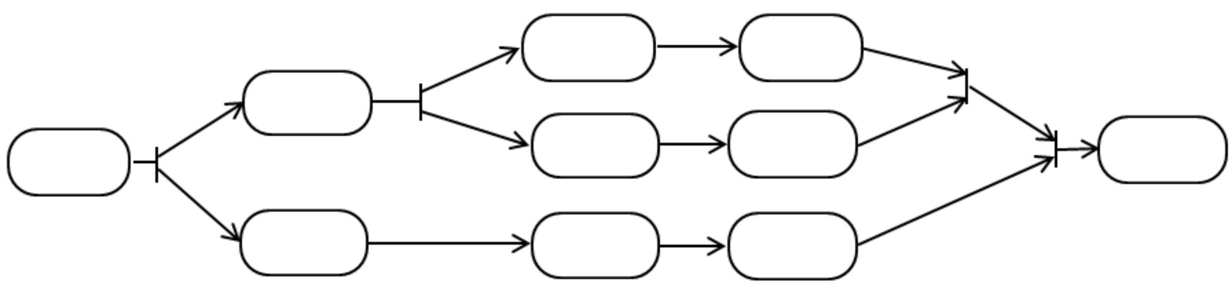
There is a graphical language used in state diagrams. Below are the simple graphics and what they represent:



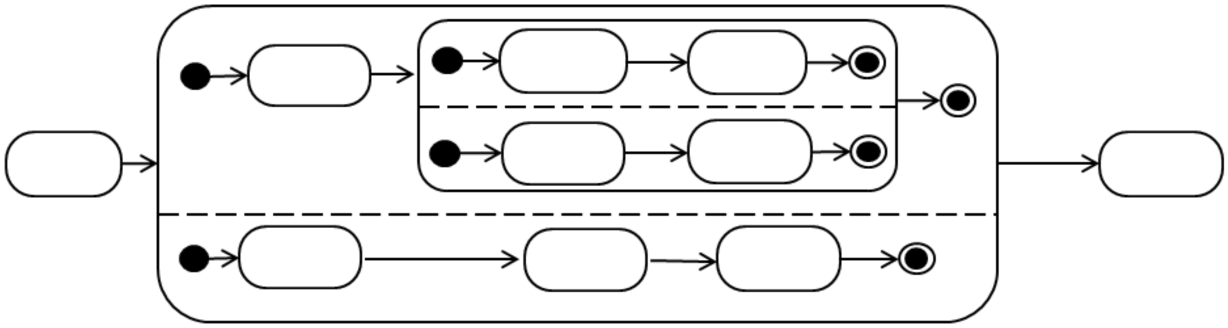
Below is a simple example of what you might create to explain a motion sensing light with a photoelectric eye. This would turn the lights on when it is dark and motion is detected. It would recheck every 15 minutes.



It is possible to clean up complicated diagrams like the one below by nesting them, creating separate state diagrams for each section. This makes them easier to read.



Before and After images of the same diagram. The nested one below allows for better organization.



Conclusion:

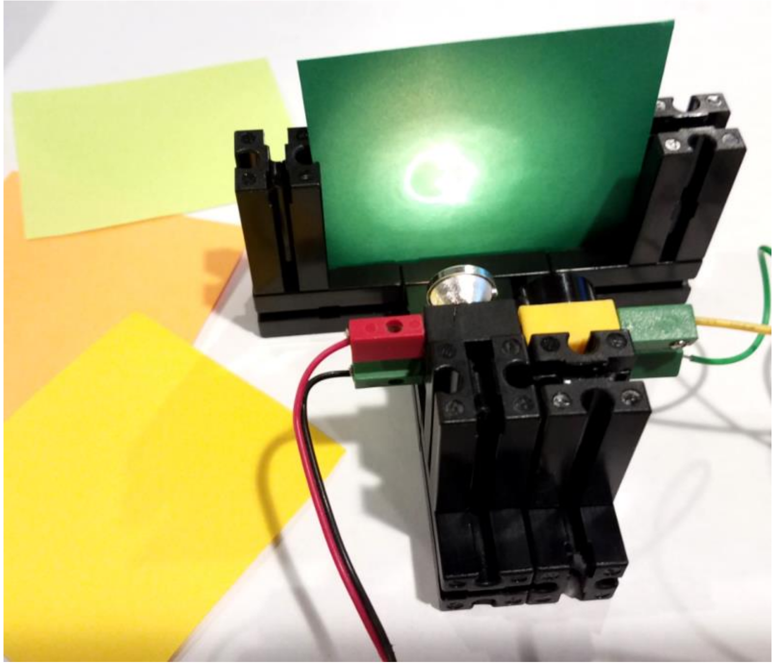
Translating diagrams into ladder logic programming requires a transition event to occur. A machine is in a running state until it pushes a limit switch. When the Boolean signal goes from low to high the state changes and the machine stops. The machine is in the stopped state until the master switch is pushed. The change in Boolean causes a transition event and the machine changes from stopped to running.

Before attempting a difficult program get some experience creating state diagrams.

1. Create a state diagram for the process of buying lunch.
2. Create a state diagram for the lights in a car. Include off, automatic, low beams, driving lights, and high beams. There will be several switches involved.

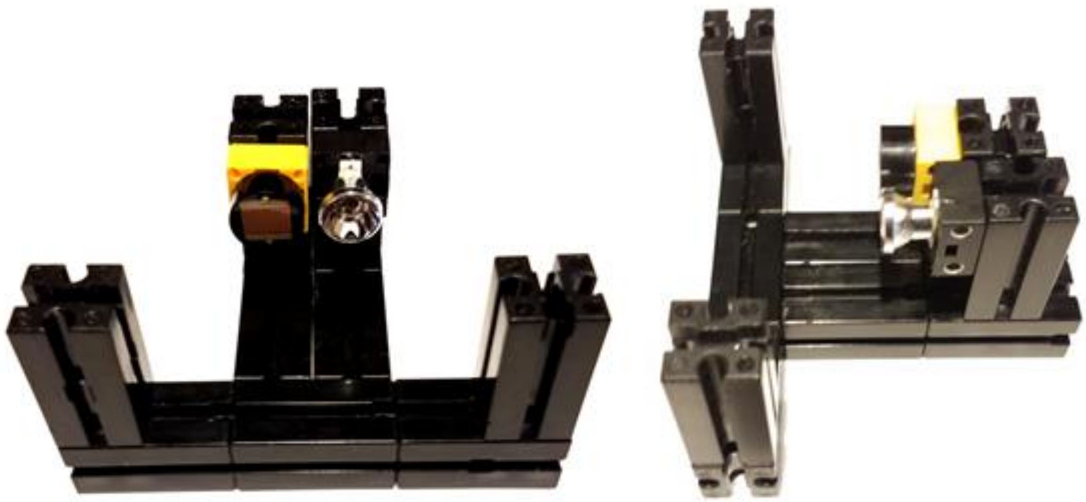
[Back](#)

Analog Inputs



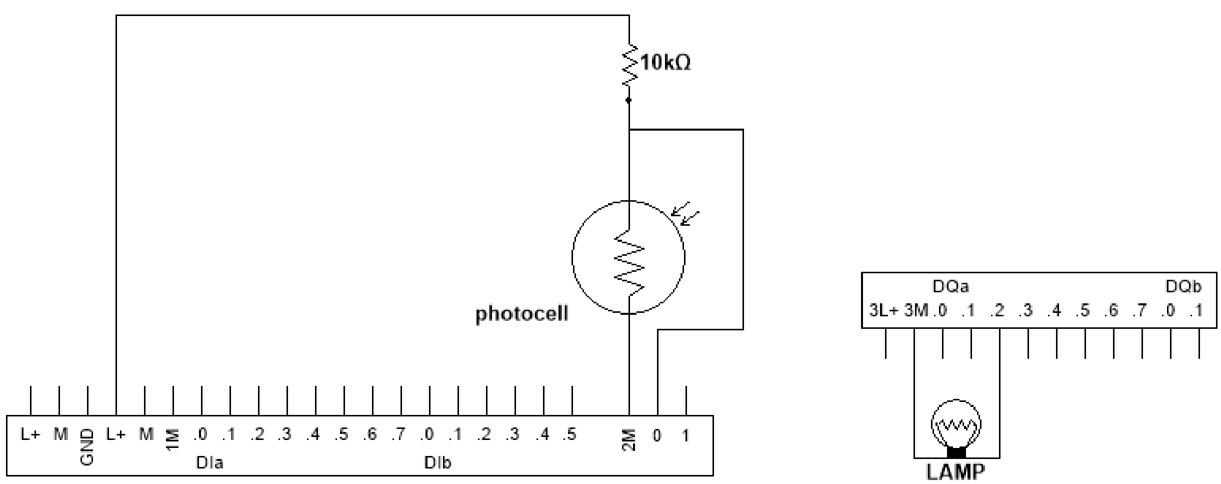
Analog sensors produce a change in an electrical property to indicate a change in its host environment. Most things that we need to measure have a range of possibilities. Sensors are designed so they have a measurement section that is fairly linear but frequently the low and upper ranges of the device are not. It is important to select a sensor of the appropriate range to allow fairly good response to the property being measured. The price will vary on sensors depending on the precision and accuracy requirements of the measurement being performed. There are differences between two sensors made at the same time in the same factory. Because of this difference calibration of sensors is sometimes necessary if exact results are required. The fuel level in the gas tank of a car is important to know so a refueling trip can be scheduled before the automobile stops running. However you might not need to know how many milliliters are left in the tank. Analog sensors are divided into two basic categories; active and passive. Passive sensors react to the world around them and produce a change in a passive electrical quantity, such as resistance, capacitance, or inductance which can be measured. Active sensors actively probe the environment and will require energy from a power source to function.

The Setup
Build the following setup from basic Fischertechnik components.



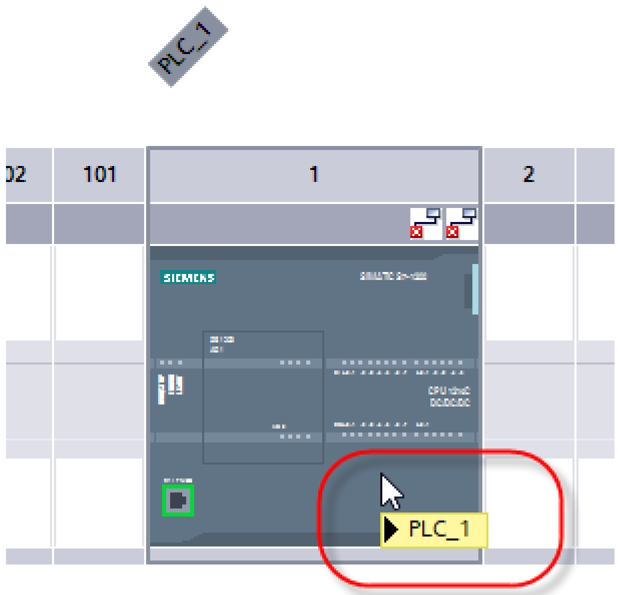
Schematic
In this exercise, the purpose is to wire a sensor to the analog inputs so data can be collected and analyzed. You will be designing a color sensor that can detect different colors. The analog input reads from 0 to 10 volts. The power source of the PLC is 24 volts so a voltage divider needs to be employed to limit the input.

In this example a volt meter was used to monitor the voltage before connecting it to the Analog Input (AI) of the PLC. After some experimentation a 10K ohm resistor is placed in series with the sensor. Measure your setup as all sensors are different. Any sensor used will require some conditioning before being used.

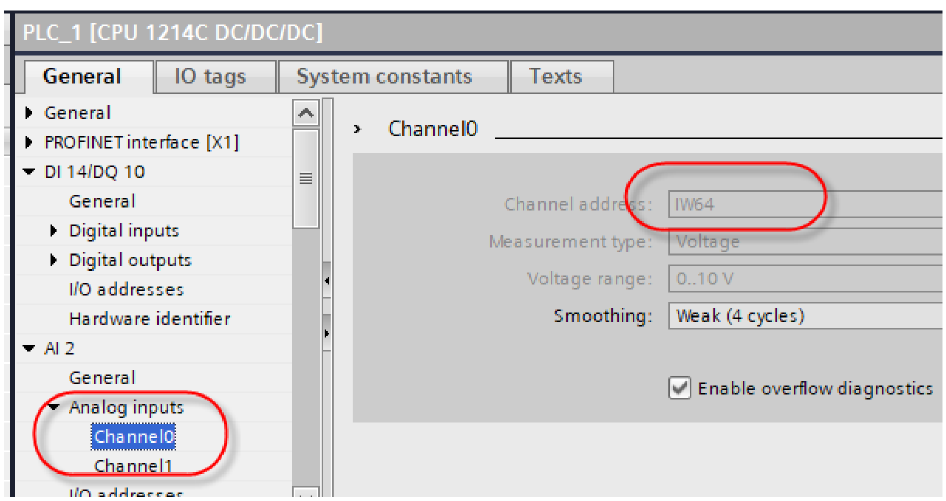


The Program
Begin a new project. Switch to the project view. Place your PLC in the device configuration menu.

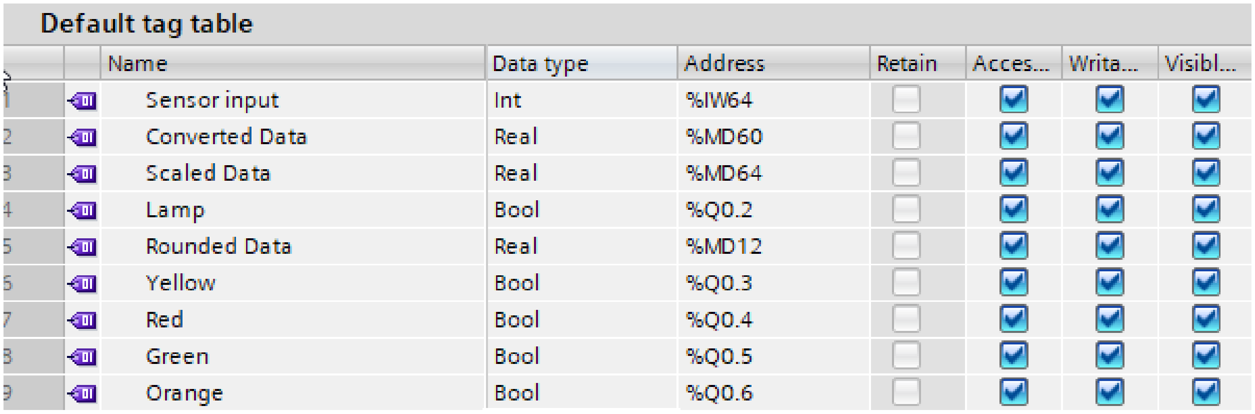
Double click on a blank area of the PLC in the device configuration screen.



This will open the PLC information menu. Expand the AI2 section and the analog inputs section to reveal the settings. Record the channel address of the Analog input. In this example it is IW64.



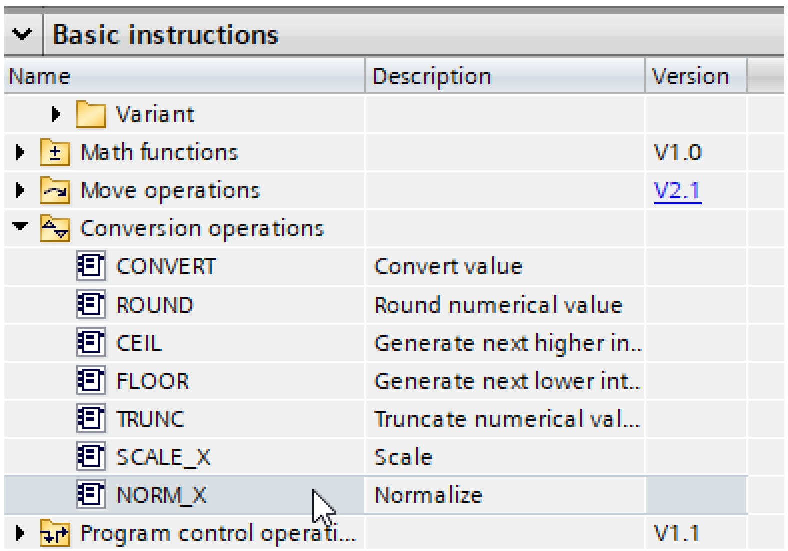
Create the following tag table. Note the first entry. The data type is Integer and the address is %IW64. If your address was different use that one so the program will know how to talk to the input.



Default tag table

	Name	Data type	Address	Retain	Acces...	Writa...	Visibl...
1	Sensor input	Int	%IW64	☐	☑	☑	☑
2	Converted Data	Real	%MD60	☐	☑	☑	☑
3	Scaled Data	Real	%MD64	☐	☑	☑	☑
4	Lamp	Bool	%Q0.2	☐	☑	☑	☑
5	Rounded Data	Real	%MD12	☐	☑	☑	☑
6	Yellow	Bool	%Q0.3	☐	☑	☑	☑
7	Red	Bool	%Q0.4	☐	☑	☑	☑
8	Green	Bool	%Q0.5	☐	☑	☑	☑
9	Orange	Bool	%Q0.6	☐	☑	☑	☑

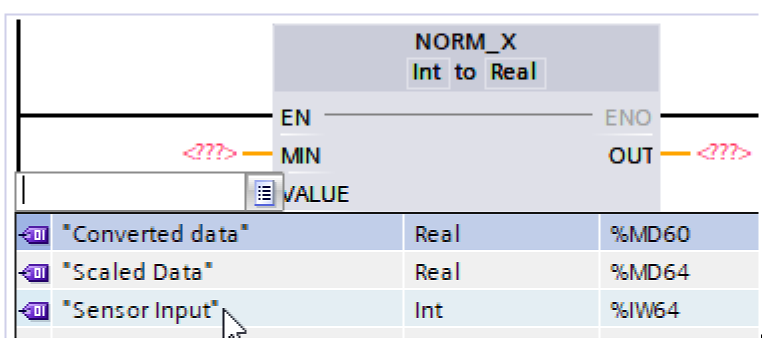
Open the Main [OB1] object block program area. From the basic instructions/Conversion operations area select the Norm_X block.



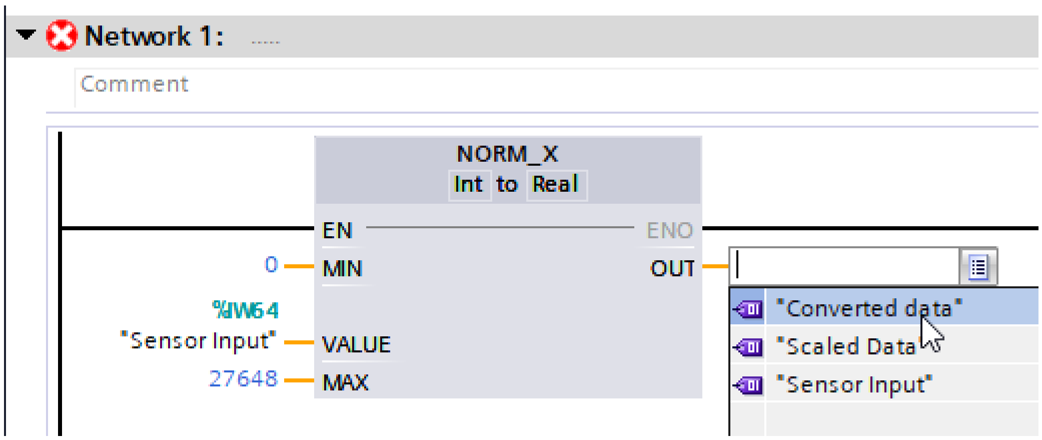
Basic instructions

Name	Description	Version
Variant		
Math functions		V1.0
Move operations		V2.1
Conversion operations		
CONVERT	Convert value	
ROUND	Round numerical value	
CEIL	Generate next higher in...	
FLOOR	Generate next lower int...	
TRUNC	Truncate numerical val...	
SCALE_X	Scale	
NORM_X	Normalize	
Program control operati...		V1.1

The block will take the input from the sensor and then place it on a linear scale between 0 and 1.You can see by the block you need to provide this with some data. The obvious first piece is the analog input. Select INT to Real for the numerical conversion

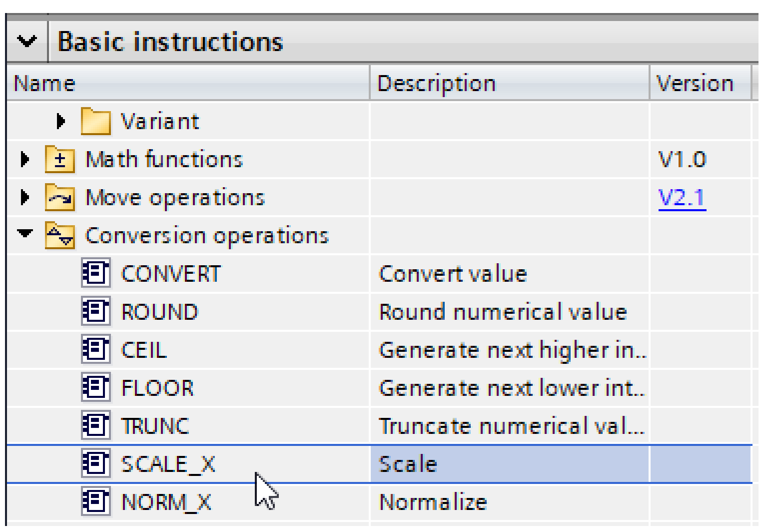


The next step is to define the minimum and maximum values. In this case the minimum value will be 0. The resolution of the block is important. If we have a 1 bit resolution we will be able to see if the voltage is between 0V and 5V or between 5V and 10V. In the case of the PLC we will need a little more accuracy than that. 2 bit resolution will give us 4 divisions. In the PLC we have 15 bit resolution providing 32,767 divisions total before we exceed the range. Typically Siemens recommends using 27,648 as the maximum number of divisions to allow for exceeding the limit before the PLC throws an error. This provides a about .00036 V or about .00072 ma.

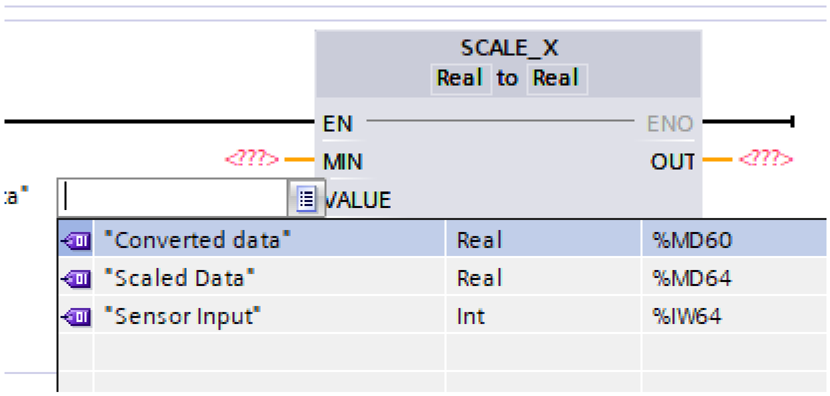


Set the out terminal to the Converted data.

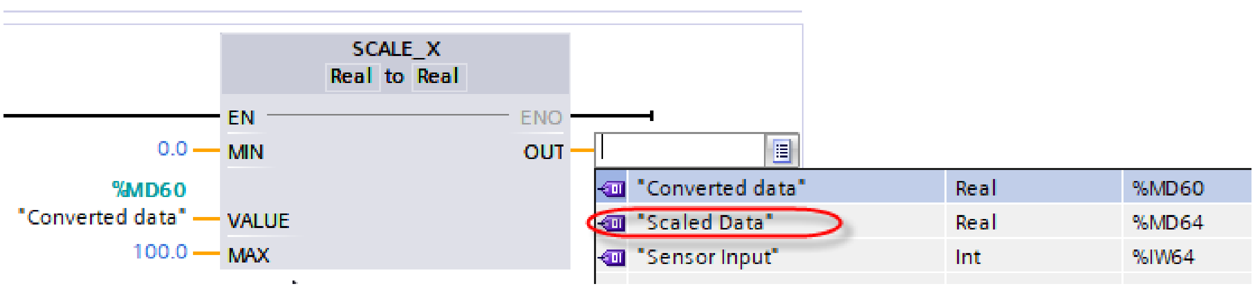
Now the data is normalized, representing a linear arrangement of values between 0 and 1. The scale can be set to a value that will allow us to see and make decisions. The next block to be added is a Scale_X block that will allow the user to create their own scale from the data. The block is found under the basic instructions/conversion operations menu.



Place the block in the first network next to the Norm_X block. Set the converted data from the Norm_X Out. Select Real to Real for the numerical conversion.

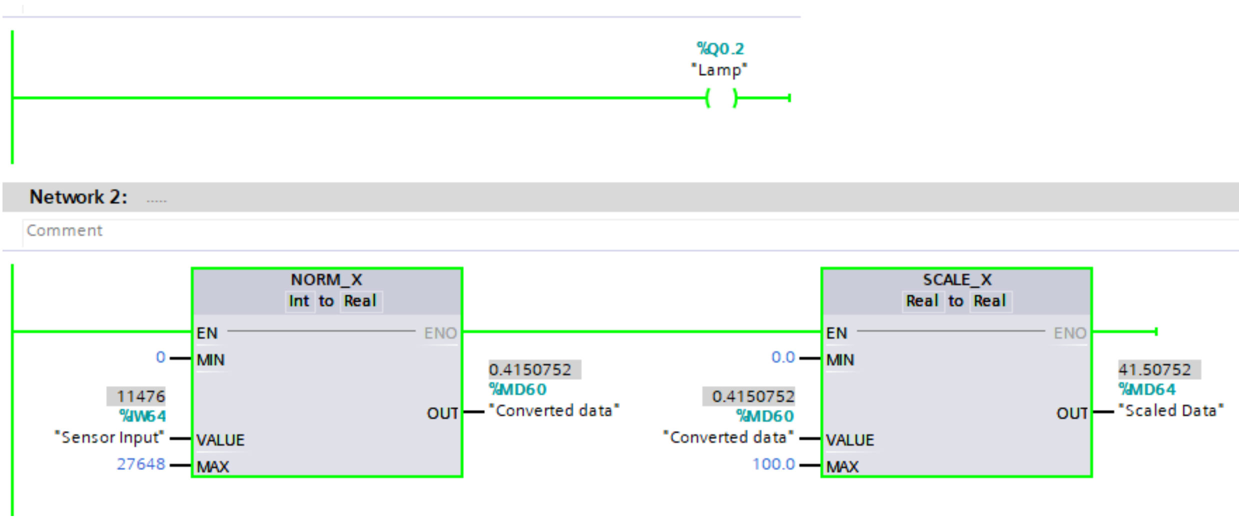


At this point the scale needs to be defined. If using a pressure differential sensor you would want it to convert to pounds for example. In our case we are looking at data from a photocell to make a decision on a color. A scale of 0-100 is set up. The out of the scale block is set to scaled data.

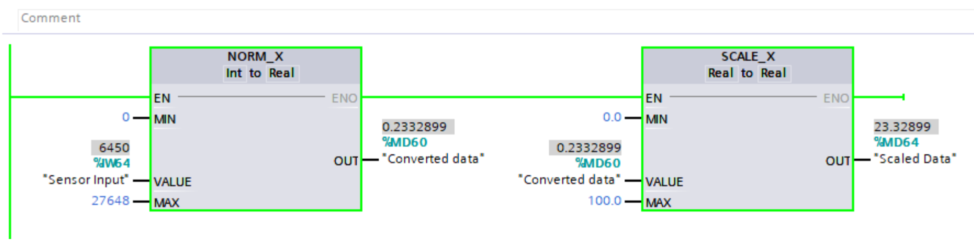


Experimentation with the scale will allow you to observe the output of the sensor in a manner that make sense. Save your project.

Download the program as it exists to the PLC and get it started. Turn monitoring on. Your lamp should light and your sensor should be reading.

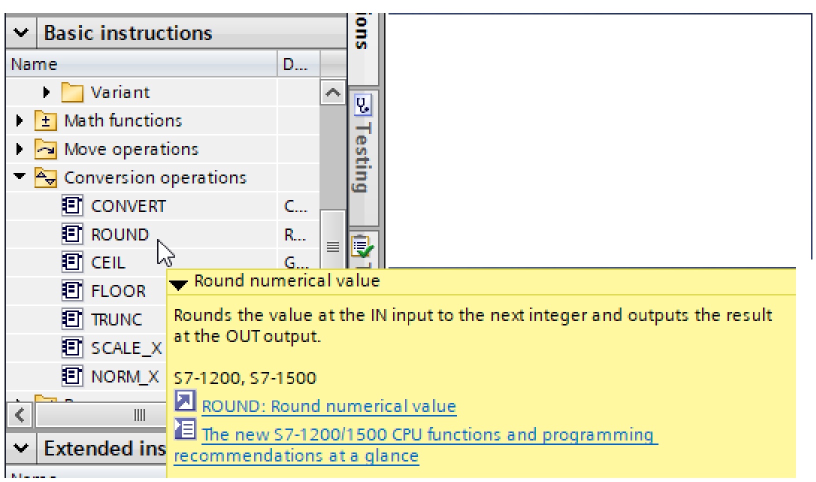


Try different colors in front of the reader and notice the changes.

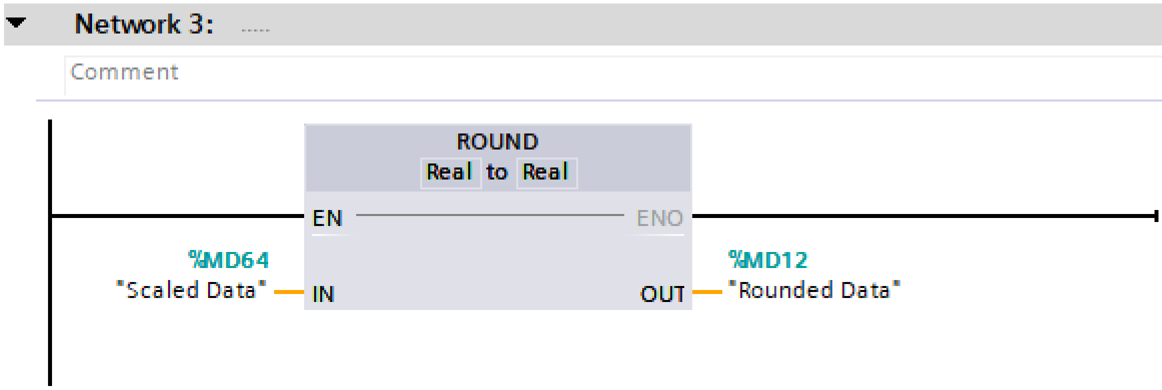


Stop the PLC and take it off line.

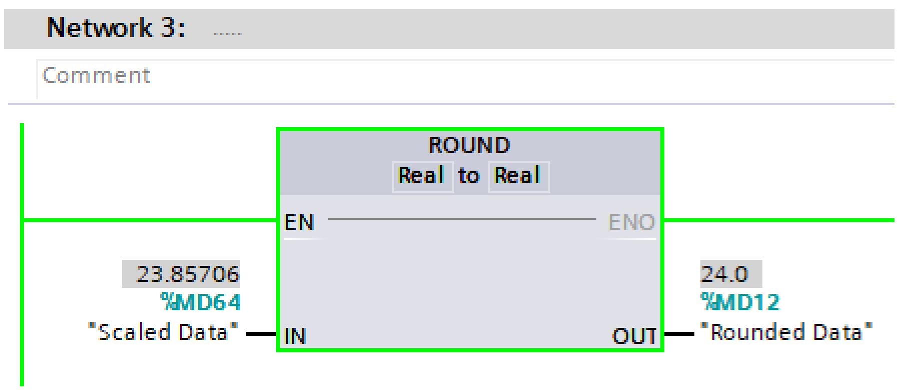
The values reported were to the nearest 100,000th. The constantly changed and it was difficult to see. Begin a new network. Place a Round block from the conversion operations from the basic instructions. This will round off the data to the nearest whole number.



Changed font and pt to match above Set the data type to Real to Real. Select the scaled data for the input.

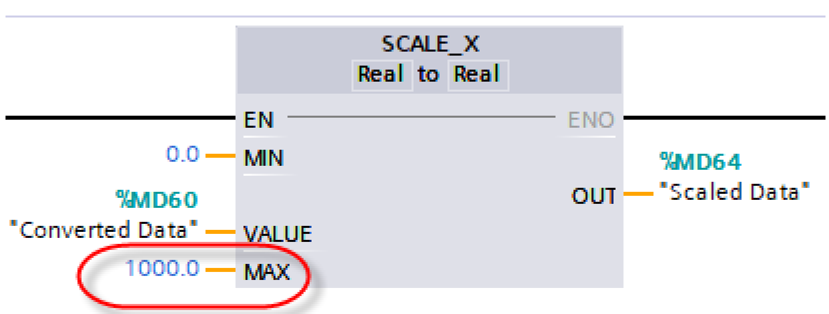


The output should be set to Rounded Data. This will provide data as a single number to make recording levels easier. Download your program again and start the PLC. Use monitoring to see what effect the round block has.



Take individual color strips and place them in front of the sensor and record the value the sensor reports. Stop the PLC. Turn off monitoring.

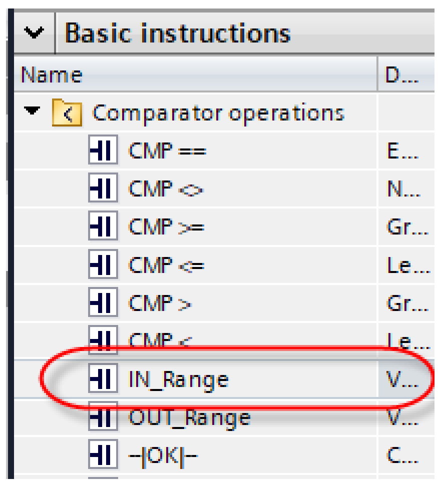
Edit the scale block changing the max value of the scale to 1000.



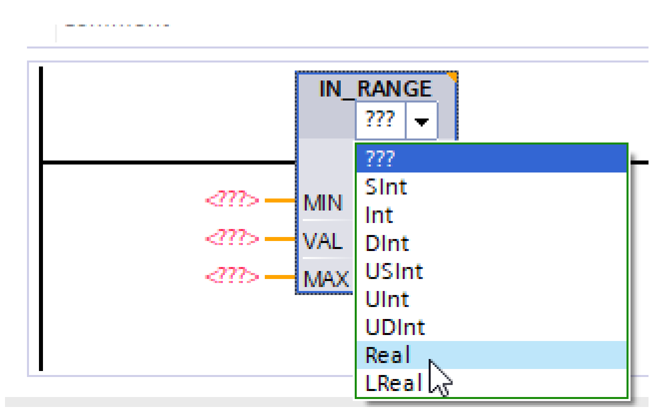
Create a new network. Place an assignment on the network. Select Yellow for the assignment.

When the sensor picks up something yellow in front of it we want this assignment to go positive. In this example the yellow paper caused a scaled reading of 214.5182 which the round block makes into 214. Depending on how close your colors are, you need a range the color will trigger without causing a false positive. In this case we might say any color between 210 and 218 should be yellow.

Place an In Range block from the comparator operations section of the basic instructions.

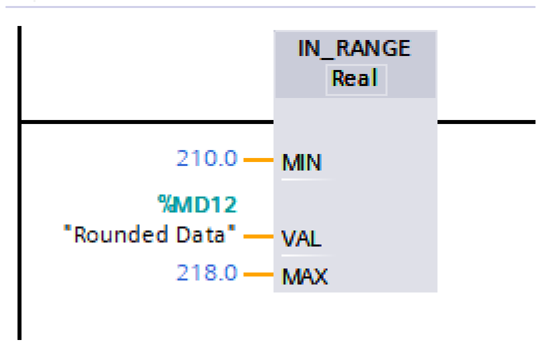


Set the data type to Real.

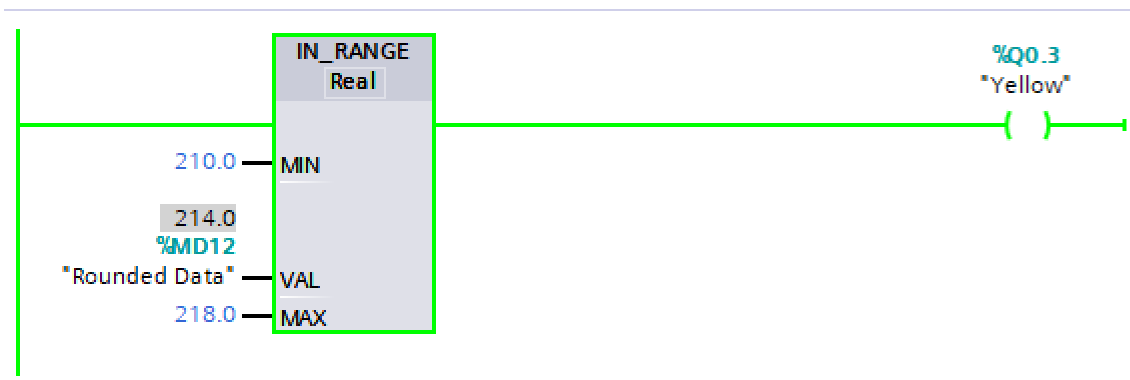


Select Rounded Data for the input to the Val terminal. Once that is in place we can then put in our minimum value and then our maximum value.

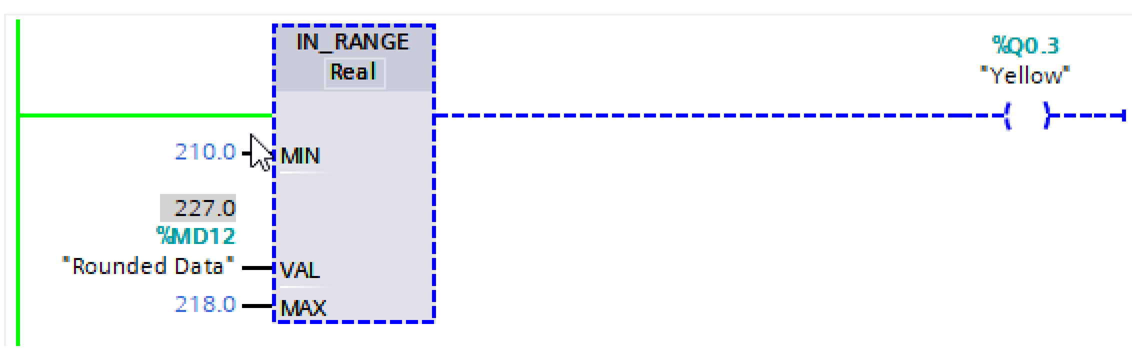
This example will cause the Yellow assignment to go positive when our value is in the range between the minimum and maximum amounts.



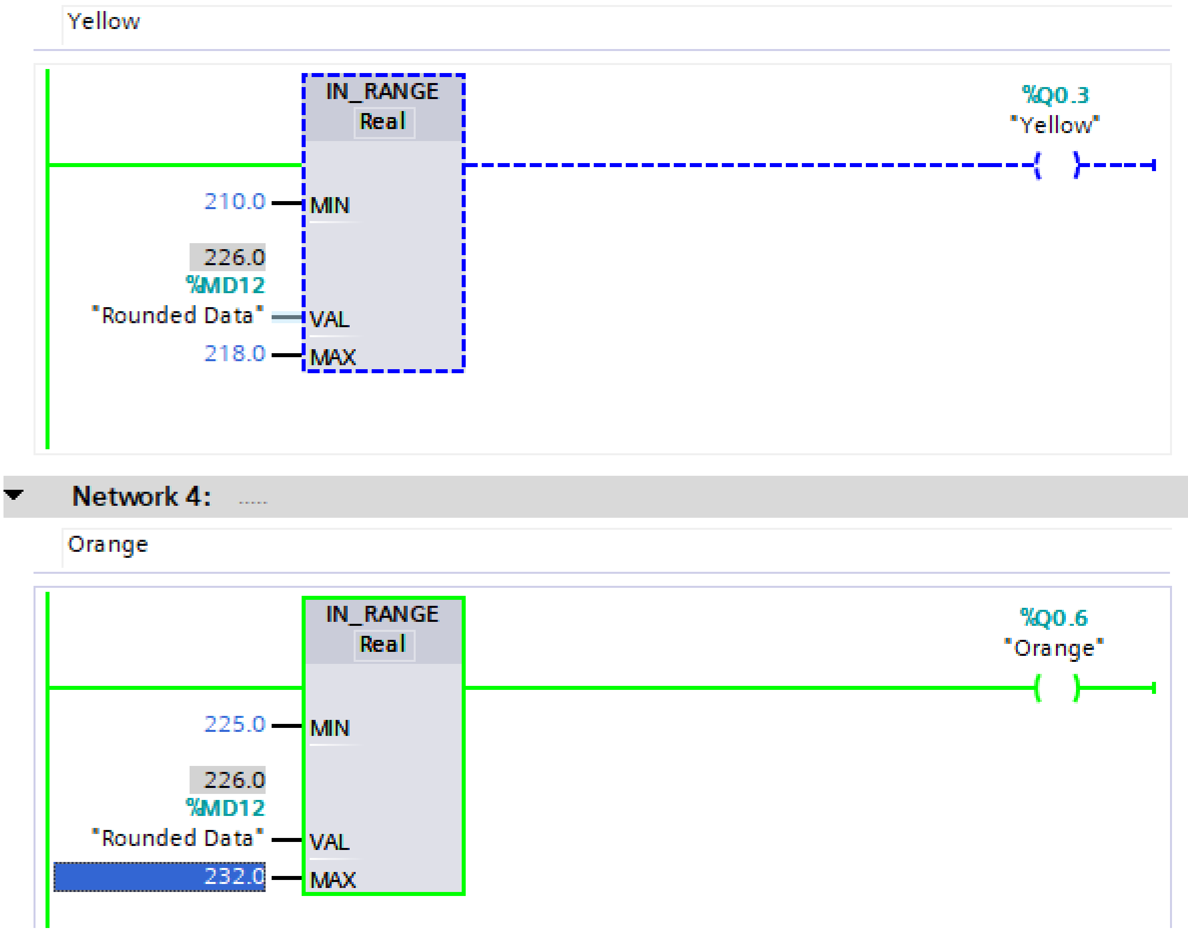
Download the program to the PLC. Start the PLC and turn monitoring on.



If the rounded data is not between the minimum and maximum value the yellow assigned output will be off. In this example a light orange piece of paper gave a reading outside the value. The yellow output will be off.



Stop the PLC. Add a network for every color paper you have. Adjust the settings so you can reliably differentiate the colors.



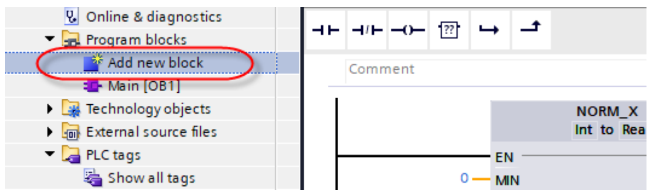
Apply this analog color sorting to a conveyor so different colored items are sorted and placed in the appropriate bin.

Save your project.

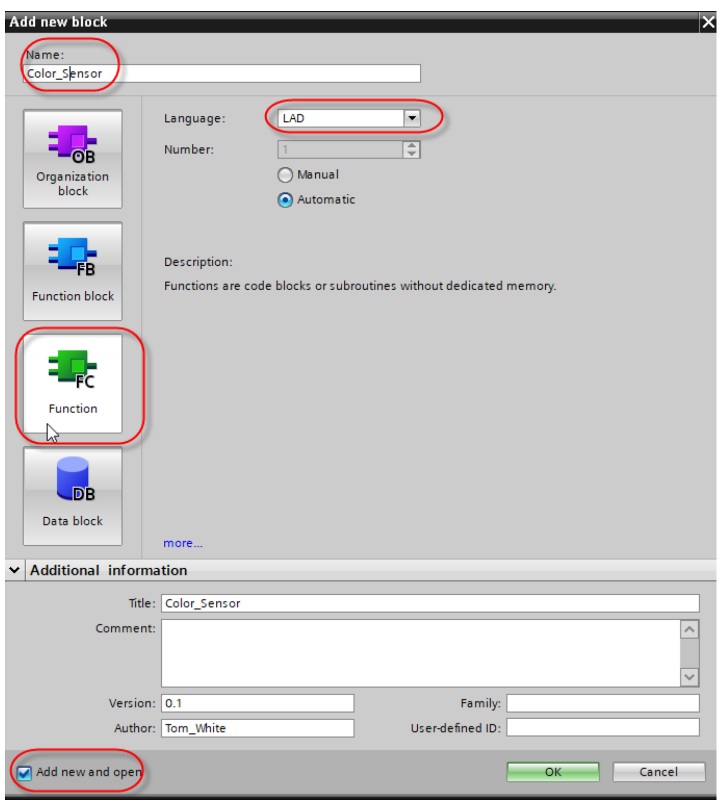
Back

Program Blocks
As your programs get more complex, the main object block gets crowded and much effort is duplicated. You have just finished an exercise using a color sensor as an analog input. In this exercise you will take the work put into creating the color sensor and create a block that can be used in any of your future work. This will save a lot of time and simplify your programs.

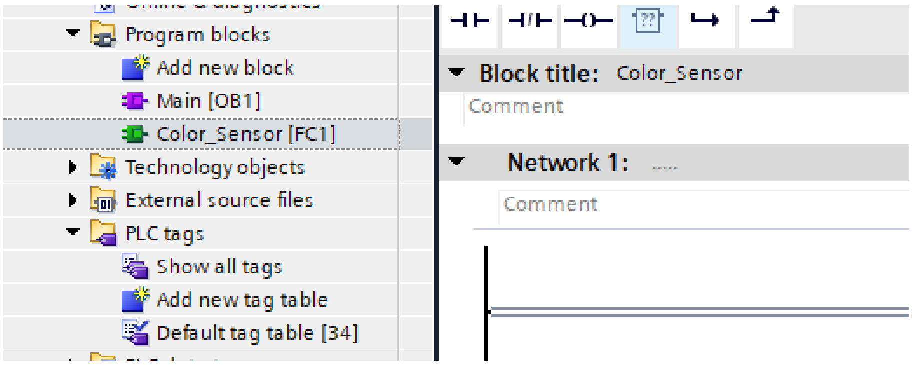
Open the project where you designed the color sensor. Set the view to project view so you can see the PLC_1 in the project tree. Expand the PLC_1 and then expand the program block section. Double click on the add new block option.



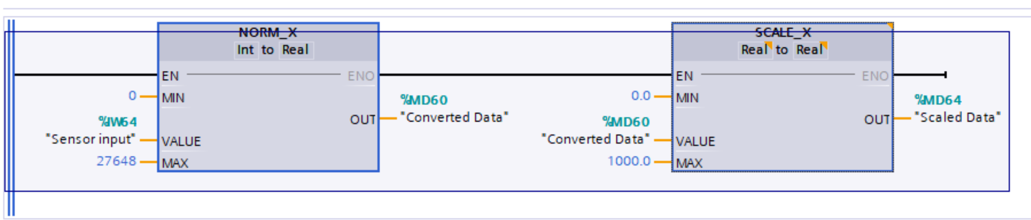
When the add new block dialog box opens Give the block a name you will remember and that will give you a clue in the future what this does. Select LAD (short for Ladder Logic) for the Language. Leave Automatic for the number. Enter information at the bottom about the title and author. Be sure there is a check mark in the add new and open at the bottom. Then click on the FC Function icon to identify the type of block. Click OK.



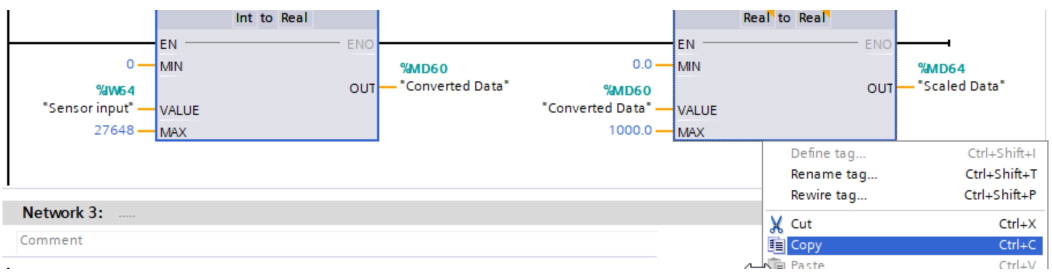
This creates a block with the name you entered. It also opens the network view for the block.



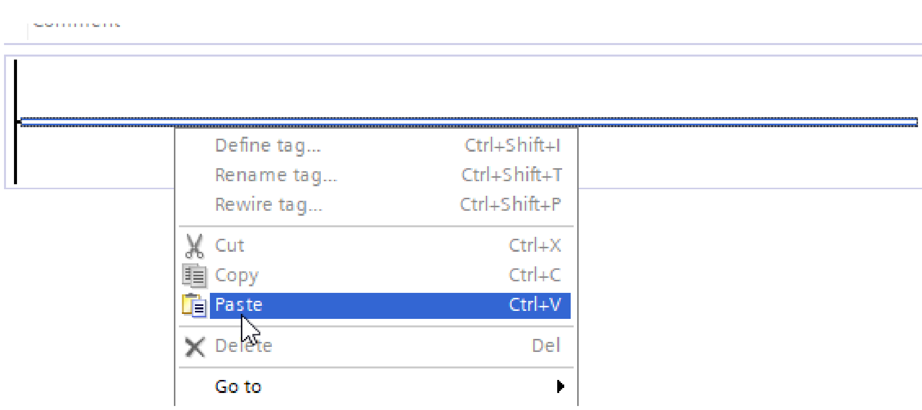
We can now copy the data into this block. To do that click on the main [OB1] so you are looking at the program you wrote before. Stretch a rubber band around each network.



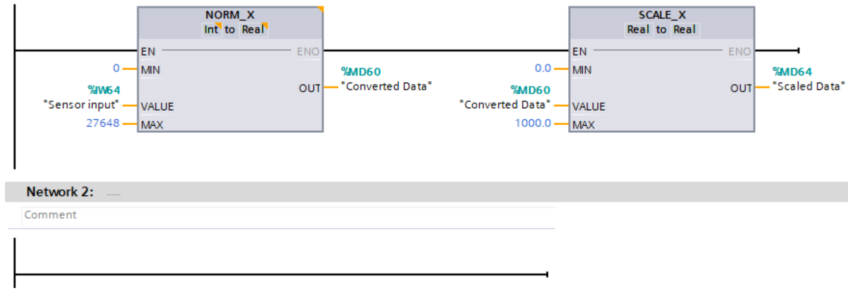
Right click and select copy.



Return to the block you created and paste the content into block 1.

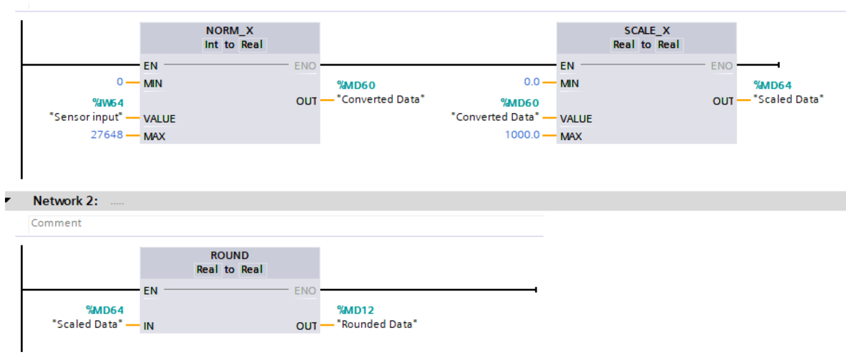


The network should have been pasted into the new block.

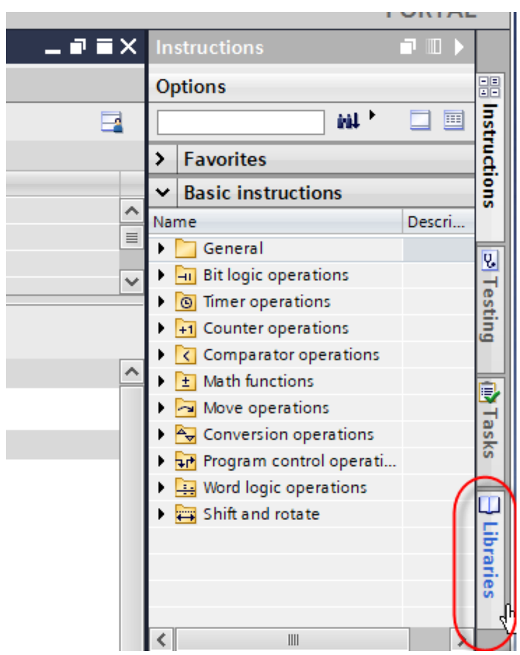


Return to the main [OB1] and copy the other network.

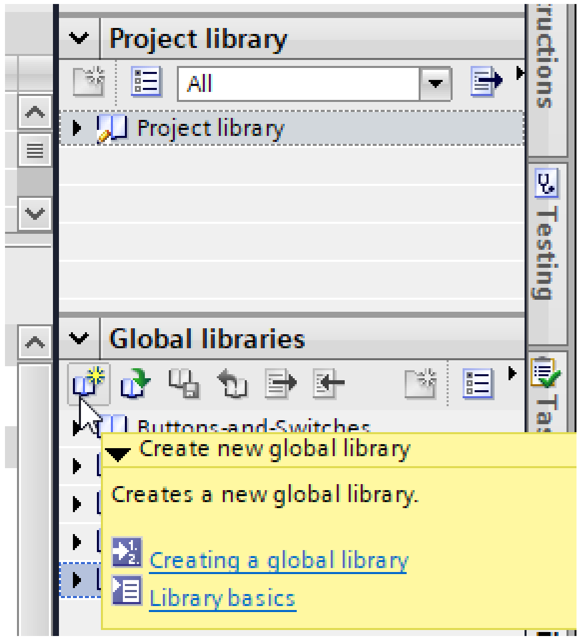
The new block should have the three components included now.



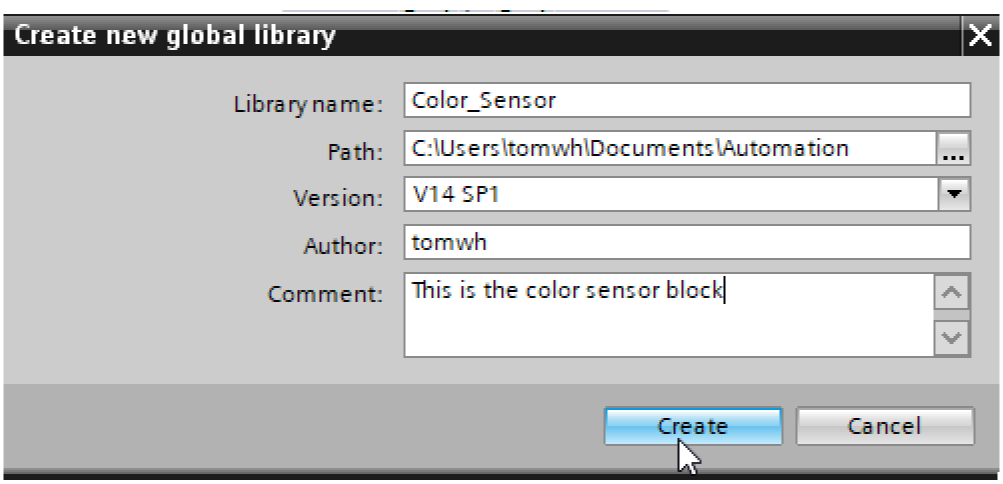
To make this available anytime you want to build a new block it is necessary to save this in a library of blocks. Open the library tab in the Instructions area.



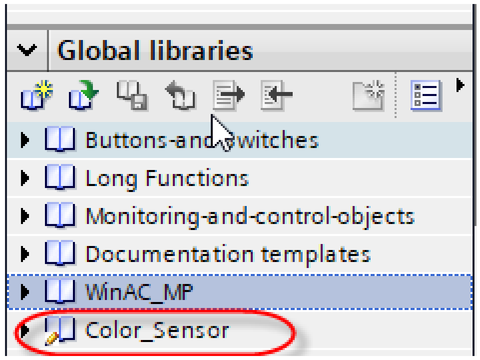
Expand the Global libraries. Click on the create new global library icon.



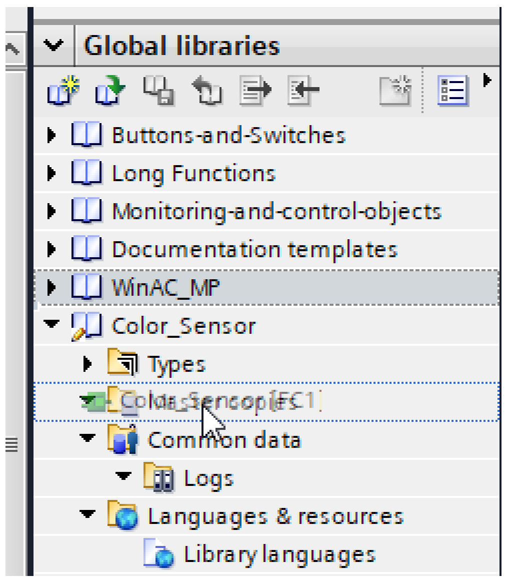
When the dialog box opens give the new library area a name you will remember. In this example the global library is called Color_Sensor.



Select Create. The library named Color_Sensor should appear in the list of libraries.

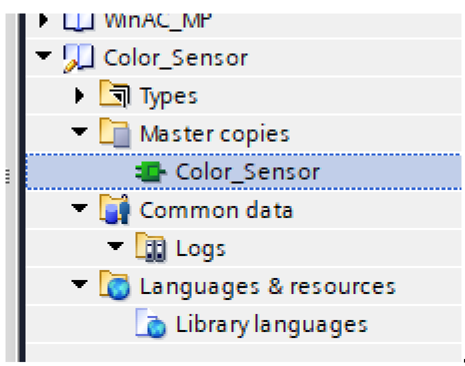


Expand the Color_Sensor folder by selecting the arrow next to it to see the folders it contains. Then left click and drag the block we just created over to the library and place it in the master copies folder.

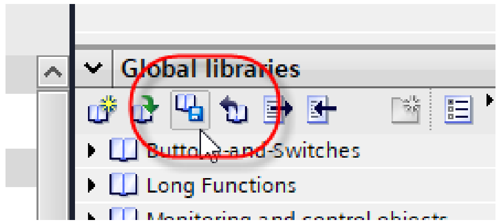


It will not allow you to put it in other places.

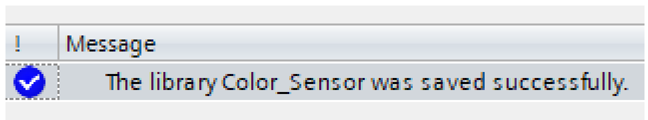
A note will be shown that it is being created. Your block appears in the master copies area.



Select save from the tools in the global libraries.

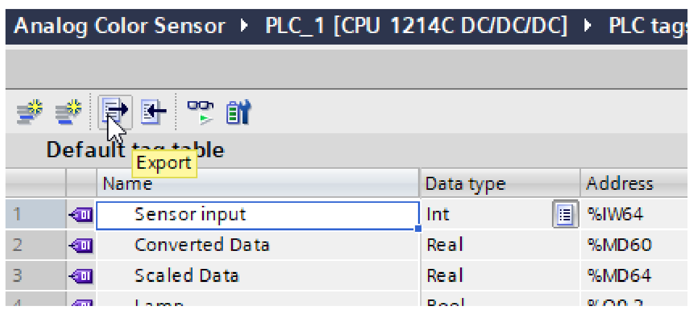


Your library will be saved. The info area should report that it was saved.

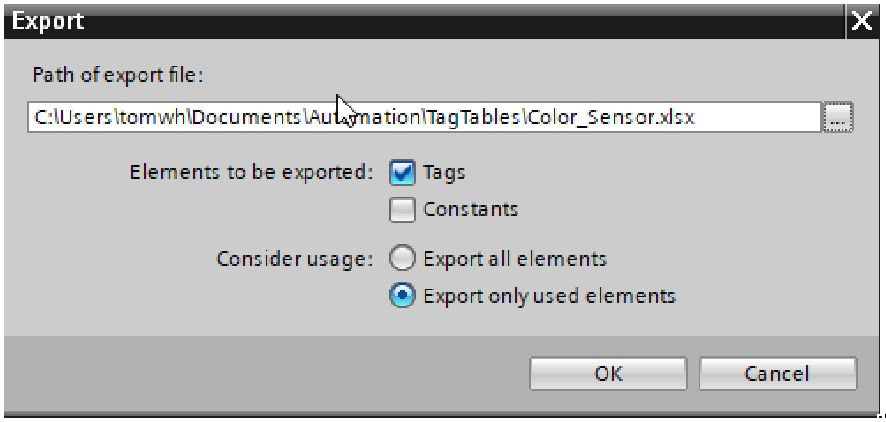


You can now bring the block into any program you write. The next step is to export the tag table so you don't have to rewrite that whenever you want to use the block.

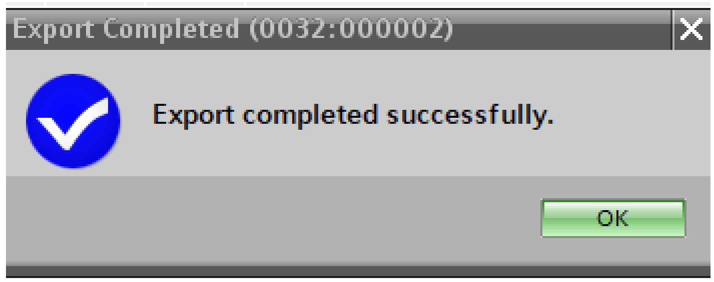
Open the tag table. Select export from the tools.



In the dialog box provide a pathway and name for the file. Be sure the name is descriptive so you can easily find it again. In this case the file is being kept in a folder called TagTables and the file is named Color_Sensor.xlsx. By checking the box for export only used elements you will limit the amount of items in the list.



Three months from now if you need it you will be able to find it. As you build blocks you can keep all your tag tables together as long as you name them.



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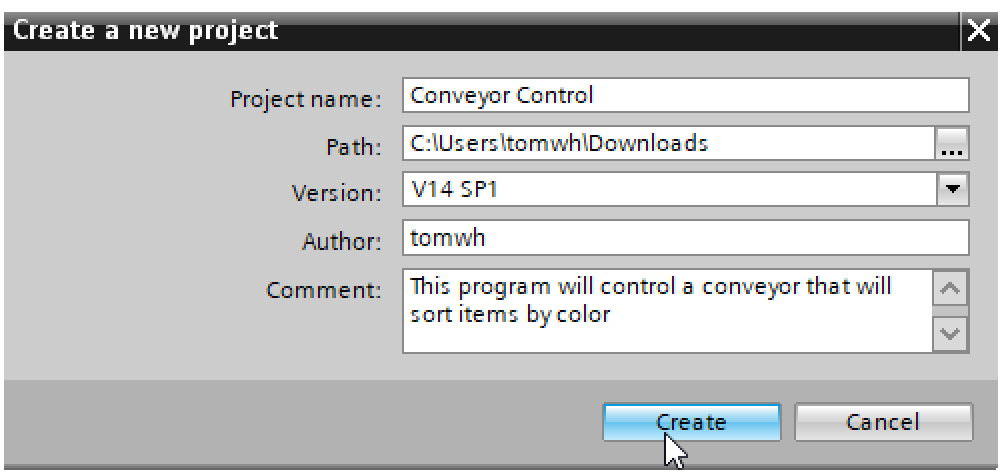
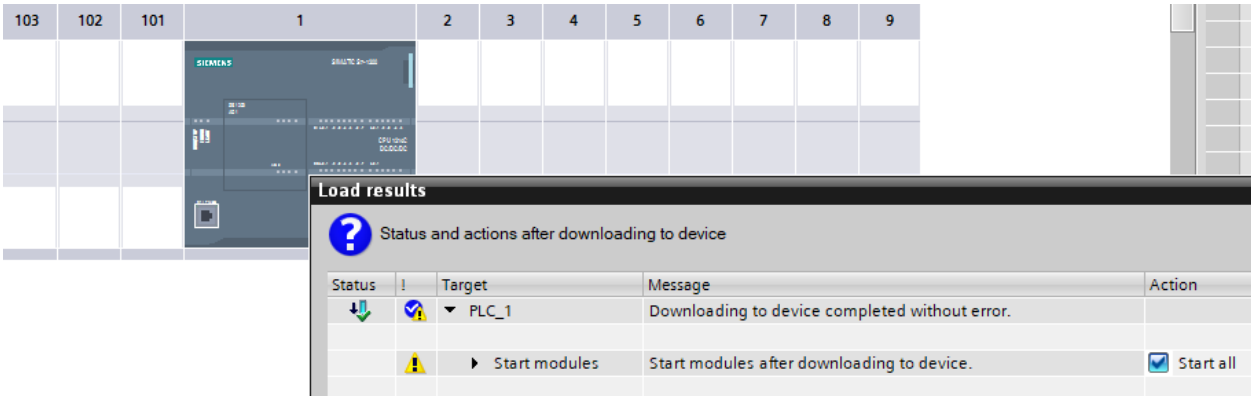
Using Blocks

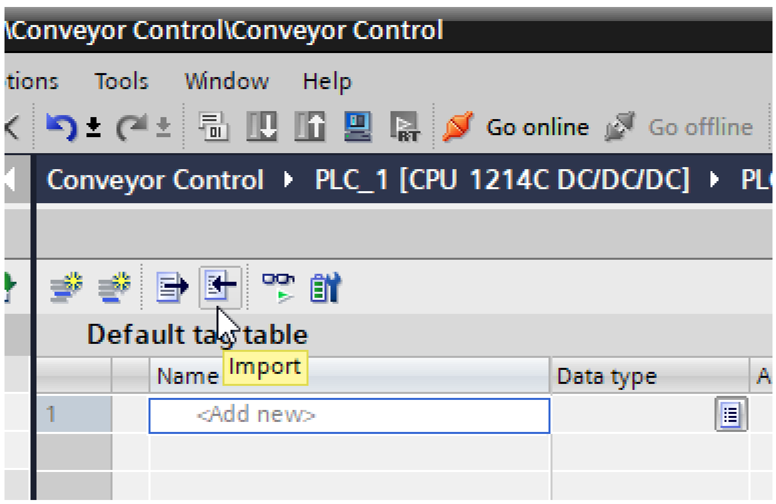
When you begin a new program you can access your library created. In this example a control is being constructed to operate a conveyor sorting system. This system requires a color sensor. It will perform different functions dictated by the color of the object.



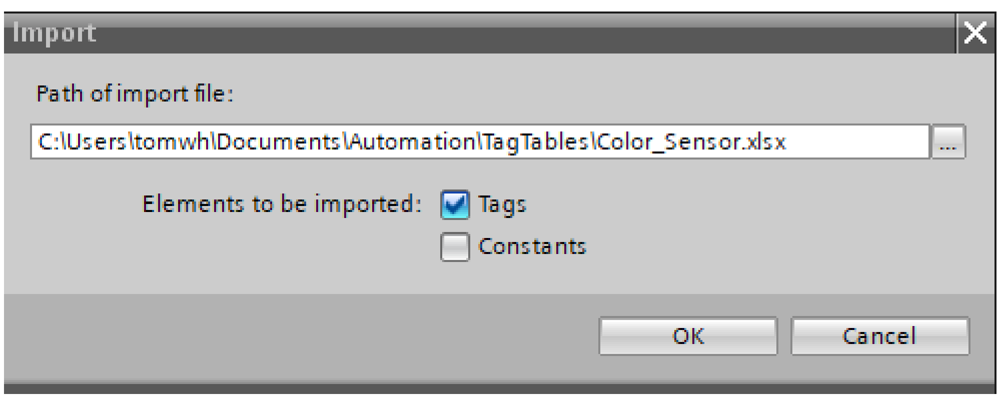
Add the PLC device creating the new program environment. Load the hardware configuration as you have done in other programs.



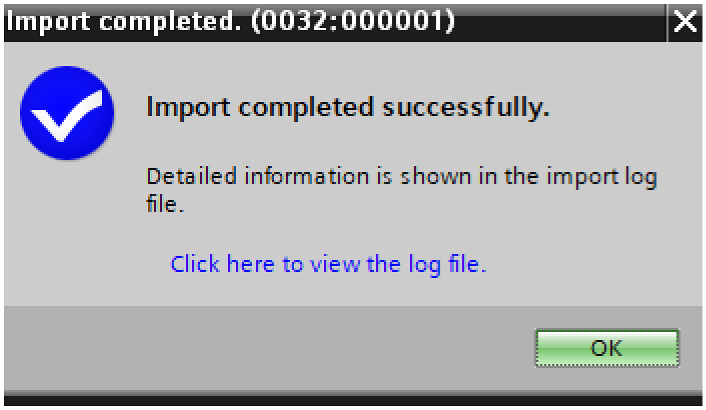
Open the default tag table. There is nothing in the table yet. Select the tool for import and navigate to where the tag table was saved.



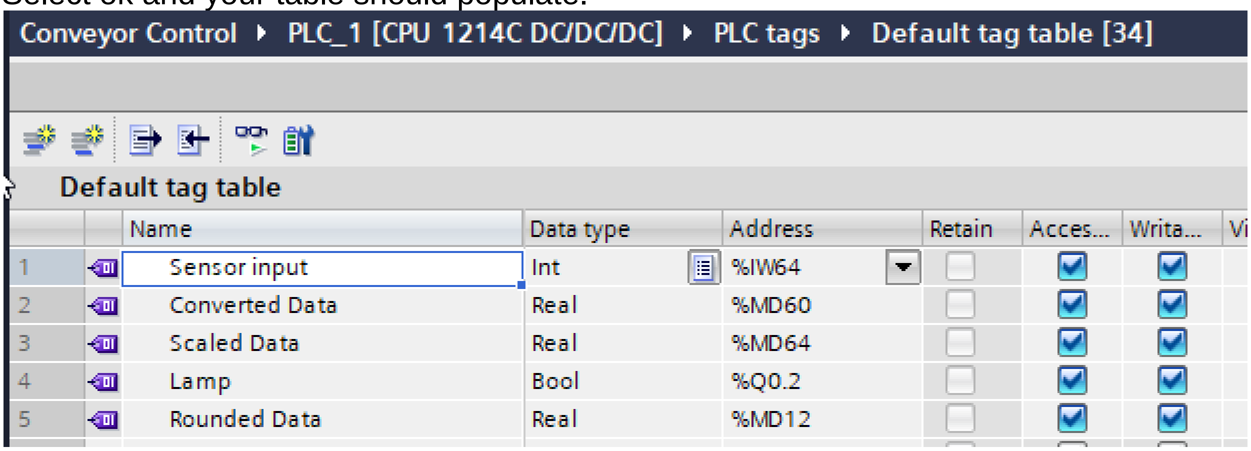
In this case it was saved in a folder called TagTables and the file name was Color_Sensor.xlsx.



Select OK and your table will begin the import process.



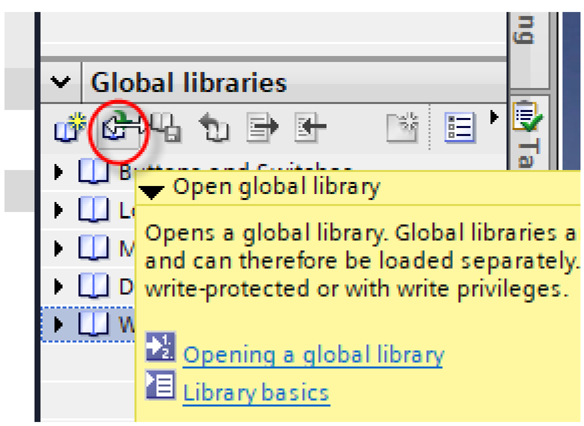
Select ok and your table should populate.



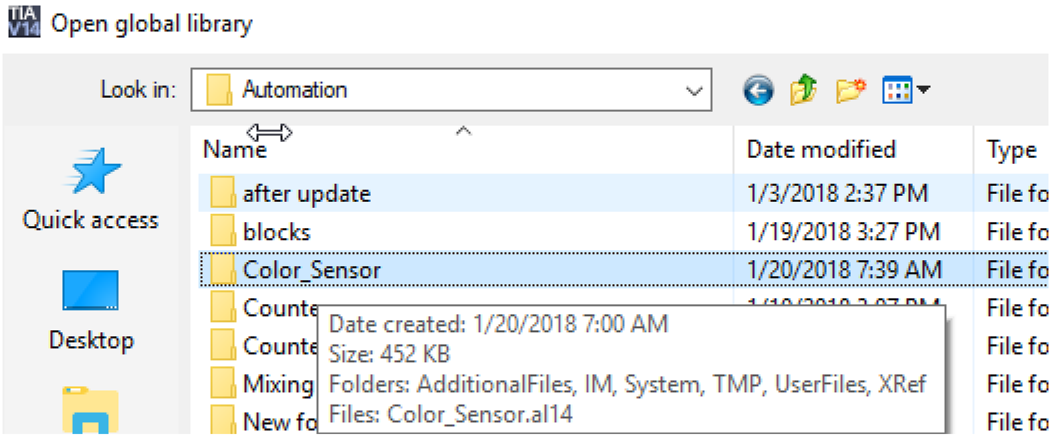
You can now place the color sensor block.

Open the Main [OB1] block table and you will be looking at a blank network.

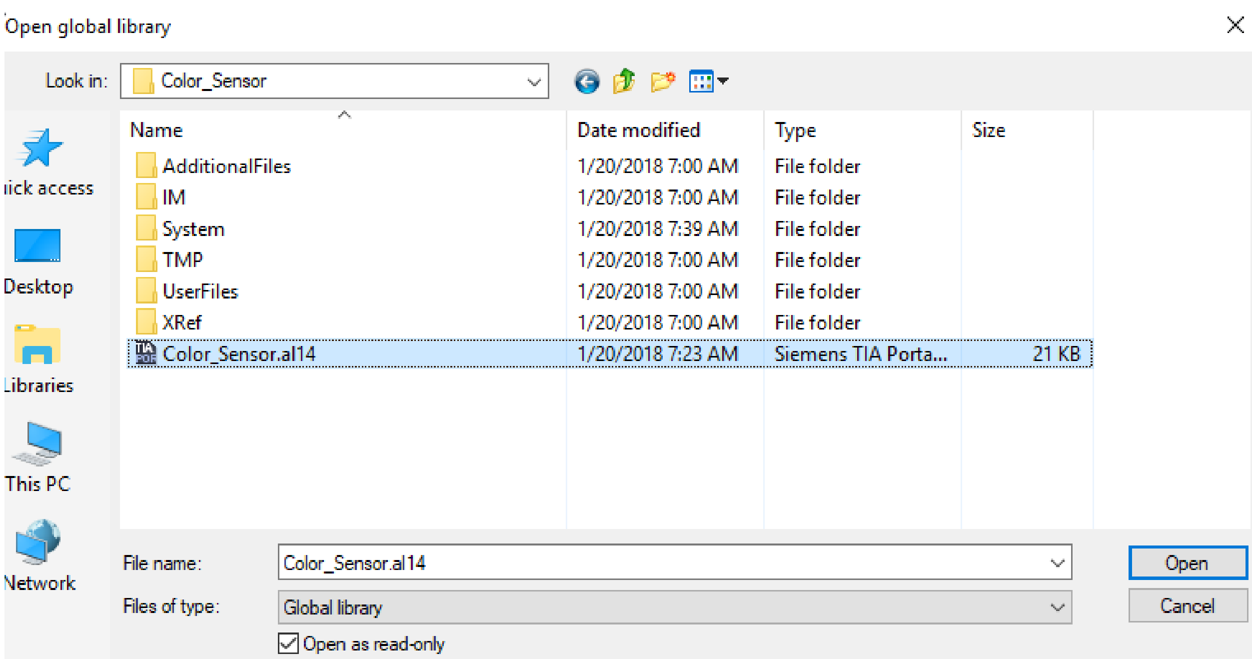
In the libraries area on the right hand side of the screen navigate to the global libraries area. Select open to retrieve your created block.



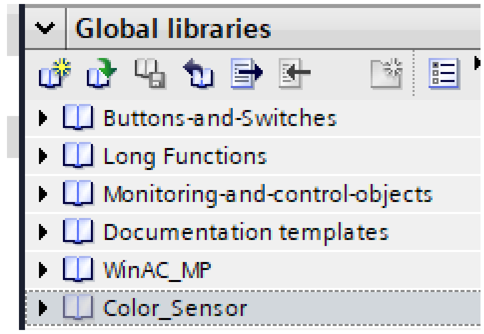
Navigate to the folder you created when you saved your block.



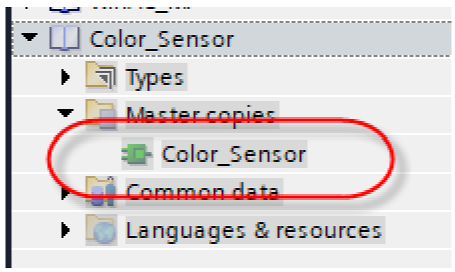
Double click on the folder to open it. Select the file. At the bottom of the open dialog box is a check box for read only. If you don't need to make changes it is better to leave this checked to protect the work.



The global library now has an entry for color sensor.

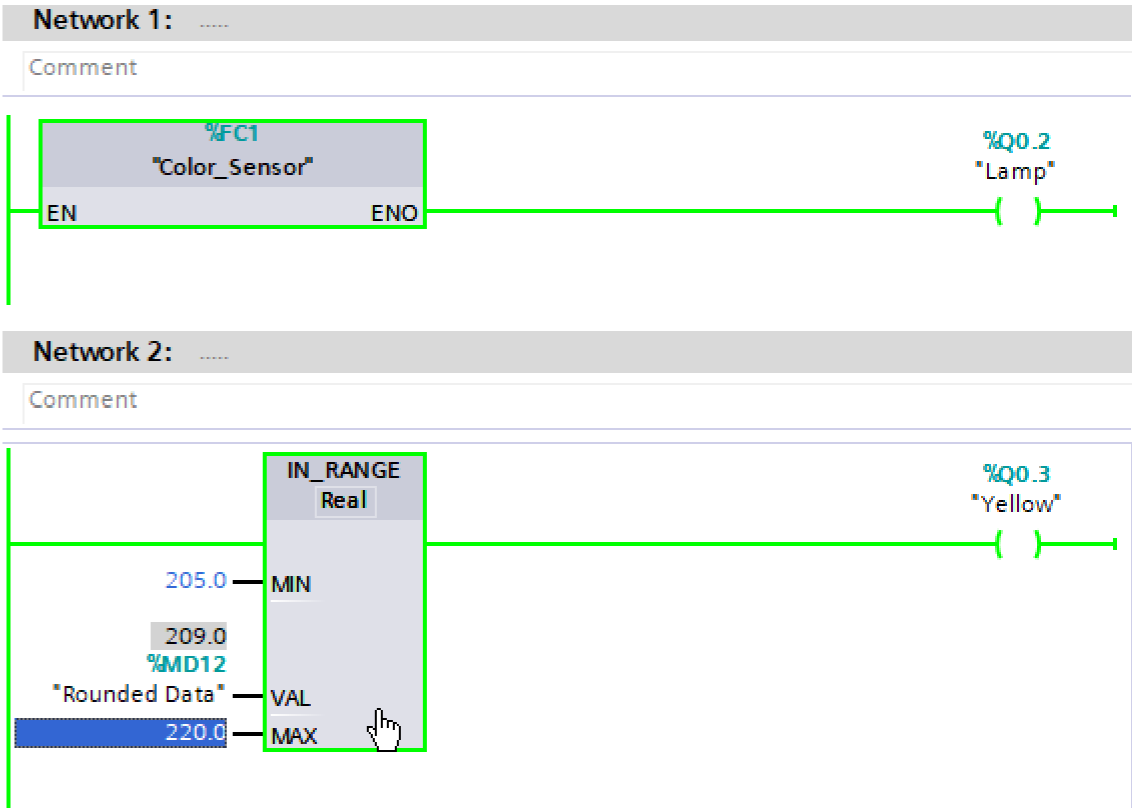


Expand the color sensor and you will find the block in the master copies folder.



Drag this out and place it on a network.

It will appear in the program blocks area now and will display on the network. It is a single block that does the function. It works the same way. You can use the same in range command. In this example the yellow instance will cause a conveyor to move forward a certain amount so a pneumatic ram can remove the device from the belt.


Network 1:
Comment
%FC1
"Color_Sensor"
EN
ENO
%Q0.2
"Lamp"
Network 2:
Comment
IN_RANGE
Real
205.0
MIN
209.0
%MD12
"Rounded Data"
VAL
220.0
MAX
%Q0.3
"Yellow"

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Pneumatics and Control

Pneumatics is the branch of science and engineering that deals with compressed gas. This allows the transfer of power to machinery by means of pressurized air in a piping system. It can be adjusted at point of use, making it a desirable power source for many automation installations.

Pneumatics is a component of fluid power. Fluid power employs fluids under pressure to transmit power. Hydraulics deals with liquids under pressure. Liquids such as water and oil are not compressible. Air is an example of a compressible fluid. The laws listed below explain how a compressible fluid behaves in relation to pressure, volume, and temperature.

Pascal's Law: Pressure exerted by a confined fluid will transmit the power equally in all directions.

The formula $\rho = \frac{F}{A}$ expresses the relationship of pressure to force and area. This applies to pressure acting on a cylinder. Since there is only one direction, the piston in a cylinder will transfer the air pressure in that direction. The input force will equal the output force. In a pneumatic system, we know the air pressure being used. We can calculate the amount of force we can deliver.

Boyle's Law: The volume of a gas at constant temperature varies inversely with the pressure exerted on it. In pneumatics we are interested in the relationship between pressure and volume.

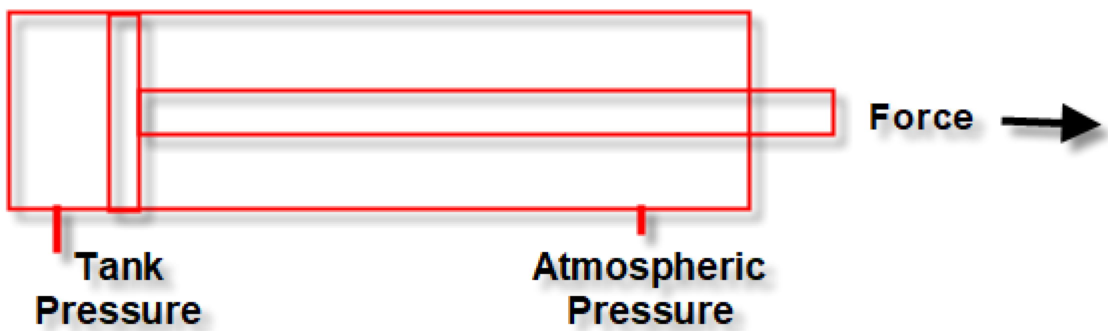
The formula $\rho V = k$ explains that for a given mass at constant temperature the pressure times the volume is constant. As the gas expands, the temperature changes and this is why the air used in pneumatic systems feels cool or cold when it exits. It is also why we are concerned with moisture in the system. As the air cools, the water vapor condenses and in a larger system a few gallons might be found in the tank on a hot muggy day.

Charles' Law: The volume of gas increases or decreases as the temperature increases or decreases provided the amount of gas and pressure remain constant. The same number of gas molecules will occupy different volumes at different temperatures. If the temperature rises the gas will expand. If we pressurize a tank when it is cold and the tank heats up what happens?

Force exerted by a piston is calculated by the formula $F = \rho\pi({d_1}^2 - {d_2}^2)/4$

Where F is the force exerted
p is the pressure
d_1 is the diameter of the piston
d_2 is the diameter of the piston rod

In the example below we will apply 80 pounds per square inch of air pressure to a two inch cylinder with a ¼" diameter piston rod.



$$F = \rho\pi({d_1}^2 - {d_2}^2)/4$$

$$F = 80 \times 3.14(2^2 - .25^2)/4$$

$$F = 989.601/4$$

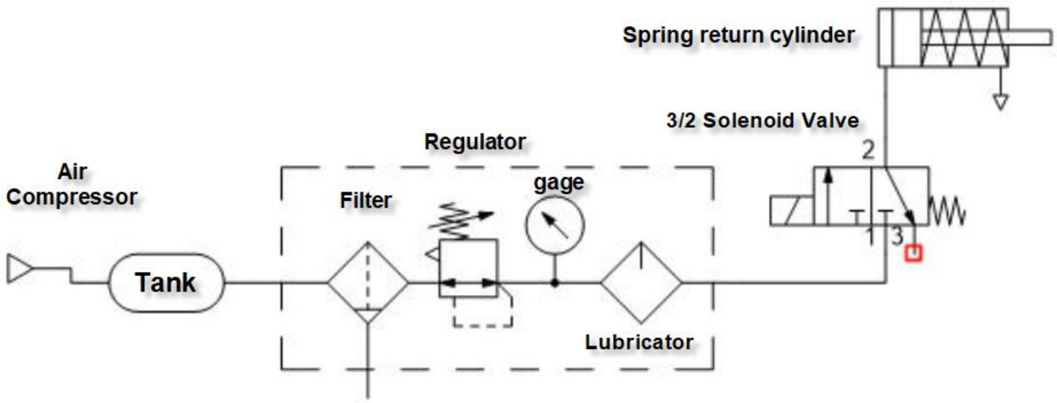
F=247.400 pounds of force delivered by the piston.

Air systems

Schematics

Air systems can be quite complicated. We use schematics to indicate components in a system. Having a schematic for a complicated system allows the viewer to quickly figure out what is happening and how to narrow the search for an issue if there is a problem.

Below, the schematic is an explanation of the components and a picture so they can be identified in a laboratory setting. Please note the different symbols for each component. These symbols are the accepted method to communicate using a schematic and actually form what one might call a "vocabulary of symbols".



Air Compressor
This example below displays the electric motor (left) that drives the compressor on the right.

A compressor is a type of pump. It uses pistons similar to pistons in a car motor to compress air into a tank. This compression creates heat. If you look closely at a compressor you will see slots or fins on the surface of the cylinders which create more surface area to allow for air cooling. A one way valve allows the compressed air to flow into the tank. As more is added the pressure rises. Most compressors have a pressure switch which will turn off the compressor or divert the air flow when a set pressure is reached. Pressure is measured in pounds per square inch or the Bar (SE) system. 1 Bar roughly equivalent to atmospheric pressure at sea level. 1 Bar equals approximately 14.7 psi or 100 kPa (kilopascals)

Tank
The tank is frequently the largest component of a compressor system. The picture below shows the tank under the compressor. Also, the compressor is on the right and the electrical motor that drive the compressor is on the left. The electrical motor and the compressor are connected by a drive V belt. They frequently come preassembled.

The tank receives the compressed air from the compressor. The tank volume helps keep the pressure constant in the system absorbing spikes in demand. The compressor can be reduced in size due to this averaging. The compressor is cycled on and off to maintain a constant range of pressure in the tank.

Regulators and Gauges

The schematic above shows several components together within a dashed line. When you see this on a schematic it indicates close proximity to the other components in the system. In the schematic you see air entering from the tank. In the picture below you see a ball valve with a blue handle. This allows the system to be drained and locked for repairs and maintenance. When the electricity is turned off the tank is filled with compressed air and could power devices for a long time so the need for a manual cutoff switch.

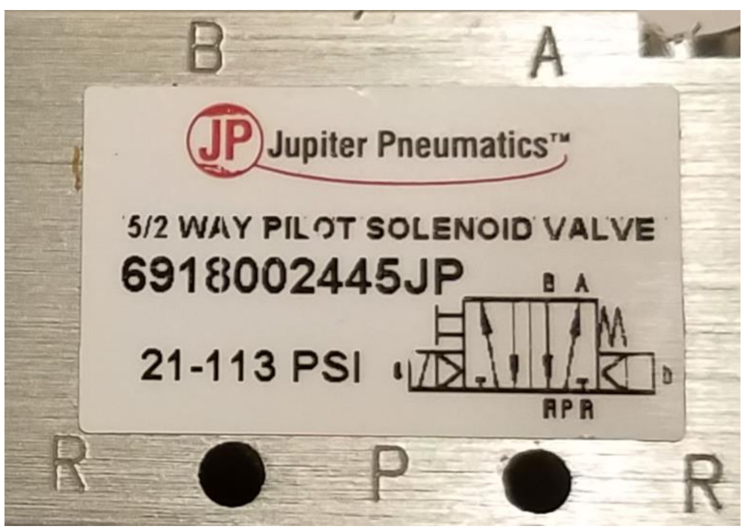
After the ball valve there are filters and dryers to remove any water left in the compressed air. When air leaves the tank it expands and following the laws of gas, drops in temperature. Without filters and dryers, water would be sent through the system contaminating and corroding the system components. Sometimes an oiler is connected here to provide a fine mist of oil to protect the equipment from corrosion at the point of use. Regulators are used to adjust the output pressure of the system. They have a knob to increase or decrease pressure and often have a pressure gauge attached to see what the pressure is.

Pipes hoses and fittings
Every pneumatic system needs to supply the air to point of use. In many plants the air compressor is located in a central location with a system of pipes to deliver the air where needed. Wherever a piece of equipment will be disconnected from the system a quick connect air coupling is used. When the quick connect end of the hose is disconnected, the fitting seals the connection so there is no loss of air pressure. The picture below shows an air hose with the quick connect end on the top and the quick connect coupling on the bottom. The manifold next to the air hose coil has the coupling on the left. This allows the manifold to be plugged into the system and the push to connect fittings on the top can run to individual components of the system. In this example the hose that connects to the manifold is pushed into the connecting fittings which in this case is ¼ inch. The hose is cut to length and inserted into the fitting. To release the connection, the gray sleve is pushed down while the hose is pulled out.

The larger the lines, hoses, and fittings are, the more pressure can be delivered. There are many styles of fittings, so it is important that the fittings are compatible.

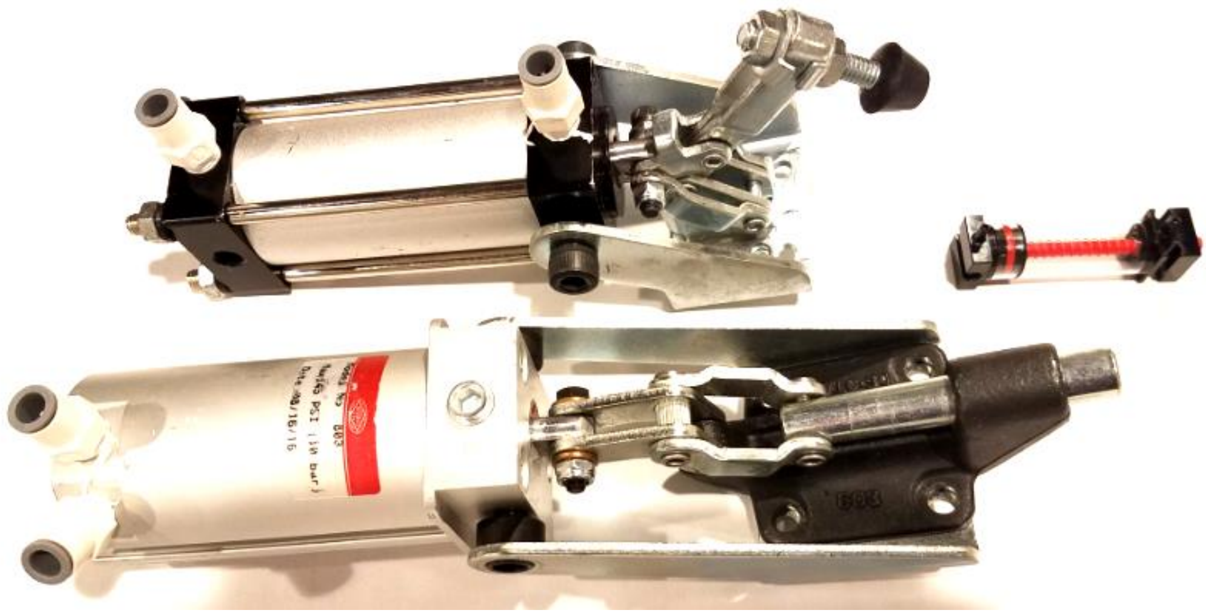
Solenoid Valves
Air is controlled to individual circuits by valves. Valves can be operated either manually or automatically. When valves are operated manually the use of levers, pedals, or hand switches is common. When valves are operated automatically, they are controlled by powered valves similar to the ones in the photo below. These automatic applications are based upon solenoid valves and are described by the number of ports and positions among other factors.

In the picture above, the small solenoid valve in the upper right and the valve on the bottom left are both 3/2 solenoid valves. The difference is one of size. The number 3 stands for three ports which are the openings into the valve. The solenoid on the top left is a 5/2 valve. Air pressure is supplied to the appropriate port. In the example below the air is supplied to the P (pressure) terminal. In its initial position pressure flows to port A and anything connected to B will vent out the R on the left side. When the solenoid is engaged the pressure is attached to B and A vents out the R on the right.



This solenoid valve might be used on a cylinder where there is no return spring. Position A holds the cylinder in one position and when the solenoid is triggered the air pressure is released and the cylinder moves to the other position. The 3/2 solenoids are more like an on/off switch. Power in the solenoid allows air through the valve. When the power is removed the air is vented from the other port on the valve.

Actuators
An actuator in a pneumatic system converts the air pressure into movement or work. The picture below shows several different kinds of actuators though there are thousands of different types depending on the motion or force needed.



Helpful Sites
https://www.boschrexroth.com/en/xc/products/engineering/econfigurators-and-tools/d-c-scheme-editor/forms/registration-33#
http://www.logiclab.hu/index.php

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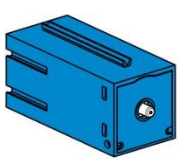
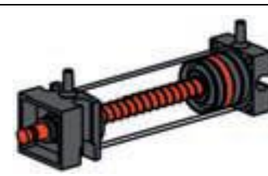
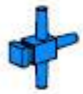
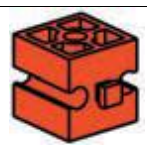
Build a system

 Compressor	 Hose	 Cylinder 60 with spring
 Soda Bottle (tank)	 Pneumatic hand valve	 3/2 Solenoid Valve

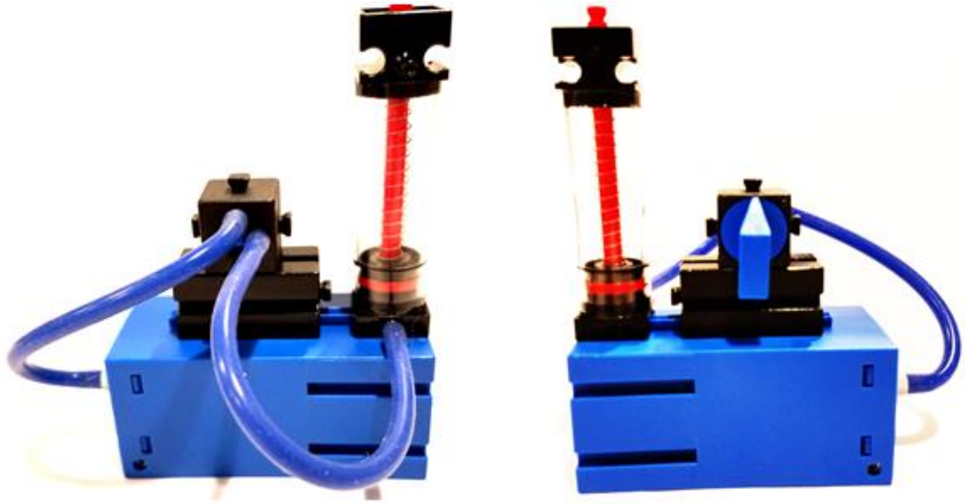
 T-Piece	 Hose connection solenoid	 Hose connection Compressor
 Hinged block Tab	 Hinged Block Claw	 Suction Cup
 Building Block 15 With Bore		

This activity is designed to introduce you to some of the components used in pneumatic systems. Pneumatics involves transferring energy to create and control motion through the use of pressurized gasses. Pneumatic devices include paint spray equipment, jack hammers, brakes for trucks and other large equipment, rock drills, construction nailing equipment, food processing equipment, soda fountains, pipe organs, and industrial equipment of all types. Pneumatic devices are popular because of their simple design, reliability, and safety.

It is important to be familiar with how the equipment works to have confidence when building a system.

Begin by hooking the compressor to the center pin of the hand valve. You will need to use a hose connector for the compressor. Connect one of the side pins of the hand valve to the cylinder. You now have a path for the air from the compressor through the valve and to the cylinder.

The cylinder is comprised of a piston in the middle of a clear tube. The air pressure forces the piston up in the cylinder and the red shaft exits the top of the cylinder. If this is connected to a mechanism, it can then provide power to move. Charles' Law explains the science behind how this operates and creates the pressure. Larger cylinders are usually made from stainless steel and can provide a lot of power from the piston. In this case we are powering the bottom port in the cylinder. With two valves you can power each side of the cylinder. This allows power in both directions.



Be sure the valve handle is pointed straight up. Connect the power to the compressor. Use the power supply to provide the 9V to the compressor.

Turn the handle of the valve so the pointer points to the hose going to the cylinder. If you hooked everything up right, the cylinder should extend. If you push gently on it what happens? Sketch the setup in your Engineering Notebook. Explain what happens when you turn the valve toward the cylinder. Turn the compressor off. If you gently push down on the cylinder explain what happens. Now position the valve so it is pointing to the unconnected side. Gently push down on the cylinder. Explain what happens in your Engineering Notebook.

Creating the Tank

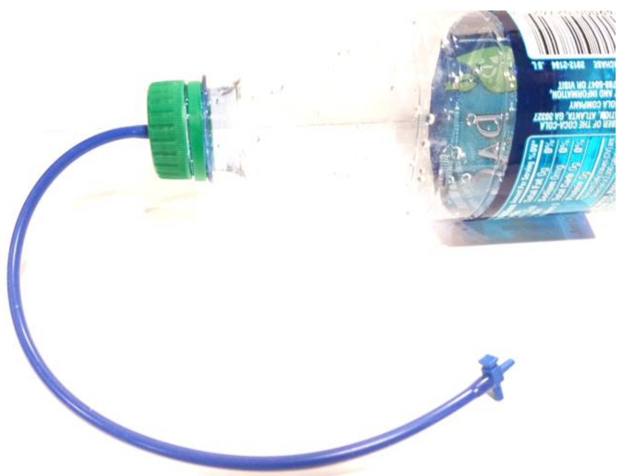
This is a low pressure, low volume system. Experience has shown that we need a tank to even out pressure swings.

To accomplish this, we will use an empty soda or water bottle and screw top. To make the connection to the air we will need to drill a hole in the bottle top that is slightly smaller than the connecting adaptor for a solenoid valve. In this case we will use a 3/32 drill bit.

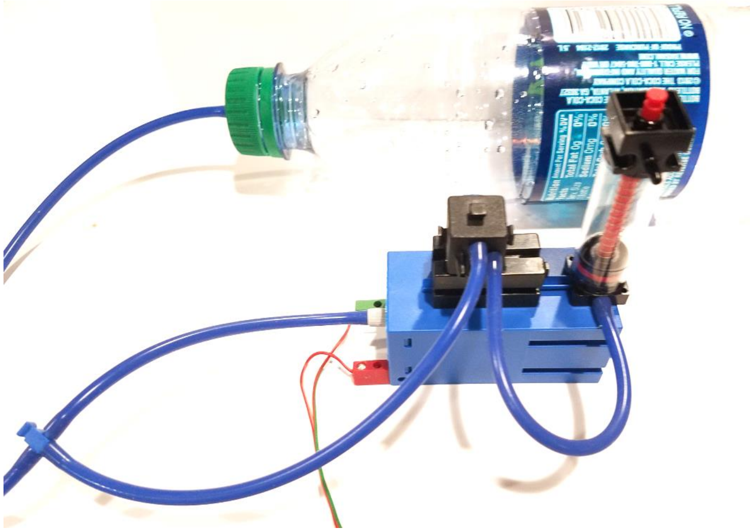
Drill in the center of the cap.

Clean the excess plastic shavings from the hole and then gently push the connecting adaptor through from the inside.

Attach a length of hose to the top and screw the top back on the bottle. Place one of the tees in the line so you have two pathways for air.



You can attach a hose from the tee to the compressor and the other end to the shutoff.



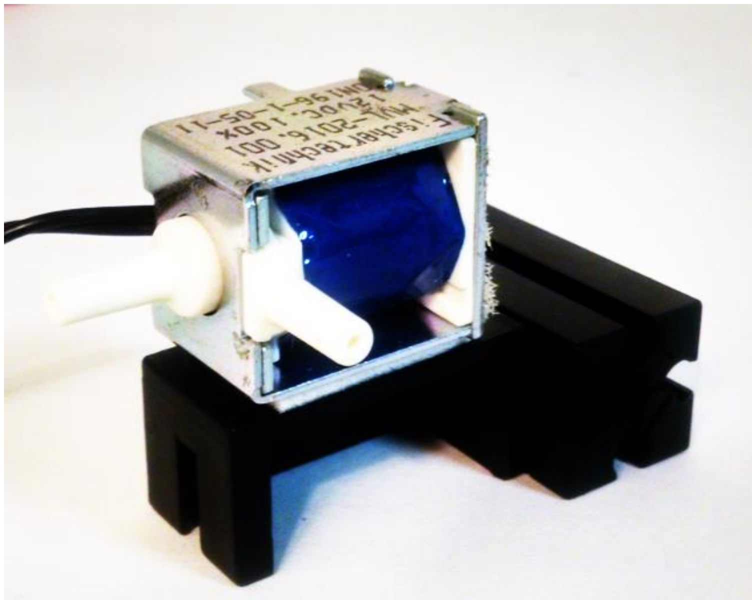
The bottle becomes the storage tank for the system, helping to keep the pressure constant.

Adding the Solenoid

In this section, you will replace the hand valve with the solenoid valve. Connect the air compressor to the top of the solenoid valve.

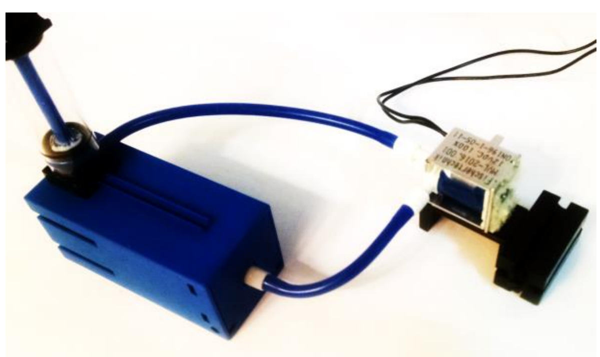
The solenoid valve is an electromechanically operated valve. When an electric current passes through the solenoid valve, the solenoid switches states. In the case of a 3 port valve, the outflow is switched to either run the cylinder or exhaust through the end of the valve. This solenoid will connect to the PLC the same way a motor does. It will connect to one of the outputs.

The solenoid valve is attached to a 30mm girder with double sided tape. This allows you to attach the solenoid valve to the structure to keep it stable.



This solenoid valve is a 3/2-way solenoid valve. The simplest directional control valve is the 2-way valve. A 2-way valve stops flow or allows flow. A water faucet is a good example of a 2-way valve. A water faucet allows flow or stops flow by manual control. A single-acting cylinder needs supply to and exhaust from its port to operate. This requires a 3-way valve. A 3-way valve allows fluid flow to an actuator in one position and exhausts the fluid from it in the other position. The 3 in the name stands for 3 ports. You can see two of the ports in the picture above. The third port is hidden behind the covering at the other end. This covering acts as a muffler and diffuser when the air is released from the cylinder.

Because air is released from the cylinder when the solenoid valve closes it is important to know which port is the supply and which port feeds the cylinder. When the valve closes, the spring in the cylinder returns the piston rod to its initial position. This forces the air back down the hose and out the open port of the 3/2-way valve. If the valve is connected in reverse, the cylinder will never return.



A switch will be used for our program to recognize it is time to allow air to flow to the cylinder.

If your connection to the solenoid valve has the air pressure going to the incorrect port the cylinder piston will not retract. If that is the case, turn off the power to the circuit so the air compressor stops. Drain the air from the system and then swap the hose connections to the valve and try it again.

Use the simple program you began writing for the PLC where you were able to turn a motor on and off. In this case we will turn the solenoid on and off.

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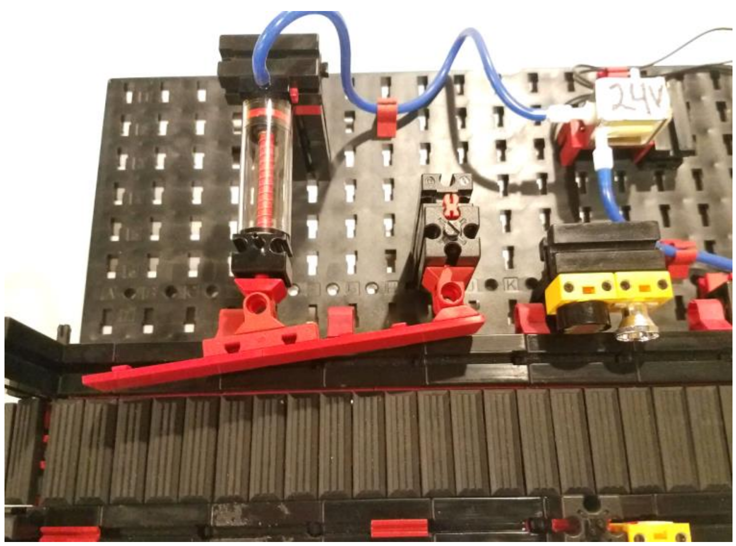
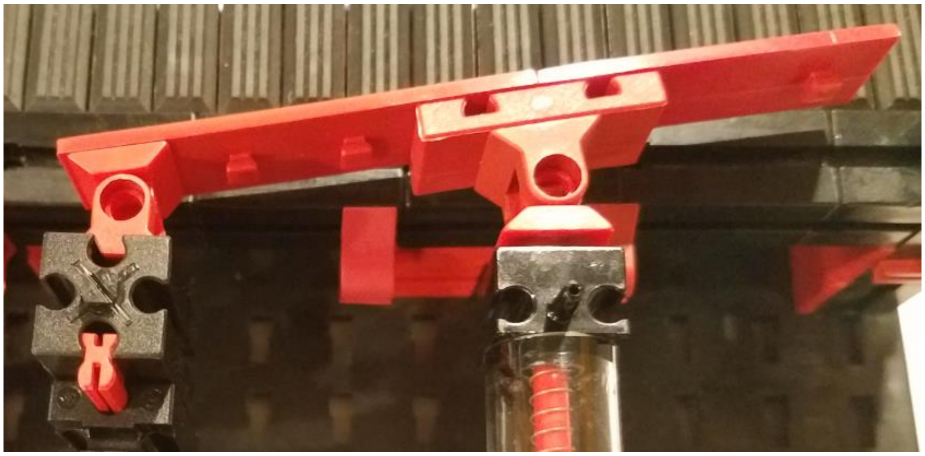
Sorting connection
The power delivered by the piston rod can be harnessed in many different ways.

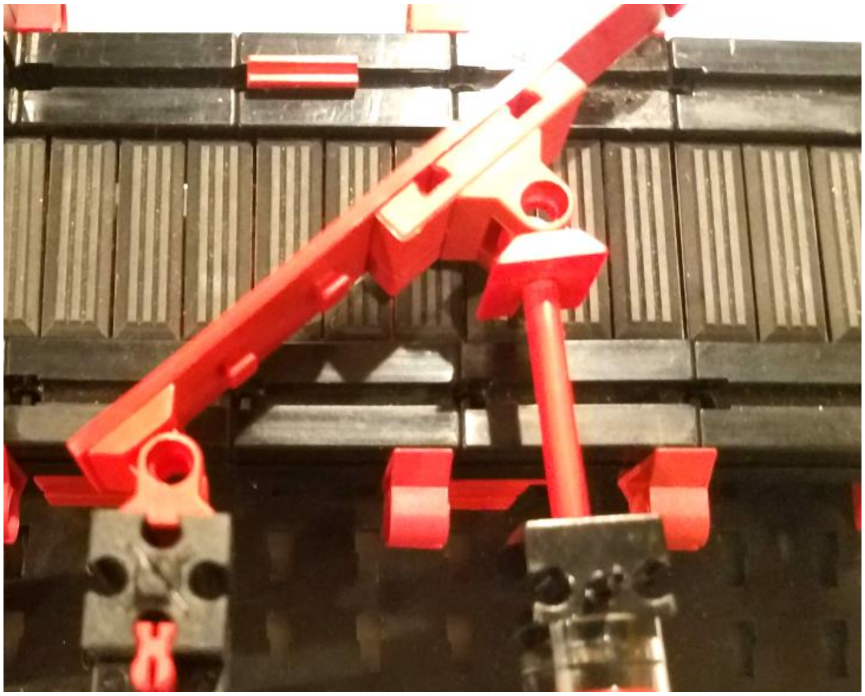
In the picture below is a directional arm. The conveyor will be running continuously and the program will decide when to remove a part.



The arm is attached at two pivot points. Each pivot is made from a hinge block tab and a hinge block claw.



When the solenoid is energized, the cylinder forces the gate across the conveyor changing the direction of the components to another conveyor or storage bin.



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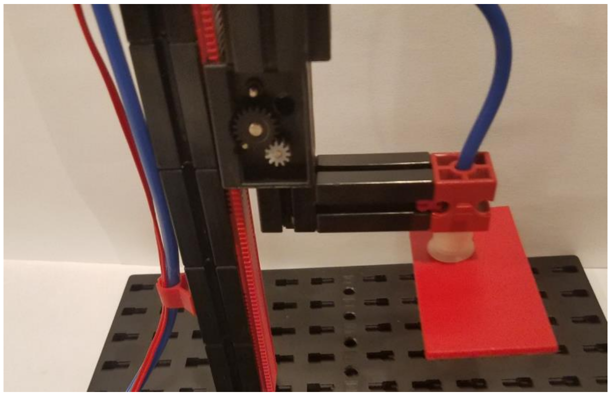
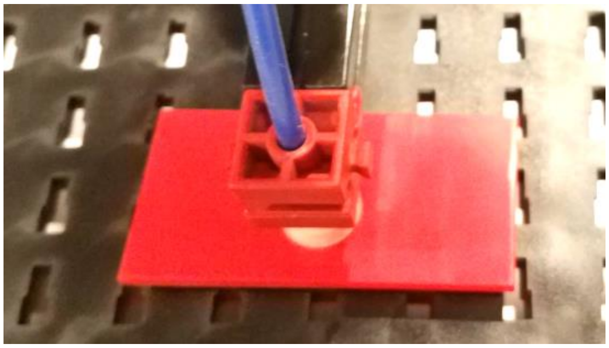
Using the suction cup

A common way to pick up flat stock is with suction cups. The picture below shows a motorized elevator with a suction cup attachment.

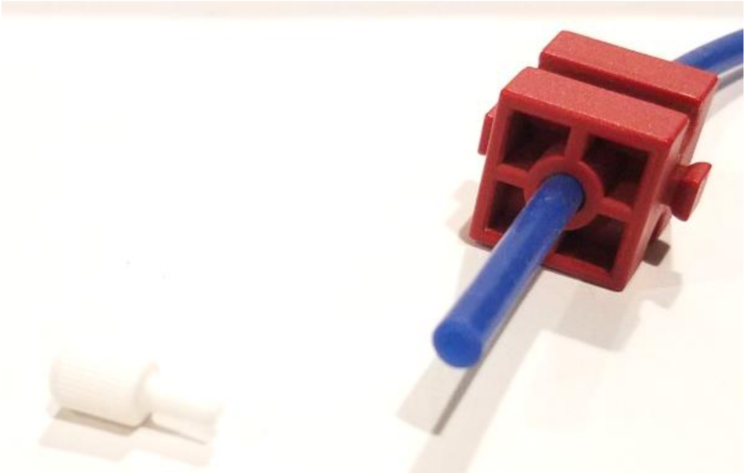


This feeder lowers the pickup to the top of a stack of material, the suction cup is actuated and the top piece is picked up.

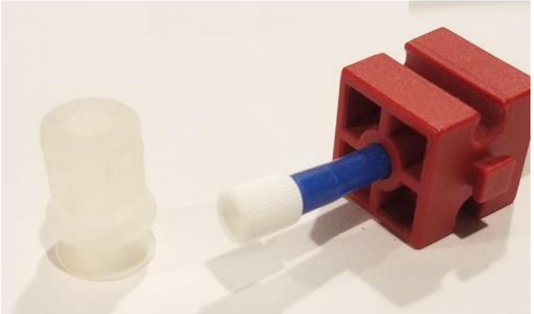


The piece is raised then rotated and the part is lowered into position. The suction is released and the part is deposited in the desired position.

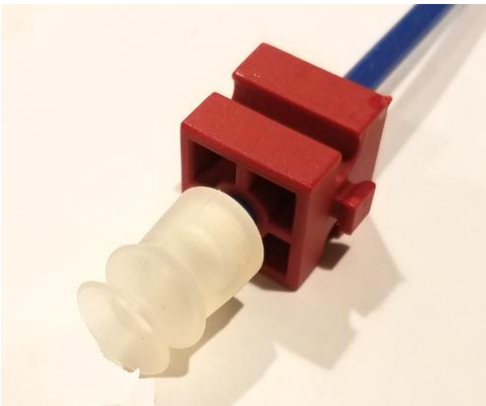
To begin to construct the suction cup run the hose through the block with a bore.



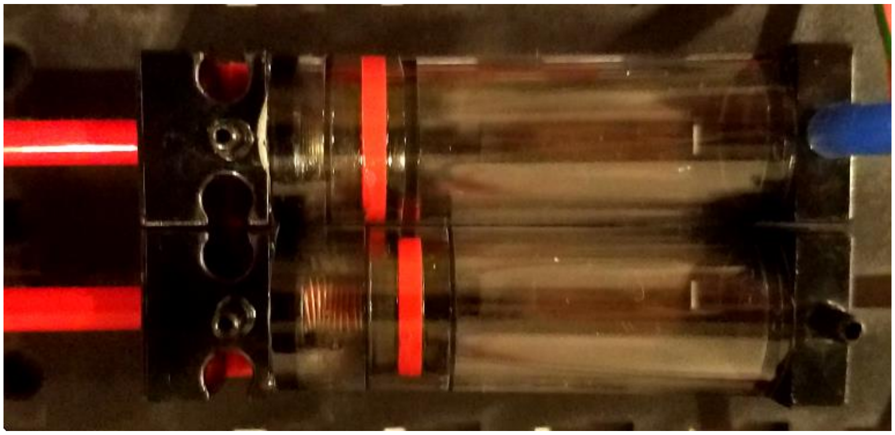
The hose connection is attached. This will give the suction cup something to attach to.



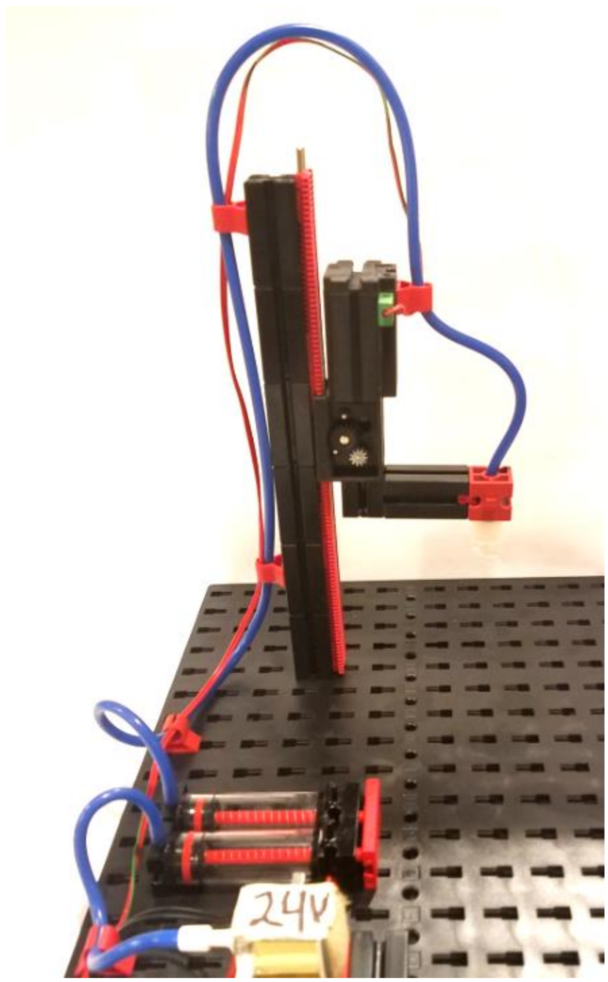
The suction cup is placed over the hose connection and then slid into the block with the bore. This connection will be fairly tight, keeping the assembly firmly attached so it will not pull off when picking up objects.



To create the suction two cylinders are used. The two piston rods are tied together. One cylinder will be powered and the other will not. This is known as the master/slave relationship. When the powered cylinder is energized it drags the other with it. With the end left open as in the picture below, it pulls air from the atmosphere and travels with the other cylinder.



Connect the hose from the suction cup to the open end. Now when the powered cylinder is energized the pull from being attached creates suction and whatever the cup is sitting on will be attached.



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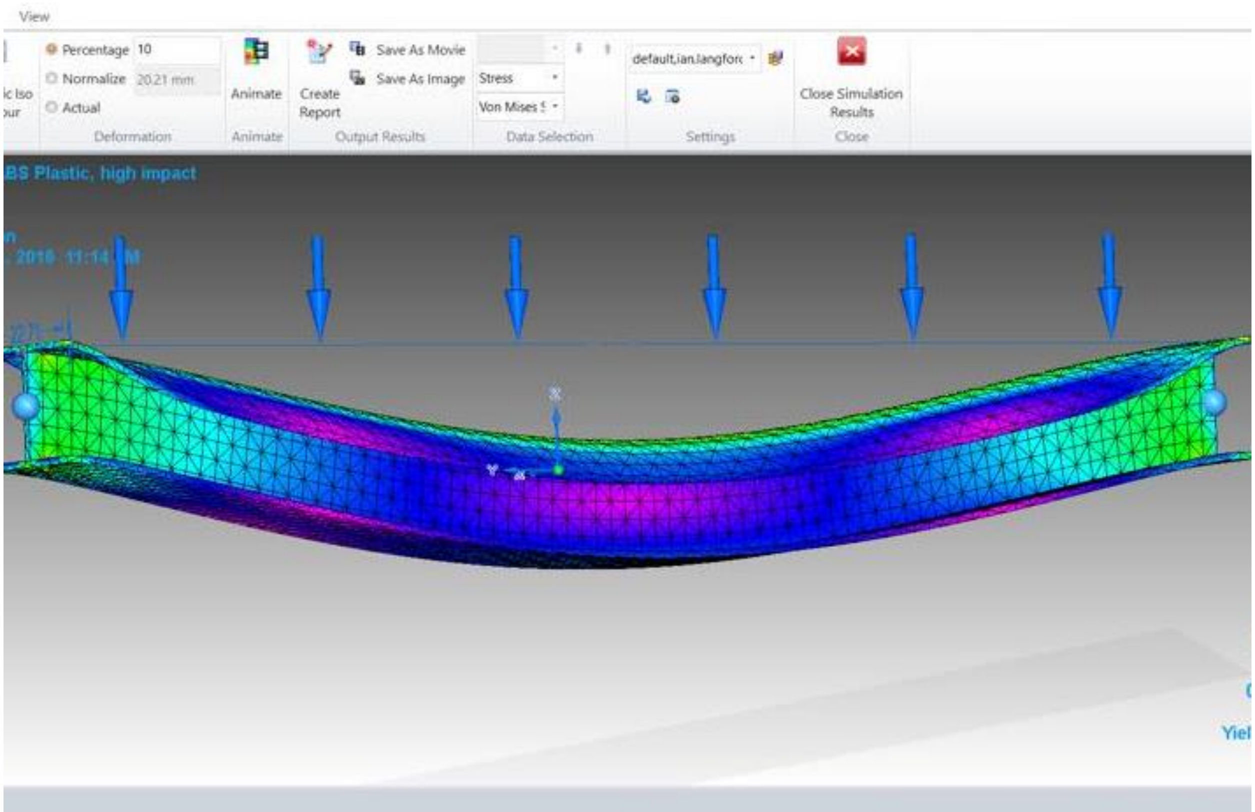
Engineering Documents

This section contains documentation to help students manage their projects. This allows students to take control and embeds technical literacy into the projects.



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Design Process

The engineering design process is a series of steps that engineers follow when solving problems. There are many variations of the design process in use and every situation or problem will have different elements that you should investigate. The steps listed below as well as the bullets included should inform the process but not dictate the process for every situation.

Design Process
Conduct Preliminary Research • Research Background Information and Identify Vocabulary. • Identify Criteria and Constraints for the Problem • Define Limits of the Problem to be Solved • Refine the Problem Statement in the Context of Criteria and Constraints • Define Areas of Research Needed to Solve the Problem • Independent Research • Enabling Activities • Lab Activities
Create the Project Management Plan • Overview • Scope • Schedule • Budget • Communication • Closure

Create a Design Brief • Objectives and Goals of the Design • Client and Context • Scope of the Project • Problem Statement or Description • Resources and Budget • Constraints • Time Needed
Brainstorm Possible Solutions • Generation of Ideas • Preliminary Sketches
Design Testing Methods and Protocol for Critical Assumptions • Introduction • Test Strategy • Data Collection Plan; Sampling Plan • Definition of a Successful Test, Pass / Fail Criteria • Test Conditions, Setup Instructions • Logistics and Documentation: • Analysis of Data • Conclusion
Create Optimization Matrix for Decision Making and Select Solution • Design Matrix • Identify Key Criteria • Assign Value to Each • Rate Possible Solutions
Develop, Refine and Document Selected Solution • Creation of Design Documentation • Identify New Issues
Create a Prototype • Turning the Plans into a Prototype
Test and Acquire Data • Design Testing to Evaluate the Prototype • Acquire Testing Data
Analyze Test Data • Creation of Graphs and Charts • Statistical Examination of Data

Refine and Iterate the Design • Apply the Changes Suggested by the Analysis of the Test Data. • Retesting of the Prototype • Repeat
Finalize Documentation of Design • Complete Documentation of Changes • Finalize Analysis
Prepare Communication Plan for Authentic Audience • Research Audience • Plan for Explanations and Graphics • Plan for Feedback
Prepare Communication Documents • Reports • Design Documentation • Design Proposals • Presentations for the Authentic Audience
Present/Defend to an Authentic Audience with Feedback

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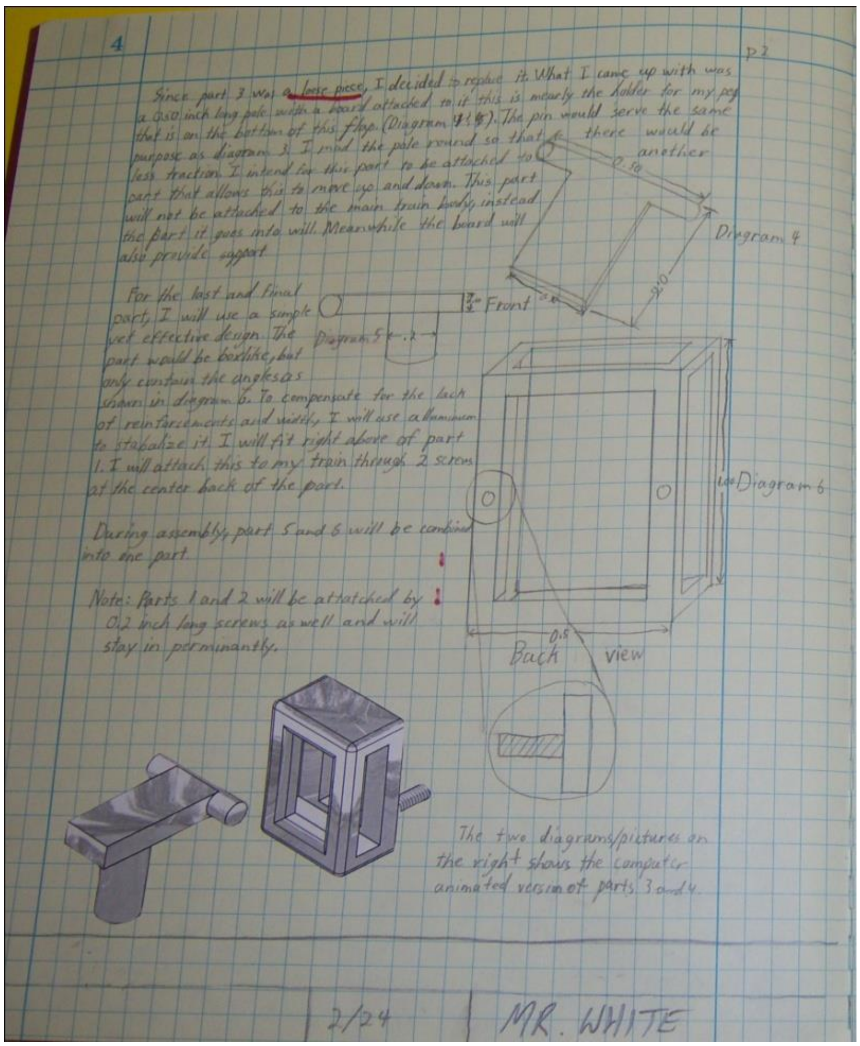
The Engineering Notebook



An Engineering Notebook is known by several names depending on the person and industry it is being used in. It is a bound book that contains the time-sequential written documentation of the development of the ideas of its author, along with all notes, data, observations, calculations, and other information relevant to the discovery or experiment being conducted. It provides an important record of the progress of an engineer, scientist’s or inventor's work. When properly maintained, it may be submitted as a legal document for patent purposes or legal records.

It is the equivalent of a technical diary and has multiple uses. It presents the authors thought process and work in an easy to access manner, allowing an author to confirm conclusions, details, or dates.

Engineering research and development organizations usually require their engineers to keep a running record of their activities. In the event that a project is shelved or the person leaves employment it can provide others working on a project the paths of inquiry that have been investigated, and can offer justification for decisions or courses of action taken.

Use a bound notebook with a stitched binding. Do not use a loose leaf or Spiral bound notebook.

All entries should be in ink not pencil.

The title, project number, and book number should be accurately recorded when starting a new Page.

All data is to be recorded directly into the notebook. Elaboration of details is preferable. Notes and calculations should be recorded in the notebook. In the case of an error, draw a single line through the incorrect data. Do not erase or use correction fluid. All corrections should be initialed and dated. When making a correction, make a notation of the page number where the correct information is found.

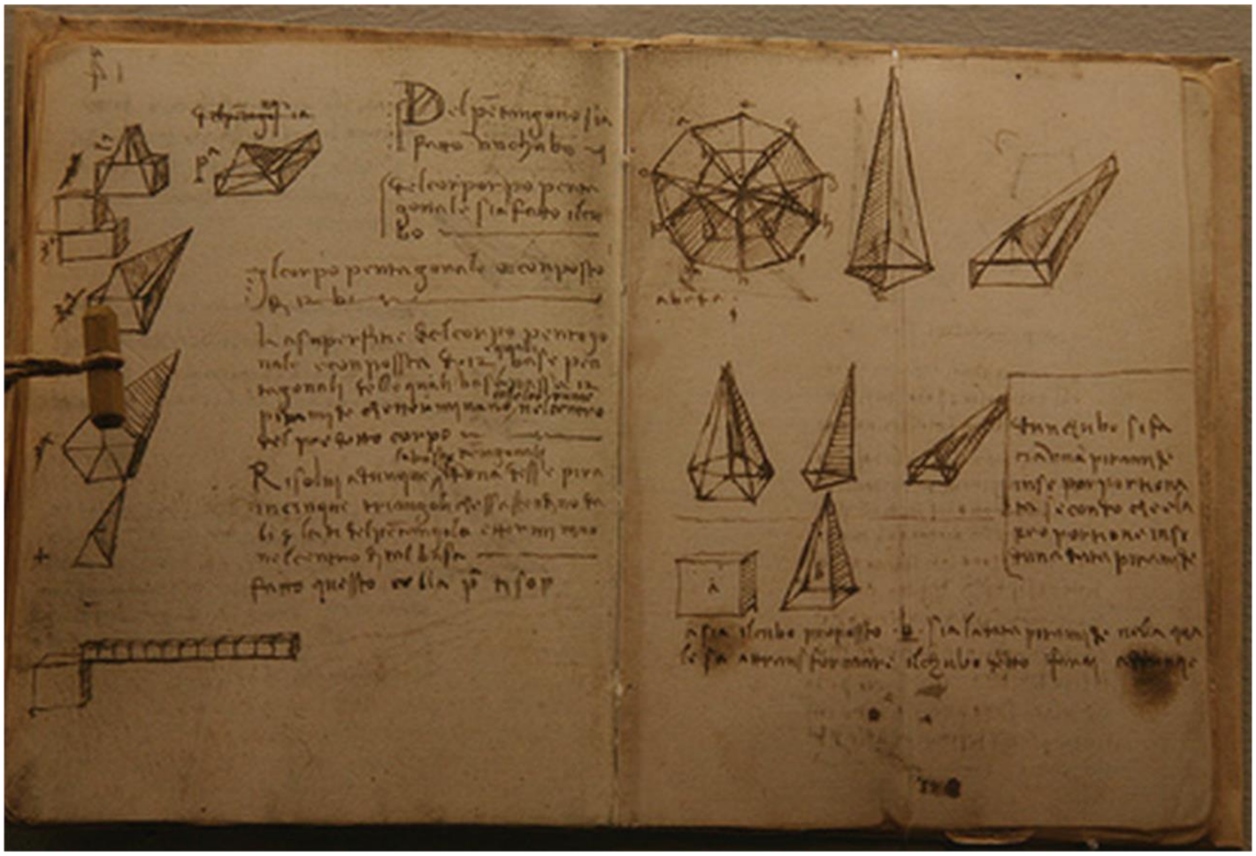
After entering your data, sign and date all entries. Witness or witnesses should sign and date each entry. The witness must observe the work that is done, and have sufficient knowledge to understand what they have read. Names of all who were present during any demonstration, phone conversation or discussion should also be recorded.

Never leave any White Space: "X" out or Crosshatch all unused space, and don't forget to initial and date the entry. Use both sides of the page.

When the notebook is full, begin a new notebook with the title, project number, and book number. Also make a notation of the preceding notebook number. Archive the full notebook in a safe location.

If necessary, items may be taped into the notebook with a handwritten date and title. Permanently attach inserted items (glue is preferred). Sign across the edge of the inserted sheet with half of the signature on the page.

Following this procedure can help students. It will foster improved documentation, research and sketching skills. It can help with time management skills and provide a convenient method for class closure. Early adoption by students of the use of the Engineering Notebook will help with project reports they will be expected to complete.



The pages above come from an Engineering Notebook kept by Leonardo da Vinci. It is a bound notebook containing sketches and explanations.

An example can be found at:
http://web.mit.edu/me-ugoffice/communication/labnotebooks.pdf

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Design Documentation

- A design isn't "read" it is "used".
- The design process goes from least specific to most specific.
- Never write a paragraph when a sentence will do.
- Never write a sentence when a bullet point will do.
- Use Diagrams.
- A good table replaces long narratives.
- Never use adjectives. That is the function of sales people and project managers. (Examples: great, beautiful, wonderful, etc.)
- Use appendixes for supportive information that you think is relevant.

Design documentation is the collection of details about the final design requirements and specifications that illustrate and thoroughly describe a designed product. Writing effective design documentation (like design itself) is really all about making sure you serve the needs of your audience.

Each document must have identification such as Project title, original date of document and names of students in the team, name of person approving the original document, dates of revisions and name of person approving the revision and brief explanation of the revision. Each design might include conceptual drawings, assembly drawings, parts' list, parts drawings, process drawings, flowcharts, state diagrams, use cases, relational tables, tables, programs developed, charts, graphs, rules, symbol diagrams, decision matrix, ladder diagrams, CNC Control programs, schematics, etc.

Items might include:

- 3D CAD Design
- Analysis
    - Finite Element Analysis (FEA)
    - Stress
    - Load Distribution
    - Fluid Flow
    - Heat Transfer
- Conceptual Designs

- Flowcharts
- Instructions
- Linkage Diagrams
- Reference Guides
- Sketches
- Specifications
- Tutorials
- Working Drawings
- Prototypes
    - Black Box Prototype: An existing enclosure or box with mechanical, electrical, optical and or software internals fully functioning.
    - Concept Model: formally describing some aspects of the physical and social world around us for the purposes of understanding and communication
    - Evolutionary Prototyping (also known as breadboard prototyping) a very robust prototype in a structured manner with the ability to constantly refine it.
    - Feasibility Prototype: Determine feasibility of various solutions
    - Functional Storyboarding: Determine useable sequences for presenting information
    - Horizontal Prototype: Demonstrates outer layer of human interface only, such as windows, menus, and screens
    - Mathematical Prototype: algorithm development for analysis operations
    - Mock up: A rough construction using crude materials such as cardboard, foam, paper or wood typically done to show the idea in 3D form.
    - Model: A form built and painted for aesthetic appearance only
    - Presentation Prototype: representation of the product as it will be manufactured. Often used for promotional purposes.
    - Proof of Concept: The use of existing materials, parts and components to prove the new Idea works or not.
    - Rapid Prototype: A group of techniques used to quickly fabricate a scale model of a part or assembly using three dimensional CAD data. Frequently associated with 3D printing.
    - Usability prototypes used to define, refine, and demonstrate user interface design usability, accessibility, look and feel.
    - Vertical Prototype: Refine database design, test key components early
    - Virtual Prototype: 3D Computer Aided Design (CAD) rendering
    - Working Prototype: A fully functioning item yet may not be fully designed & engineered for manufacturability, nor it may not be appearance like.

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Problem Statement

The problem statement is the statement that the students write from their preliminary research and is their definition, or redefinition, of the problem as they understand it. It is a clear and concise description of the issues that need to be addressed by the team.

The problem statement becomes part of the Design Brief and consists of several parts in a few sentences. It includes:

- The **Vision Statement**: This statement describes the goals, values or the desired results that solving the issue will have.
- The **Issue Statement**: This statement is a sentence or two that describes the problem or what is preventing the vision from being accomplished using specific issues. This would consist of the "Who, What, When, Where, and Why" of what is getting in the way of solving the issue.
- The **Method Statement**: This describes the approach the team will take to solve the problem.

Example:

Bicycles are an efficient and low pollution method of transportation in overcrowded urban areas that frequently move faster than motorized transportation. Secure storage, passenger safety and inclement weather all impact the desirability of adopting this mode of transportation. We are proposing to design an enclosed hybrid pedal powered vehicle that will allow use in all weather, provide greater passenger safety and have the same ability to be secured as a car while taking up a fraction of the space.

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Design Brief

A design brief is used to provide a summary of how a problem will be approached. This way the customer will know the exact problem you will be solving for them and a projection of the resources needed. This is usually a one to two page document meant to quickly communicate the scope and goals of a specific design project. The document is focused on the desired results of design. It is frequently done in conjunction with the client.

Design briefs should have the following sections.

- Objectives and Goals of the Design
- Client and Context
- Scope of the Project
- Problem Statement or Description
- Resources and Budget
- Constraints
- Time Needed
- Other (depending on need)

Example:

Client and Context of the Problem
Reflective Gear, manufacturer of safety gear for cyclists is designing a new line of gear for people who cycle or run in periods of low light. Accidents are four times more probable at night.

Problem Statement:
Ideally the clothing should be lightweight, comfortable to wear, durable and washable. Existing clothing is either uncomfortable or not reflective enough for safety in dark environments. The company has contacted us to design new reflective designs, either passive such as reflective tape or active LED based systems.

Criteria and Constraints:

The design proposed needs to provide a reflected light with minimum loss so it is plainly visible at 100 feet. If we select an LED system it must be visible at 100 feet and have a minimum battery life of 50 hours. The design must survive repeated washings and not lose reflectivity. The total weight allowed is 6.5 ounces in addition to the base clothing.

Objectives and Goals:
We will experiment and report back on various ways to achieve the necessary visibility within the weight and comfort limits.

Scope of the Project:
We will test various methods of utilizing reflective strips. We will develop a method of attaching the reflective strips with the goal of less than 1% failure after 10 washings. We will experiment with various methods of using LEDs in clothing. We will not design the clothing, only using clothing provided by Reflective Gear. We will not test for clothing survival over a period of years.

Resources Needed:
Our team will need access to the latest clothes designs from Reflective Gear. We will need access to reflective materials and plastic strip sealer/heaters to experiment with easy methods used to incorporate the reflective material. LED strips and power sources will also be needed. We will need resources for three members of the team for a month along with necessary computer and measuring resources.

Time needed:
It is our estimate that testing and reporting can be done in one month's time from the date of the agreement. We will provide our report and examples of our visibility solution with the report.

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Project Management Plan

A project management plan is a formal written document to establish the process and procedures used to guide a project from inception to conclusion. The larger the project the greater the detail needed. It communicates to the team and their clients, information about the management of the necessary details and who will be responsible for each component. Every project will be different but the following sections give you an idea what to include.

- Customer:
- Project Summary (includes purpose, goals, assumptions/guess, and constraints):
- Scope (deployment and management, lists work to be included and excluded):
- Budget (breakdown of costs to complete the job):
- Team Communication Plan (Who should be invited, what skills, backgrounds and professions should be represented, will the audience members be presented with information/documents prior to the presentation? If so, what information? How?):
- Time Schedule (includes milestones to be met):
- Project Delivery Plan (how end products will be delivered to the customer):
- Quality Management Plan (how does it meet industry standards):
- Risk Management Plan (identification, assessment, and prioritization of risks):
- Compliance Plan (describe how it meets all regulations):

Example:

Customer:
Our client is the company Reflective Gear. They specialize in athletic clothing designed for people who work out in the dark, at dusk or dawn when accidents are more likely to occur. They would like us to design a way for their clothing line to show up better to keep their customers safer.

Project Team:
Our team consists of four people.

Wendy: Team Leader
Joe: Secretary and Editor
Linda: Time Keeper and Communications Director
Jose: Technical Lead and Researcher

Summary:
Our goal is to conduct research and experiments to determine which types of reflective devices should be incorporated to meet the customer needs. We believe that we must test several different combinations of materials and LED lighting. We will design testing to assure our final recommendation meets the needs of our client.

Scope:
Our goal is to research reflectivity and light generation to provide the most durable combination of elements with the greatest visibility to drivers. We will be testing reflective materials and various combinations of LEDs. We will make recommendations for how these materials will attach to existing clothing designs. We will not be creating new clothing designs or suggesting manufacturing options.

Budget:
Our team will need four weeks to complete our testing and report generation. We will need testing equipment such as cameras as well as computer equipment for recording the process. In addition to salaries and benefits our standard overhead of 40% applies to provide electricity, data connection, heat, phone service and printing costs.

Communication Plan:
The team will create a design brief to share with the client. Feedback from the client will be incorporated in our management plan. At the conclusion of our work we will provide an overview of the work, samples of our selection and a printed copy of our report including data gathered for client use.

Time Schedule:

Week 1	Week 2	Week 3	Week 4	
Team Formation				
Basic research				
Budget				
Management plan				
	Research into reflective materials			
	Preliminary Testing			
	Survey Designs			
	Testing Protocol			
		Prototype creation		
		Testing of prototype		
		Testing setup		
		Evaluate and Improve		
			Report generation	
			Presentation preparation	
				Presentation
				End of project life

Quality Management Plan
The team will develop the testing protocol and monitor testing to assure the prototype will last the predicted number of washings and to assure that the design can meet the visibility criteria

.

Risk Management Plan
The team will create a plan to identify and plan for addressing all types of risk. If the clothing will utilize LEDs the plan will include electrical safety.

Compliance Plan
The team will create a plan for compliance with all applicable regulations. The plan will include how the clothing will meet the UL electrical codes.

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Testing Protocol

- *Introduction:* What is the project about and what are the critical parts that need testing?
- *Test Strategy*: How are you going to test the part or component and under what conditions?
- *Data Collection Plan*: Sampling Plan: How are you going to collect the information? Will this be a random sample of a run? One time testing of a craft build prototype?
- *Measurement Capability and Equipment*: What are you measuring and how accurate do you have to be? What kind of testing equipment will be needed?
- *Definition of a Successful Test, Pass / Fail Criteria*: This is a description of what constitutes success. For example, not breaking after 100 repetitions or being within measurement tolerances etc.
- *Test Conditions, Setup Procedure:* How will you set up the test? If someone else has to duplicate your test, will they use the same procedure?
- *Logistics and Documentation*: This is a description of what was tested and how.
- *Analysis of Data – Design Summary*: What happened during testing?
- *Conclusion or Design Summary:* What did the test tell you?

Example:

Introduction:
This project involved the creation of a method to alert drivers to the presence of a person in the dark near the highway. The system to be tested must be visible from 100 feet away in dim light situations. To assure the design meets the criteria a testing method must demonstrate the ability of the product to communicate the bicycles presence to a driver more than 100 feet in advance.

Test Strategy:
Various designs will be tested for reflective light at 100 feet. All tests will require the equivalent of a car head light pointing at the reflective gear from 100 feet away. We will photograph results of each test of the reflective gear and/or LED display. The photographs will be compared and analyzed to determine the best selection or combination of strategies to incorporate. In addition to cameras we will also use light meters to measure lumens. Our last test will involve a survey of drivers who will provide feedback on the easiest system to see when driving down the road.

Data Collection Plan
Photos will be labeled and the data tagged upon the picture. The pictures will include data upon the brightness of the reflected light as well as the contrast. Surveys will ask four questions relating to the easiest design to see as well as the drivers comfort level when seeing the test reflected object. Surveys will be given to test subjects about the comfort of the item and ease of use.

Measurement Capability
We will need a standard digital camera and software to allow the pictures to be analyzed to show which combination of reflectors/LEDs are the brightest at 100 feet. Lumens will be measured utilizing a lux meter and the results added to the database of pictures and driver responses. A stationary headlight, 12V battery and a camera will be used to simulate cars at 100 feet. Real drivers will drive by the test subject and record their impressions. Visibility distance will need to be measured.

Definition of a Successful Test:
The selected solution will provide a combination of the greatest reflected light, driver responses and distance measurements. The solution will need to below the preset weight limit and be comfortable to test subjects. The solution must survive the laundry test and be comfortable to wear as judged by the survey of users.

Test Conditions:
The tests will be conducted at dawn, dusk and fully dark. Fog or mist would be beneficial to have when tests are conducted but not necessary.

The laundry test will be conducted after the first night light test. Items will be washed 10 times and then the tests with cameras, lights, and drivers will be repeated.

Two surveys will be given to people wearing the device. The first before the washing test and the second after it has been washed 10 times.

Logistics and Documentation:
Surveys for the test drivers will be combined with the measurement data for each proposed solution. Graphs of visibility will be created along with a chart with all solutions so they can be compared.

Analysis of data:
Pictures will be measured to determine which provide the greatest reflected light. The driver responses will be added to the data to account for "human factor" and perception. The optimum solution will provide the best combination of results. The picture analysis will count for 50% of the score, light detection at 100 feet will account for 25% of the final result and the driver reactions to what they observed while driving will count for other 25%.

Conclusion:
We hope that the combination of test results will provide us with the best possible solution to recommend. A major component of the engineering report will be based upon the results of the testing and anecdotal reporting on surveys.

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Decision Matrix

When the list of options needs to be limited to one choice, design engineers sometimes use a decision matrix based upon weighted priorities and available information. It is easier to make decisions if they are based upon the protocol you set up. The decision with the highest score is the one to begin with.

General steps in the process are -

1. *Define the ideal solution*: Members define all the characteristics that are important for the decision. There is usually a brainstorming session to define the criteria for inclusion or exclusion.
2. *Establish Priorities*: From all the characteristics listed which are the most important or least. The examples below rate the weight as 1-10
3. *Place these in a matrix form*.
4. *Assign values for each choice*: Each characteristic is compared to the ideal and rated on a scale. These examples use a 1-5 scale but any scale is posible. (1 through 5 is ideal)
5. *Calculate weighted scores*: The rating on each characteristic times the weighting
6. *Summation of the scores***:** Consider using Microsoft Excel for developing the matrix and formatting the document to calculate the scores automatically.

Sample Decision Matrix
What is the best social media for our business?

Characteristic	**Weight**	**Website**		**Blog**		**LinkedIn**		**Twitter**	
		Raw	**Total**	**Raw**	**Total**	**Raw**	**Total**	**Raw**	**Total**
Generate new customers	**9**	5	45	5	45	2	18	1	0
Improve networking and making connections with new and old customers	**7**	3	21	2	14	5	35	4	28

Deepen existing connections with my customers	**8**	3	24	4	32	4	32	4	32
Receive customer feedback	**6**	2	12	0	0	0	0	1	6
Increase the visibility of my business to the public	**9**	4	36	5	45	4	36	3	27
Increase on-line sales	**9**	5	45	2	18	0	0	0	0
Totals	**---**	**---**	**183**	**---**	**154**	**---**	**121**	**---**	**93**

Matrix for siting a plant

		City 1		**City 2**		**City 3**		**City 4**	
Characteristics	Weight	Raw Score	Total Score	Raw Score	Total Score	Raw Score	Total Score	Raw Score	Total Score
Proximity of the plant to the market	6	3	18	4	24	2	12	5	30
Proximity to raw materials	2	5	10	1	2	4	8	1	2
Proximity to Transportation	9	1	9	2	18	3	27	5	45
Local Labor costs	4	2	8	5	20	4	16	2	8
Labor force education	7	2	14	4	28	3	21	5	35
Community attitude	4	4	16	3	12	2	8	3	12
Availability of supporting industries	6	3	18	2	12	3	18	5	30
Suitability of land	6	5	30	2	12	5	30	4	24
Cost of Land	4	3	12	3	12	5	20	1	4
Community regulations	8	3	24	4	32	4	32	2	16
Communication infrastructure	3	4	12	5	15	2	6	5	15
Utility infrastructure	7	4	28	5	35	2	14	5	35
Community resources for workforce	2	5	10	4	8	2	4	5	10
Total Score			209		230		216		266

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Engineering Report

Good report organization should promote readability and reflect the scientific method, which proceeds with objective, method, results, and conclusions. It is logical to report a project in the sequence in which it is done. Many engineering reports are organized on this basis. Two improvements to the logical sequence are the addition of an abstract or executive summary and the insertion of headlines. These two features facilitate "scanning" of the report. Thus, a busy executive or engineer may quickly assess the major findings and conclusions of the report, and then easily find further details as required.

Sections that should be included:

- Title Page. Identify the group members, project, dates and timeframe.
- Summary or Abstract (Executive Summary)
- Nomenclature. Students need to list and define all science and engineering terms and measurements used in the report.
- Introduction. This should include the entire project description.
- Theory and Analysis
- Experimental Procedures
- Results and Discussion
- Conclusions and Recommendations
- Acknowledgments
- Literature Cited
- Appendix

Assessment Rubrics

Assessment comes in both formative and summative. It is an integral part of quality instruction. During the course of the projects one of the teacher's main functions is to work with student groups, keeping track of progress and providing formative assessment in the form of feedback and promoting reflection on the part of students. The focus should be on lifetime and 21st century skills. The goal of instruction is to promote abilities in research, problem solving, design, experimenting, testing and collecting data.

Rubrics are used in the assessment process to communicate expectations of quality of a task. Rubrics should be shared with students at the beginning of a project so they can clarify any misconceptions before beginning work. They can then build the skills and gather knowledge to solve the problem presented to the expectations of excellence described.

General Rubrics for Literacy tasks

Individual Project Rubrics

Quarter 1

Quarter 2 Projects

- Engraved Name Plate Rubric
- Soda Can Opener Rubric
- Game Piece Design Rubric
- Box Design with Interlocking Top Rubric
- Split Mold Rubric

Quarter 3 Projects

- Conveyor with Counter Rubric
- Garage Door Rubric
- Sun Tracking Solar Panel Rubric
- Sort by Color Rubric
- Elevator Control Rubric
- Parking Lot Gate Rubric

Quarter 4 Projects

- Automatic Pneumatic Clamping Rubric
- Automatic Pneumatic Feeder Rubric
- Conveyor Sorting Rubric
- Automated Work Cell for CNC Rubric

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Literacy Rubric for Argumentative or Persuasive Project				
	Not Yet	**Getting There**	**Meets Expectations**	**Exceeds Expectations**
	1	**2**	**3**	**4**
Focus	An attempt to answer the problem, but the response lacks focus.	Answers the problem and states a position but the focus is varying or weak.	Fully answers the problem keeping a clear focus. Argument is generally convincing.	Fully answers the problem keeping a very clear focus and strong, convincing argument.
Main Idea	Attempts to create a main idea but lacks focus and clarity. No mention of argument other than their own.	Creates an argument and makes note of claims of other than their own.	Creates a convincing argument; develops and presents argument and counter argument fairly.	Creates a convincing and meaningful argument; develops and presents argument and counter arguments fairly and fully.
Reading & Research	Tries to present information but does not connect it to the problem.	Presents information from research that addresses the problem with only small errors.	Presents accurate and relevant information from research that helps develop their argument	Effectively presents accurate and relevant information from research that develops a strong argument.
Development	Tries to give details but they are poorly written or do not apply to the problem. They make no claim, or make an irrelevant claim	Gives details to support their main idea with only minor weaknesses in reasoning. Makes a weak claim.	Gives details that fully support the main idea and answer the problem. Gives an example that helps clarify the claim.	Gives thorough details that fully support the main idea and strongly answer the problem. Makes strong connections to their argument that clarifies and helps the reader

				understand the claim.
Organization	Tries to organize ideas but lacks structure.	Organizes ideas to fulfill requirements, with some gaps in structure.	Organizes response to meet all requirements of the problem. Organization reveals the reasoning behind the claim.	Organizes response in a way that enhances the information given in response to the problem. Organization reveals the reasoning behind the argument and creates more support for it.
Conventions of English	Writes response with many errors in grammar, usage and writing mechanics. Sources of research are not cited.	Is inconsistent with grammar, usage, and mechanics; uses tone and language inappropriate to audience or topic. Only some sources are cited.	Work has very few errors in grammar, usage, and mechanics; tone and language are appropriate to the project and audience. Few errors in citation formatting.	Demonstrates a full command of the conventions of English; tone and language enhance the response. Consistently and correctly cites sources.
Understanding of Content	Tries to show understanding of content but knowledge is weak or incorrect.	Connects basic knowledge of content to problem, shows minor errors in understanding.	Presents full factual understanding of content as it applies to the project.	Presents in-depth understanding of content that applies to, and enhances, the response to the project.

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Informational Explanatory Rubric				
	Not Yet	**Getting There**	**Meets Expectations**	**Exceeds Expectations**
	1	**2**	**3**	**4**
Focus	An attempt to answer the problem, but response lacks focus.	Answers the problem but the focus is varied or distracted.	Fully answers the problem keeping a clear focus.	Fully answers the problem keeping a very well developed and clear focus.
Main Idea	Attempts to create a main idea but lacks focus and clarity.	Creates a basic main idea with general purpose.	Creates a main idea with a clear purpose that is carried though the piece.	Creates a strong main idea with a clear purpose that guides the response throughout the piece.
Reading & Research	Tries to present information but does not connect it to the problem. Does not evaluate the integrity of sources.	Presents information from research that addresses the problem with only small errors Starts to evaluate the integrity of sources.	Presents detailed information from research that helps answer the problem. Evaluates the integrity of sources.	Selectively presents detailed information that helps answer all parts of the problem. Evaluates the integrity of sources and identifies credible sources.
Development	Tries to give details but they are poorly written or do not apply to the problem. Does not address implication of project, or it is irrelevant.	Gives details to support the main idea and answer the problem. Mentions implications of project or an unanswered question.	Gives details that fully support the main idea and answer the problem. Explains the implications of project and an unanswered question.	Gives thorough details that fully support the main idea and strongly answer the problem. Entirely explains the implications of project and one or

	Does not address unanswered questions.			more unanswered questions.
Organization	Tries to organize ideas but lacks structure.	Organizes ideas to fulfill requirements, with some gaps in structure.	Organizes response to meet all requirements of the problem.	Organizes response in a way that enhances the information given in response to the problem.
Conventions of English	Writes response with many errors in grammar, usage and writing mechanics. Sources of research are not cited.	Is inconsistent with grammar, usage, and mechanics; uses tone and language inappropriate to audience or topic. Only some sources are cited.	Work has very few errors in grammar, usage, and mechanics; tone and language are appropriate to the project and audience. Few errors in citation formatting.	Demonstrates a full command of the conventions of English; tone and language enhance the response. Consistently and correctly cites sources.
Understanding of Content	Tries to show understanding of content but knowledge is weak or incorrect.	Connects basic knowledge of content to problem, shows minor errors in understanding.	Presents full factual understanding of content as it applies to the project.	Presents in-depth understanding of content that applies to, and enhances, the response to the project.

Comments: **Total---->**

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SIEMENS

Ingenuity for life

Archimedes Screw Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches or research	Shows some evidence of notes, sketches and research	Evidence of most notes, sketches and research	Clear notes and sketches with all research documented and signed	
Cooperative Group Work	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The sketches are incomplete or poorly drawn. They are hard to read	The sketches are complete , but design is poor and will not link to other blocks	The project is complete, well constructed and will link to other blocks	The project is complete, well planned, always works and is easily adaptable to the set.	
Presentation	Some difficulty communicating ideas. 1 member presents to class	Good communication. 1 member presents to class	Group communicates well and all members present to class.	Entire group communicates with enthusiasm. All members contribute and know their responsibilities	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Archimedes Screw Characteristics	Prototype is incomplete	Prototype is complete but does not work	Prototype is complete and works but parts fit together poorly	Prototype is complete, works and parts fit perfectly	

Comments:

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Ingenuity for life

Windmill Hub Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches or research	Shows some evidence of notes, sketches and research	Evidence of most notes, sketches and research	Clear notes and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or partially designed.	The project is complete, but design is poor and will not work	The project is complete, well constructed	The project is complete, well planned, always works and is greatly improved.	
Presentation	Some difficulty communicating ideas. Drawings are hard to read	Reasonable communication. Tough to follow at times. Fair drawings	Communicates very well and easy to follow. Good drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional drawings	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Windmill Hub Characteristics	Prototype is incomplete	Prototype is complete but does not work	Prototype is complete and works but parts fit together poorly	Prototype is complete, works and parts fit perfectly	

Comments:

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Ingenuity for life

Reverse Engineering Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches or research	Shows some evidence of notes, sketches and research	Evidence of most notes, sketches and research	Clear notes and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or poorly created. Drawings are hard to read	The project is complete, but design is poor and did not meet original criteria	The project is complete, well-constructed and meets requirements	The project is complete, well planned, always works and is easily adaptable to many situations	
Presentation	Some difficulty communicating ideas.	Reasonable communication and tough to follow at times	Communicates very well and easy to follow	Communicates with enthusiasm, well prepared and well spoken.	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Reverse Engineering Characteristics	Prototype is incomplete	Prototype is complete but does not work	Prototype is complete and works but parts fit together poorly	Prototype is complete, works and parts fit perfectly	

Comments:

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Ingenuity for life

Spool Mechanism for Kite Spool Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches or research	Shows some evidence of notes, sketches and research	Evidence of most notes, sketches and research	Clear notes and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or partially designed.	The project is complete, but design is poor.	The project is complete, well-constructed.	The project is complete, well planned, always works and is greatly improved.	
Presentation	Some difficulty communicating ideas. Poor drawings	Reasonable communication. Tough to follow at times. Fair drawings	Communicates very well and easy to follow. Good drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional drawing techniques.	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Kit String Winder Characteristics	Prototype is incomplete	Prototype is complete but does not work	Prototype is complete and works but parts fit together poorly	Prototype is complete, works and parts fit perfectly	

Comments:

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Ingenuity for life

Hair Dryer Caddy Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes , sketches or research	Shows some evidence of notes, sketches and research	Evidence of most notes, sketches and research	Clear notes and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or poorly created. Drawings are hard to read	The project is complete, but design is poor and did not meet original criteria	The project is complete, well-constructed and meets requirements.	The project is complete, well planned, always works and is easily adaptable to several sets.	
Presentation	Some difficulty communicating ideas.	Reasonable communication and tough to follow at times	Communicates very well and easy to follow.	Communicates with enthusiasm, well prepared and well spoken.	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Hair Dryer Caddy Characteristics	Prototype is incomplete	Prototype is complete but does not work	Prototype is complete and works but parts fit together poorly	Prototype is complete, works and parts fit perfectly	

Comments:

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Ingenuity for life

Engraved Name Plate Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches or research	Shows some evidence of notes, sketches and research	Evidence of most notes, sketches and research	Clear notes and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or partially designed.	The project is complete, but design is poor and will not work with original requirements	The project is complete, well-constructed and meets requirements	The project is complete, well planned, always works and is an innovative solution.	
Presentation	Some difficulty communicating ideas. Drawings are hard to read	Reasonable communication. Tough to follow at times. Fair Drawings	Communicates very well and easy to follow. Good Drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional Drawings	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Name Plate Characteristics	Prototype is incomplete	Prototype is complete but program is not efficient	Prototype is complete and program is efficient	Prototype is complete and professional looking. Program is well documented	

Comments:

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Ingenuity for life

Soda Can Opener Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches or research	Shows some evidence of notes, sketches and research	Evidence of most notes, sketches and research	Clear notes and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or partially designed.	The project is complete, but design is poor and will not work with original constraints	The project is complete, well-constructed and will work	The project is complete, well planned, always works and is easily adaptable	
Presentation	Some difficulty communicating ideas. Poor drawings	Reasonable communication. Tough to follow at times. Several mistakes on drawings	Communicates very well and easy to follow. Few mistakes on drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional drawings	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Soda Can Opener Characteristics	Prototype is incomplete	Prototype is complete but program is not efficient	Prototype is complete and program is efficient	Prototype is complete and professional looking. Program is well documented	

Comments:

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Ingenuity for life

Game Piece Design Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes , sketches or research	Shows some evidence of notes, sketches and research	Evidence of most notes, sketches and research	Clear notes and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or poorly made.	The project is complete, but design is poor and will not contain an object	The project is complete, well-constructed and will hold an object	The project is complete, well planned, always works and is easily adaptable to different objects.	
Presentation	Some difficulty communicating ideas.	Reasonable communication, tough to follow at times.	Communicates very well and easy to follow.	Communicates with enthusiasm, well prepared and well spoken.	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Game Piece Characteristics	Prototype is incomplete	Prototype is complete but program is not efficient	Prototype is complete and program is efficient	Prototype is complete and professional looking. Program is well documented	

Comments: **Total---->**

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Ingenuity for life

Box Design with Interlocking Top Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches or research	Shows some evidence of notes, sketches and research	Evidence of most notes, sketches and research	Clear notes and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or partially designed.	The project is complete, but design is poor and will not work with original constraints	The project is complete, well-constructed and will work	The project is complete, well planned, always works and is easily adaptable	
Presentation	Some difficulty communicating ideas. Poor drawings	Reasonable communication. Tough to follow at times. Several mistakes on drawings	Communicates very well and easy to follow. Few mistakes on drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional drawings	
Completeness of Requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Box Characteristics	Prototype is incomplete	Prototype is complete but program is not efficient	Prototype is complete and program is efficient	Prototype is complete, and professional looking. Program is well documented	

Comments: **Total---->**

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Ingenuity for life

Split Mold Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches or research	Shows some evidence of notes, sketches and research	Evidence of most notes, sketches and research	Clear notes and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or partially designed.	The project is complete, but design is poor and will not work with original constraints	The project is complete, well-constructed and will work	The project is complete, well planned, always works and is easily adaptable	
Presentation	Some difficulty communicating ideas. Poor drawings	Reasonable communication. Tough to follow at times. Several mistakes on drawings	Communicates very well and easy to follow. Few mistakes on drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional drawings	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Mold Characteristics	Mold is incomplete	Mold is complete but done incorrectly	Mold is complete but is lacking details	Mold is complete, has met all requirements, well documented and is ready to cast	

Comments: **Total---->**

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Ingenuity for life

Conveyor with Counter Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches or research	Shows some evidence of notes, sketches and research	Evidence of most notes, sketches and research	Clear notes and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or partially designed.	The project is complete, but design is poor and will not work with original constraints	The project is complete, well-constructed and will work	The project is complete, well planned, always works and is easily adaptable	
Presentation	Some difficulty communicating ideas. Poor drawings	Reasonable communication. Tough to follow at times. Several mistakes on drawings	Communicates very well and easy to follow. Few mistakes on drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional drawings	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Conveyor with Counter Characteristics	Prototype is incomplete	Prototype is complete but program is not efficient	Prototype is complete and program is efficient	Prototype is complete and professional looking. Program is well documented	

Comments: **Total---->**

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Ingenuity for life

Garage Door Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes , sketches or research	Shows some evidence of notes, sketches and research	Evidence of most notes, sketches and research	Clear notes and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or partially designed.	The project is complete, but design is poor and will not work with original constraints	The project is complete, well-constructed and will work	The project is complete, well planned, always works and is easily adaptable	
Presentation	Some difficulty communicating ideas. Poor construction	Reasonable communication. Tough to follow at times. Fair construction	Communicates very well and easy to follow. Good construction	Communicates with enthusiasm, well prepared and well spoken. Exceptional construction	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Garage Door Characteristics	Prototype is incomplete	Prototype is complete but program is not efficient	Prototype is complete and program is efficient	Prototype is complete and professional looking. Program is well documented	

Comments: **Total---->**

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Ingenuity for life

Sun Tracking Solar Panel Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches, research and calculations	Shows some evidence of notes, sketches, research and calculations	Evidence of most notes, sketches, research and calculations	Clear notes, calculations and sketches with all research documented and signed	
Cooperative Group Work	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or partially designed.	The project is complete, but design is poor and will not work with original constraints	The project is complete, well-constructed and will work	The project is complete, well planned, always works and is easily adaptable	
Presentation	Some difficulty communicating ideas. Poor drawings	Reasonable communication. Tough to follow at times. Several mistakes on drawings	Communicates very well and easy to follow. Few mistakes on drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional drawings	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Sun Tracking Solar Panel Characteristics	Prototype is incomplete	Prototype is complete but program is not efficient	Prototype is complete and program is efficient	Prototype is complete and professional looking. Program is well documented	

Comments: **Total---->**

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Ingenuity for life

Sort by Color Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches, research and calculations	Shows some evidence of notes, sketches, research and calculations	Evidence of most notes, sketches, research and calculations	Clear notes, calculations and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or partially designed.	The project is complete, but design is poor and will not work with original constraints	The project is complete, well-constructed and will work	The project is complete, well planned, always works and is easily adaptable	
Presentation	Some difficulty communicating ideas. Poor drawings	Reasonable communication. Tough to follow at times. Several mistakes on drawings	Communicates very well and easy to follow. Few mistakes on drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional drawings	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Sort by Color Characteristics	Prototype is incomplete	Prototype is complete but program is not efficient	Prototype is complete and program is efficient	Prototype is complete and professional looking. Program is well documented	

Comments: **Total---->**

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Ingenuity for life

Elevator Control Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches or research	Shows some evidence of notes, sketches and research	Evidence of most notes, sketches and research	Clear notes and sketches with all research documented and signed	
Cooperative Group Work	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or partially designed.	The project is complete, but design is poor and will not work with original constraints	The project is complete, well-constructed and will work	The project is complete, well planned, always works and is easily adaptable	
Presentation	Some difficulty communicating ideas. Poor drawings	Reasonable communication. Tough to follow at times. Several mistakes on drawings	Communicates very well and easy to follow. Few mistakes on drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional drawings	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Elevator Control Characteristics	Prototype is incomplete	Prototype is complete but program is not efficient	Prototype is complete and program is efficient	Prototype is complete and professional looking. Program is well documented	

Comments: **Total---->**

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Parking Lot Gate Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches, research and calculations	Shows some evidence of notes, sketches, research and calculations	Evidence of most notes, sketches, research and calculations	Clear notes, calculations and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or partially designed.	The project is complete, but design is poor and will not work with original constraints	The project is complete, well-constructed and will work	The project is complete, well planned, always works and is easily adaptable	
Presentation	Some difficulty communicating ideas. Poor drawings	Reasonable communication. Tough to follow at times. Several mistakes on drawings	Communicates very well and easy to follow. Few mistakes on drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional drawings	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Sun Tracking Solar Panel Characteristics	Prototype is incomplete	Prototype is complete but program is not efficient	Prototype is complete and program is efficient	Prototype is complete and professional looking. Program is well documented	

Comments: **Total---->**

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Ingenuity for life

Automatic Pneumatic Clamping Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches, research and calculations	Shows some evidence of notes, sketches, research and calculations	Evidence of most notes, sketches, research and calculations	Clear notes, calculations and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or partially designed.	The project is complete, but design is poor and will not work with original constraints	The project is complete, well-constructed and will work	The project is complete, well planned, always works and is easily adaptable	
Presentation	Some difficulty communicating ideas. Poor drawings	Reasonable communication. Tough to follow at times. Several mistakes on drawings	Communicates very well and easy to follow. Few mistakes on drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional drawings	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Pneumatic Clamping Characteristics	Prototype is incomplete	Prototype is complete but program is not efficient	Prototype is complete and program is efficient	Prototype is complete and professional looking. Program is well documented	

Comments: **Total---->**

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Ingenuity for life

Automatic Pneumatic Feeder Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches, research and calculations	Shows some evidence of notes, sketches, research and calculations	Evidence of most notes, sketches, research and calculations	Clear notes, calculations and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Project Design	The project is incomplete or partially designed.	The project is complete, but design is poor and will not work with original constraints	The project is complete, well-constructed and will work	The project is complete, well planned, always works and is easily adaptable	
Presentation	Some difficulty communicating ideas. Poor drawings	Reasonable communication. Tough to follow at times. Several mistakes on drawings	Communicates very well and easy to follow. Few mistakes on drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional drawings	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Feeder Characteristics	Prototype is incomplete	Prototype is complete but program is not efficient	Prototype is complete and program is efficient	Prototype is complete and professional looking. Program is well documented	

Comments: **Total---->**

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Conveyor Sorting Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches, research and calculations	Shows some evidence of notes, sketches, research and calculations	Evidence of most notes, sketches, research and calculations	Clear notes, calculations and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Solid Modeling Design	Is incomplete or partially designed.	Is complete, but design is poor and will not work with original constraints	Is complete, well-assembled and will work	Is complete, well planned, always works and is easily adaptable	
Presentation	Some difficulty communicating ideas. Poor drawings	Reasonable communication. Tough to follow at times. Several mistakes on drawings	Communicates very well and easy to follow. Few mistakes on drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional drawings	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Conveyor Sorting Characteristics	Prototype is incomplete	Prototype is complete but program is not efficient	Prototype is complete and program is efficient	Prototype is complete and professional looking. Program is well documented	

Comments:

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Automated Work Cell for CNC Rubric

Criteria	Novice-1	Apprentice-2	Proficient-3	Expert-4	
Engineering Notebook	No evidence of notes, sketches, research and calculations	Shows some evidence of notes, sketches, research and calculations	Evidence of most notes, sketches, research and calculations	Clear notes, calculations and sketches with all research documented and signed	
Cooperative Group Work (As Needed)	One student did all or most of the work in the group	Most team members did some work but workload varied	All team members did some work but workload varied	Workload is divided and shared equally by all group members	
Solid Modeling Design	Is incomplete or partially designed.	Is complete, but design is poor and will not work with original constraints	Is complete, well-assembled and will work	Is complete, well planned, always works and is easily adaptable	
Presentation	Some difficulty communicating ideas. Poor drawings	Reasonable communication. Tough to follow at times. Several mistakes on drawings	Communicates very well and easy to follow. Few mistakes on drawings	Communicates with enthusiasm, well prepared and well spoken. Exceptional drawings	
Completeness of requirements	Less than 60% of the requirements are met	Between 60 and 80% of the requirements are met	Between 81 and 99% of the requirements are met	Total inclusion of all tasks. 100% of requirements are met	
Workcell for CNC Characteristics	Prototype is incomplete	Prototype is complete but program is not efficient	Prototype is complete and program is efficient	Prototype is complete and professional looking. Program is well documented	

Comments:

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Where do you Want to Go?

This page contains links back to the Daily Plan for each project.

Quarter 1

Quarter 2

Quarter 3

Quarter 4