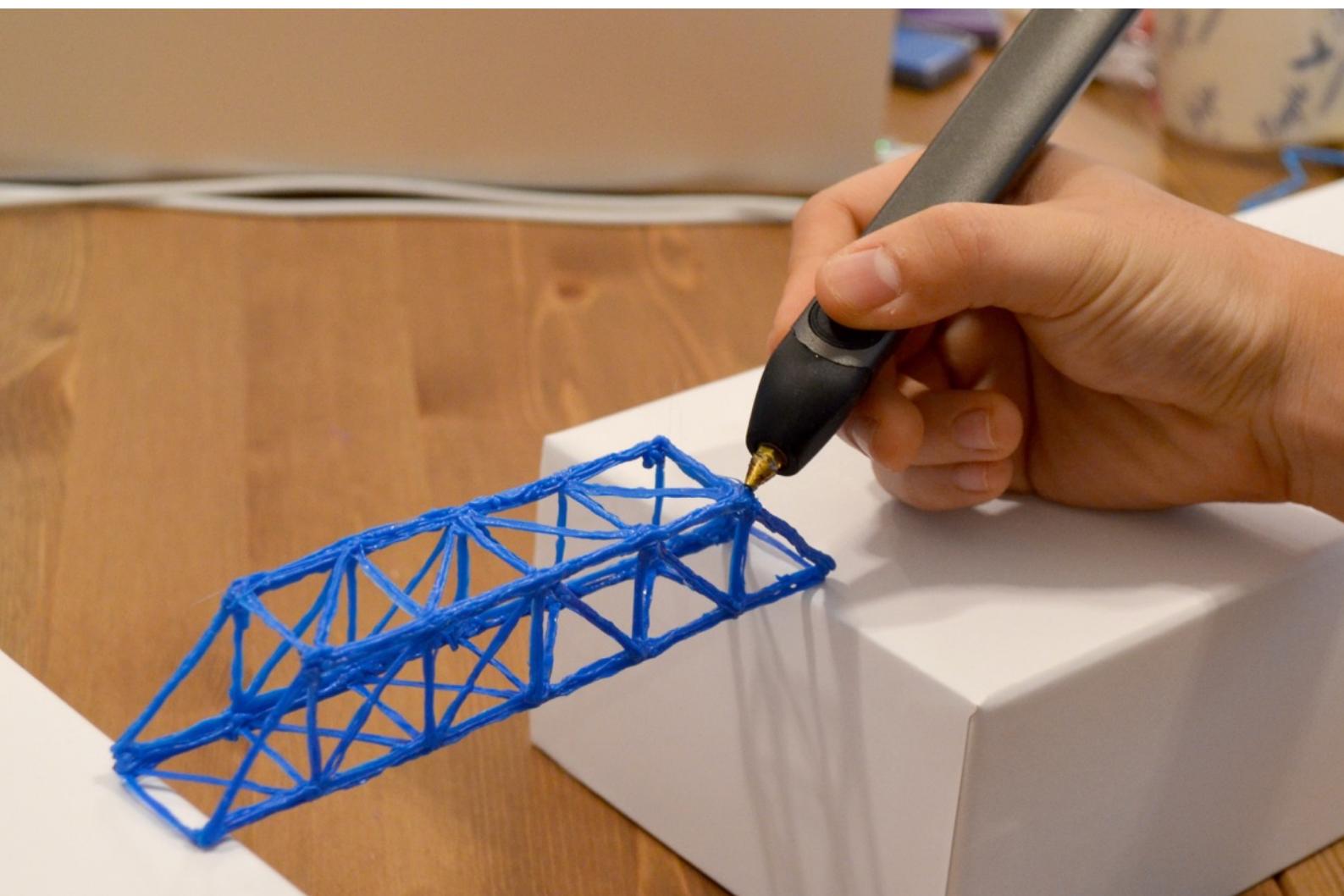


# Bridge Engineering and Design

A STEM Introduction with 3Doodler



## Suitable Ages:

Suitable for ages 14+

## Skill Level:

Intermediate

## Materials Required:

Please see the daily pacing guide at p. 10 for materials requirements for each activity.

## Duration:

Roughly 22 class periods of 45 minutes each.

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# Introduction

This plan is set out to assist teachers in an authentic STEM experience for their students. The schedule included is very tentative, and groups could take longer to complete steps along the way. Students who are not used to being in charge of their project may need help and guidance as they work thought the process. In the Project Description below is an explanation of the project the students will be creating the design for. Many of the activities along the way are designed to give them the design and analysis tools necessary to figure out their own design. No two designs will be the same. There is no single approach to solving the problem and no single correct answer. Students will learn from failure and it is important to let them know it is the process that is important.

# Applicable Standards

## Career Technical Standards

Career Technical Standards from The National Association of State Directors of Career Technical Education Consortium (NASDCTEc):

### Science, Technology, Engineering & Mathematics Career Cluster™ (ST)

1. Apply engineering skills in a project that requires project management, process control and quality assurance.
2. Use technology to acquire, manipulate, analyze and report data.
5. Demonstrate an understanding of the breadth of career opportunities and means to those opportunities in each of the Science, Technology, Engineering & Mathematics Career Pathways.
6. Demonstrate technical skills needed in a chosen STEM field.

### Engineering & Technology Career Pathway (ST-ET)

1. Use STEM concepts and processes to solve problems involving design and/or production.
2. Display and communicate STEM information.
3. Apply processes and concepts for the use of technological tools in STEM.
4. Apply the elements of the design process.
5. Apply the knowledge learned in STEM to solve problems.

### Science & Mathematics Career Pathway (ST-SM)

1. Apply science and mathematics to provide results, answers and algorithms for engineering and technological activities.
2. Apply science and mathematics concepts to the development of plans, processes and projects that address real world problems.
4. Apply critical thinking skills to review information, explain statistical analysis, and to translate, interpret and summarize research and statistical data.

## Mathematics & Science

### Mathematics Common Core College & Career-Readiness Standards:

- Number and Quantity
  - Quantities N-Q
    - 1. Use 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.
    - 2. Define appropriate quantities for the purpose of descriptive modeling.
    - CCSS.MATH.CONTENT.HSN.VM.A.1  
Recognize vector quantities as having both magnitude and direction. Represent vector quantities by directed line segments, and use appropriate symbols for vectors and their magnitudes
    - CCSS.MATH.CONTENT.HSN.VM.B.4.B  
Given two vectors in magnitude and direction form, determine the magnitude and direction of their sum.

## Next Generation Science Standards

HS-ETS1-1.

Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.

HS-ETS1-2.

Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.

HS-ETS1-3.

Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

HS-ETS1-4.

Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.

## College and Career Literacy Standards

### English Language Arts Common Core College & Career-Readiness Standards:

#### Reading: Key Ideas and Details

2. Determine central ideas or themes of a text and analyze their development; summarize the key supporting details and ideas.

#### Reading: Integration of Knowledge and Ideas

7. Integrate and evaluate content presented in diverse formats and media, including visually and quantitatively, as well as in words.

#### Writing: Text Types and Purposes:

2. Write informative/explanatory texts to examine and convey complex ideas and information clearly and accurately through the effective selection, organization, and analysis of content.

#### Writing: Production and Distribution of Writing:

5. Develop and strengthen writing as needed by planning, revising, editing, rewriting, or trying a new approach. Writing: Production and Distribution of Writing

#### Writing: Research to Build and Produce Knowledge

8. Gather relevant information from multiple print and digital sources, assess the credibility and accuracy of each source, and integrate the information while avoiding plagiarism.

#### Writing: Range of Writing

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

#### Speaking and Listening: Comprehension and Collaboration

1. Prepare for and participate effectively in a range of conversations and collaborations with diverse partners, building on others' ideas and expressing their own clearly and persuasively.

2. Integrate and evaluate information presented in diverse media and formats, including visually, quantitatively, and orally.

**Speaking and Listening: Presentation of Knowledge and Ideas**

4. Present information, findings, and supporting evidence such that listeners can follow the line of reasoning and the organization, development, and style are appropriate to task, purpose and audience.

# Teaching Plan

## Purpose

To integrate knowledge of truss design and analysis, and then, using that integrated understanding, to design, prototype, test, analyze and improve a truss bridge for pedestrians.

## Essential Question

How does a structural engineer design a truss bridge to carry pedestrians from building to building over a heavily traveled thoroughfare?

## Project Description

You are an in-house Structural Engineer for Acme Engineering. One of your clients owns a hotel across the street from a convention center. Your firm has been asked to design an efficient method to allow patrons of the hotel to access the center without going outside. Your task is to design a pedestrian bridge that will hold the load of one hundred people who will be able to cross at any one time.

After researching informational texts on truss bridge design, as well as participating in enabling learning activities intended to assist you in designing a bridge to meet your customer's specific needs, write a proposal in which you describe your design for their bridge. Support your discussion with evidence from your research and from conclusions you draw from participation in enabling learning activities.

You will need to research trusses and discover which are commonly used for the structure you will be building. You will need to become proficient with the mathematical analysis typically done on structures that are typically used in pedestrian bridges. You will create a scale drawing of your final recommended truss bridge design using knowledge of beam deflection, vector analysis and compressive and tension forces, and provide an analysis to prove your design will carry the maximum weight capacity of the bridge.

You will present your final recommendation to the CEO of the hotel and the architectural team responsible for the building. You will need to prepare a presentation and create a scale model of the bridge structure to all those attending to see the structure that will be utilized in the bridge.

## Student Deliverables

- Engineering notebook with reflections, research notes, bibliography and other processes used in the design
- Sketches and working drawings for the pedestrian bridge
- Analysis of the bridge truss design
- 3D model of the pedestrian bridge
- Engineering report of the design process
- Presentation for the authentic audience

## Concepts

1. Structural analysis is a systematic study of the relationship of the material, members, and the construction of the structure when loaded to determine the resulting deflections and forces.
2. Static equilibrium is concerned with the special condition that exists when a body is in equilibrium and at rest when subjected to force.
3. All objects can be deformed with the application of an external force. The external force is called stress. Strain is the degree of deformation.
4. A scalar quantity is one that represents force with the amount only; a vector quantity represents a force and direction.
5. Moments of Inertia are sometimes called second moments of areas. They are a mathematical expression of the strength or stiffness of the shape expressed in a unit of in<sup>4</sup>.
6. Strength of Materials deals with the behavior of solid bodies subjected to various types of loading to determine the stresses, strains, and displacements caused by the loading.
7. The engineer must take the requirements of a structure, compose a mathematical model and then analyze it for safety, cost effectiveness and for its acceptance for client and societal needs.
8. It is essential that any product, machine, or structure be safe and stable under the loads exerted on it during any foreseeable use.
9. Second moment of area (sometimes known as moment of inertia) mathematically predicts the ability of a shape to resist the deforming caused by applied force.
10. Statics is used to mathematically analyze the forces on a structure.
11. If two or more forces are acting on a body, Vectors can be graphically added or subtracted to determine what would be the result of all the forces applied. A resultant is one vector, which has the same effect on a body as the two or more vectors that are actually acting on that body.
12. Complex structures can be analyzed by breaking them down into components.
13. Testing of subscale or full-scale models is often used in industry to verify the strength predictions made from mathematical models.
14. Factor of safety is a multiplier applied to maximum stress to assure designs stand up over time.

## Enabling Learning Activities

When designing structures it is important to know how the forces will affect the structure. When we look at the forces the structure will be subjected to we need to begin to plan how we will resist those forces to achieve equilibrium. There are several considerations for these decisions. The following daily plan will allow students to explore concepts necessary to determine how to safely plan for the stresses on the structure.

In order for students to complete the project they will need research or instruction across a number of areas. The 3Doodler will play a role in the exploration of the concepts and allow students to create a structure by the end of the unit that will perform the way they want it to.

## Daily Pacing Guide

### Day 1: Introduction

Required Materials:

- Handouts:
  - Project Description
  - Design Process
  - Engineering Notebook
  - Design Documentation

Introduce students to the main problem by providing them with the Essential Question and the Project Description.

Using the handouts found in the Resources section below, cover with your students the **Design Process**, **Engineering Notebook** and **Design Documentation** requirements. Discuss the **Problem Statement**, **Design Brief**, and management plan.

Have students begin thinking about bridge designs and structures by means of a web search for bridge pictures.

### Day 2: Shapes with 3Doodler

Required Materials:

- 3Doodler 2.0: 1 for every 1 or 2 students
- 3Doodler Plastic: ~3 strands per 3Doodler
- Handouts:
  - Shapes With 3Doodler

Begin the day with a safety demonstration about the 3Doodler and other hand tools that will be used. Discuss electrical safety with the students. Discuss the heat aspect of the 3Doodler.

Have students create the basic shapes with the 3Doodler. Provide them with the document **Shapes With 3Doodler**. Allow small groups to discuss which shapes withstood the pressure of a finger pressing down better than others. If they do not discuss shapes around them and why certain shapes are used, be sure to include that in the closing discussion.

### Day 3: Exploring Bridges with 3Doodler

Required Materials:

- Computer with Internet access
- Printer
- Image editing program (optional)
- Engineering notebook

Why are bridges designed and constructed in many different ways?

Have students search the Internet for images of pedestrian bridges. Student groups select one or two bridges they like and print the picture to be used as a pattern. Have students create a pattern from the picture either by tracing or importing into a graphics program and then removing the color.

Students should Doodle a simple model of the bridge of their choice. Have students discuss which of the models they think will be the strongest. Have students apply a simple load to the 3Doodled bridge and see how they behave.

Once students have a sense of how their bridges behave under the force of a load, ask them to try to identify the key structures or shapes of which the bridge is composed.

How do these structures transfer the load to the supports? This question is central to bridge design. Students should look at the structure and can guess how the entire structure interplays to allow the various loads to be transferred.

Have the students explore different combinations of bridge components to see whether they can come up with new combinations that have different properties. These new combinations and students' observations of their characteristics should be recorded in their Engineering Notebooks.

## Day 4: Problem Statement

Required Materials:

- Handouts:
  - Problem Statement

Have students begin basic research about bridges. You can direct them to <http://www.pbs.org/wgbh/buildingbig/bridge/> or similar site to begin to see the many different types of bridges in use. Have them record their notes in their Engineering Notebook

Divide the students into teams. Have the student teams discuss the **Problem Statement**. This will make sure they identify the problem they are trying to solve. Have them write the **Problem Statement** in their Engineering Notebook.

## Day 5: Forces

Required Materials:

- 3Doodler 2.0: 1 for every 1 or 2 students
- 3Doodler Plastic: ~3 strands per 3Doodler
- Handouts:
  - Forces

Begin the day with a safety reminder.

Have students participate using the **Forces** document. You can save time by having a shape for the plank pre-Doodled, but deeper learning will come if they use the 3Doodler to create the plank themselves. Have students Doodle a plank to see how it behaves in tension and compression.

## Day 6

Required Materials:

- Computer with Internet access

Begin by reviewing the plank the students made the previous day. Have them discuss what surprised them about the material. Have them discuss other materials and why they are used. For example why is steel used in bridges? Why is concrete used for steps?

Have students discuss their thoughts on the plank they created and why it was stiffer in one direction than the other. Introduce the concept of shape to the students. Some shapes are stiffer than others. Explain that we can predict how a shape will perform, and even evaluate the performance for a specific shape and material combination.

Explain that all shapes can be evaluated as long as we know the geometry involved. To do this we need to describe the shape in relation to the Centroid which is the geometric center of the cross section of a shape.

In order to develop a sense of how to estimate the center of mass, or centroid, of a shape, have students use an online tool to explore the concept by quickly calculating the centroid of shapes of differing sizes.

This online tool is available here: <http://skyciv.com/free-moment-of-inertia-calculator/>

Have students record their observations in their Engineering Notebooks.

## Day 7: Material Strength

Required Materials:

- 3Doodler 2.0: 1 for every 1 or 2 students
- 3Doodler Plastic: ~3 strands per 3Doodler
- Computer with Internet access

Now that students are familiar with the concept of Centroids we can now begin to look at how a shape affects the strength of a component. Have the students look a website about shapes. A site similar to <http://www.pbs.org/wgbh/buildingbig/lab/shapes.html> will give the students a quick understanding of shapes. Have the students create some shapes with the 3Doodler and try to predict how the shape will hold up when they press on them.

The students should also research information about deformation. One site they might look at is <http://www.pbs.org/wgbh/buildingbig/lab/shapes.html>.

The next concept they should explore is Ductile and Brittle materials. Have the students search for resources on the Internet that explain the meaning of "ductile" and "brittle". Good examples include:

- A Level Physics - Ductile and Brittle Materials (<https://www.youtube.com/watch?v=gGXHdgsFA9s>).
- Materials Science Mechanical Engineering - Part 1 Stress and Strain Explained (<https://www.youtube.com/watch?v=0s5kBrk0d80>)

- Materials Science Mechanical Engineering - Part 2 Ductility and Toughness Explained (<https://www.youtube.com/watch?v=MyksI4O26G4>)

Have students record their observations in the Engineering Notebook.

## Day 8: Testing Beams

Required Materials:

- 3Doodler 2.0: 1 for every 1 or 2 students
- 3Doodler Plastic: ~3 strands per 3Doodler
- Handouts:
  - Testing Beams

Have students discuss how they might test some of the shapes they are thinking of. Introduce students to the Testing Beams activity.

## Day 9: Building i-Beams with 3Doodler

Required Materials:

- 3Doodler 2.0: 1 for every 1 or 2 students
- 3Doodler Plastic: ~5 strands per 3Doodler
- Handouts:
  - Building i-Beams with 3Doodler

Begin the day asking if students are familiar with the concept of the i-beam. Talk about where they have seen them used. Have them talk about the concepts of moment of inertia and how adding mass further from the centroid creates a stiffer structure.

Have the students participate in the **Building i-Beams with 3Doodler** activity.

Have students discuss in their teams why the structure is more stable in this shape and what advantages it presents. Have them record their findings in the Engineering Notebook.

## Days 10-12: Trusses

Required Materials:

- 3Doodler 2.0: 1 for every 1 or 2 students
- 3Doodler Plastic: ~5 strands per 3Doodler
- Handouts:
  - Trusses

Have the students research trusses and the various forms they take. Provide them with the **Trusses** handout and have them create a basic Howe Truss using the 3Doodler. Students should record their progress in their Engineering Notebook each day noting things that gave them trouble.

## Days 13-15: Brainstorming, Modeling

Required Materials:

- 3Doodler 2.0: 1 for every 1 or 2 students
- 3Doodler Plastic: ~5 strands per 3Doodler per day

These days are set aside for student teams to brainstorm how they want the final product to look. They work through sizing everything and then work on the scale to reduce the size to the scale model. Circulate in the room answering question and checking on students' design process. Have them record their discussions and create the design documentation they will need to present their design to the audience.

## Days 16-20: Construction

Required Materials:

- 3Doodler 2.0: 1 for every 1 or 2 students
- 3Doodler Plastic: ~5 strands per 3Doodler per day

Students should 3Doodle the pieces they will need to construct their proposed bridge and assemble it. Students should check for fit and function as they go. Students can take pictures of the structure as it is built. This will allow them to discuss what was created and the process used.

## Days 21-22: Presentations

Required Materials:

- 3Doodler 2.0: 1 for every 1 or 2 students
- 3Doodler Plastic: ~5 strands per 3Doodler per day

Students design a presentation to make the case for their design of the pedestrian bridge. Students display their model while they present the thought process that went into the design.

# Resources

The following pages contain resources for students. They can be printed or provided digitally in PDF form for their use.

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## Project Description

### Purpose

To integrate knowledge of truss design and analysis, and then, using that integrated understanding, to design, prototype, test, analyze and improve a truss bridge for pedestrians.

### Essential Question

How does a structural engineer design a truss bridge to carry pedestrians from building to building over a heavily traveled thoroughfare?

### Project Description

You are an in-house Structural Engineer for Acme Engineering. One of your clients owns a hotel across the street from a convention center. Your firm has been asked to design an efficient method to allow patrons of the hotel to access the center without going outside. Your task is to design a pedestrian bridge that will hold the load of one hundred people who will be able to cross at any one time.

To prepare, research informational texts on truss bridge design, and participate in enabling learning activities intended to assist you in designing a bridge to meet your customer's specific needs. Then, write a proposal in which you describe your design for their bridge. Support your discussion with evidence from your research and from conclusions you draw from participation in enabling learning activities.

You will need to research trusses and discover which are commonly used for the structure you will be building. You will need to become proficient with the mathematical analysis typically done on structures that are typically used in pedestrian bridges. You will create a scale drawing of your final recommended truss bridge design using knowledge of beam deflection, vector analysis and compressive and tension forces, and provide an analysis to prove your design will carry the maximum weight capacity of the bridge.

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### Deliverables

- Engineering notebook with reflections, research notes, bibliography and other processes used in the design.
- Sketches and working drawings for the pedestrian bridge
- Analysis of the bridge truss design
- 3D model of the pedestrian bridge
- Engineering report of the design process
- Presentation for the authentic audience

## 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 your process but not dictate this 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

## Design Process

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

Finalize documentation of design

- Application of the results of the test data
- Propose design changes
- Retesting of the prototype
- Repeat

Prepare communication plan for authentic audience

- Research audience
- Plan for explanations and graphics
- Plan for feedback

Prepare reports, design documentation, design proposals and/or presentations for the authentic audience

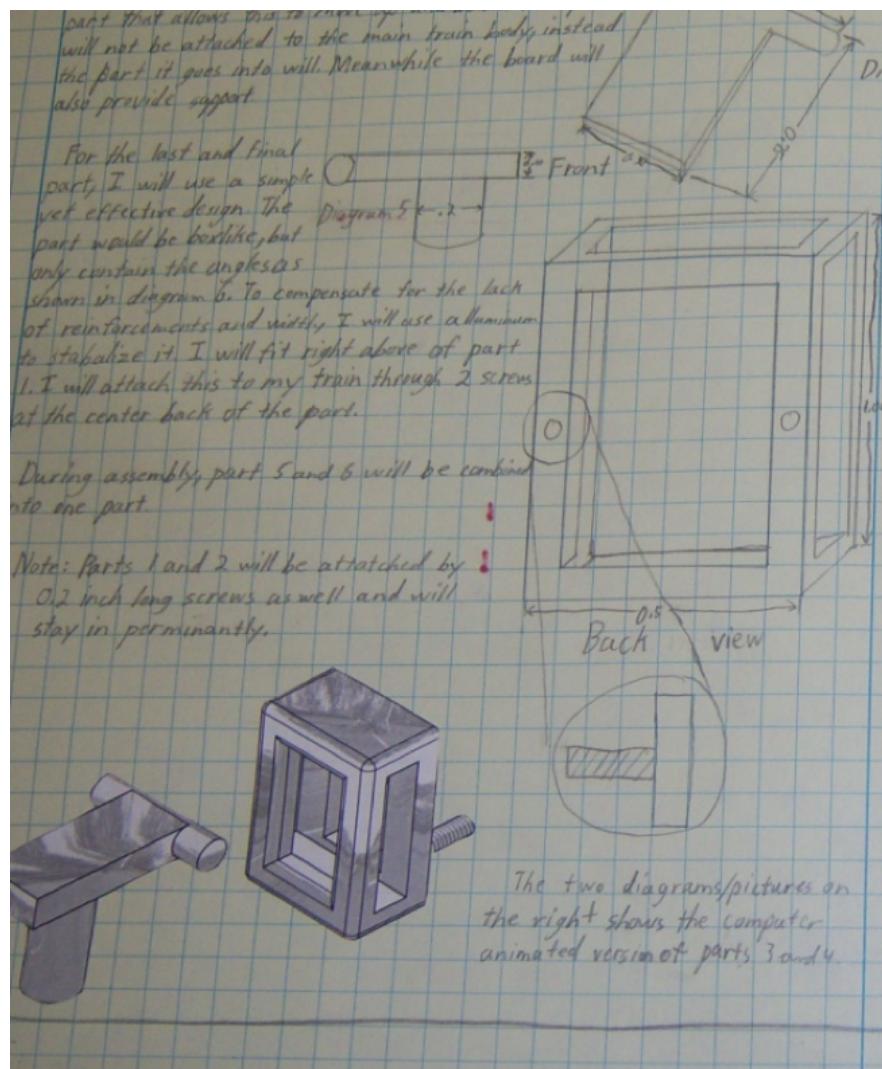
Present/defend to an authentic audience with feedback

## 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 will help with the project reports that students will be asked to accomplish.

## Example template for Engineering Notebook

Title:  
Project No.:  
Book No.:

Entry  
Date:

Signature:  
Witness:

Entry  
Date:

Signature:  
Witness:

Entry  
Date:

Signature:  
Witness:

N.B.: The space for each entry should be adjusted as needed. When an entry is complete, remaining space should be cross-hatched and the entry should be signed by the author and a witness.

## 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 bullet point will do
- A bullet point should always be used instead of paragraph
- Use Diagrams
- A good table replaces even more paragraphs
- Never use adjectives. That is the function of sales people and project managers
- Use appendices for additional (or not strictly relevant) information that you think is important

Design documentation is the collection of communications 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.

Items might include:

- 3D CAD Design
- 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 or final appearance

## Problem Statement

The problem statement is the statement that the students develop 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.

## 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 most of 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

## Shapes with 3Doodler

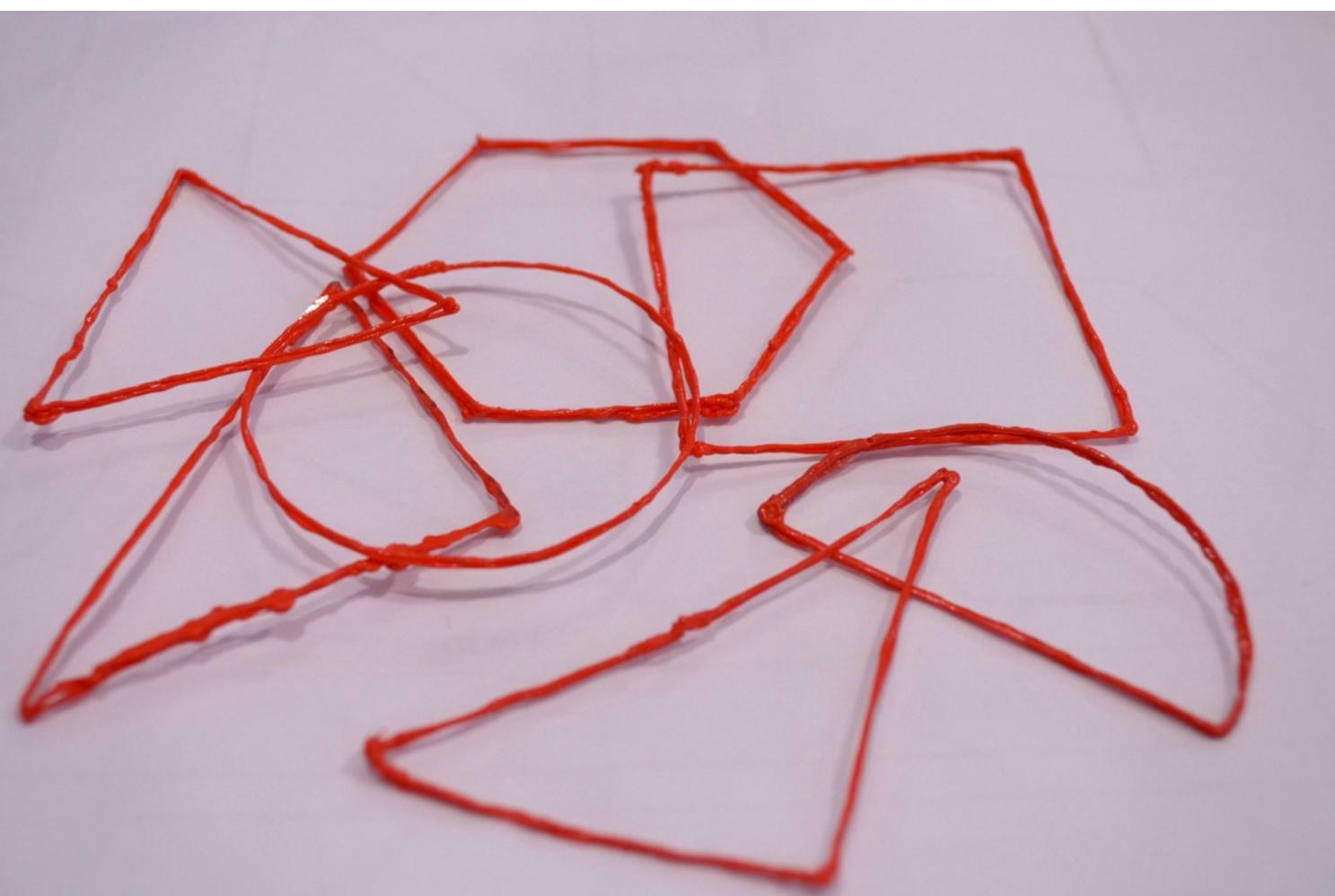
The shapes of a material will define how it responds to stress. Use the 3Doodler to create different shapes. You can use the included stencils to guide you in the creation of basic shapes to test. Using the 3Doodler, create the shapes below.

**3Doodler Pro Tip:** cover the shapes stencil with masking tape. This will make it easier to peel the 3Doodled shapes off of the page.



When you have created the shapes, stand them up and apply force to the top of the structure. How does the structure react when the force or load is applied? If you apply the force to a different face of the shape, does the reaction change?

Think about whether combining shapes might make them stronger, more stable, or even weaker and less stable. Using the 3Doodler, choose an outcome (e.g., a stronger shape) and Doodle shapes together to try to achieve that outcome.



## Forces

Forces act upon solids and the resultant behavior can be predicted by the applications of Newton's three laws. Before digging deeply into the design of structures you will need to explore these forces to see how solids react.

Newton's first law states that an object at rest will remain at rest or in uniform motion in a straight line. These rocks are at rest and not moving. Since the rocks are not moving there is no acceleration of the rock. Static equilibrium is a state achieved by objects obeying Newton's first law. There might be several forces acting on an object but as long as they are canceling each other out we can say they are in a state of static equilibrium.

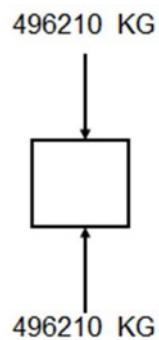


Force is an interaction which tends to change the motion of an object. A child pushing a toy car across the floor is exerting a force on the car and it accelerates in the direction of the push the child is giving the car. This is an example of Newton's second law which states the acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force and inversely proportional to the mass of the object. Simply stated force is mass times acceleration or  $F = M \times A$ . You can probably imaging a force that could move the rocks in the picture above. An earthquake would probably provide enough force to actually cause the rock to fall from its perch.

Newton's third law states for every action there is an equal and opposite reaction. This is why when you strike a ball with a bat the energy of the bat is transferred to the ball and it travels away from the bat. It is also why the rock sits on the perch. If the rock is pushing down then the ground must be pushing up to balance the forces so the state of equilibrium is achieved.



You can create a simple diagram from this to represent the forces. These diagrams are called Free Body Diagrams and we use them to help us simplify and solve problems. The diagram is shown below. The weight of the boulder pushing down equals the force of the earth pushing back.



In structures there are two basic forces to consider. These are tension and compression.



Compression is what happens when you push down on an object.

Tension occurs when you pull on an object such as a rope or fishing line (or a marshmallow!).

Forces cause materials to react. Even a fly landing on a table causes some deflection of the surface of the table. It might be too small of a change for you to see but it happens anyway. Some materials are better in tension such as metals and others do better in compression, such as concrete.

Your model will be created in ABS plastic using the 3Doodler. You should experiment with the plastic before beginning your design.

Use the included stencil to make a flat piece of stock using the 3Doodler. You will make this a solid piece consisting of one or two layers of plastic, as shown.

Compression: hold the cooled part at each end with your fingers, and then push the ends toward each other. This will have an effect similar to the picture below. This is compression.



Tension: what happens with just a little pressure? Now try pulling the two ends away from each other. This is tension. What happens when you pull on the material?

A small compressive force caused the material to change a lot. When you think about this material do you think it is better in tension or compression?



Test what happens when you apply a force to the thin edge of the plank. How is that different to how the plank behaves when you apply a force to the broad (flat) side of the plank?

What happens when an additional layer of plastic is Doodled onto the plank, making it twice as thick? Does this change how the plank responds to a force? If so, how?

Materials all deform when force is applied. When the force is removed the material could return to its original size and shape. If it does we can say it is in its **elastic state**. Like a rubber band, when you release the force it returns to its original shape. When we pull or push too hard and the material permanently changes shape, we have exceeded the elastic limit and moved into the plastic state where it is permanently deformed without actually fracturing.

## 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.

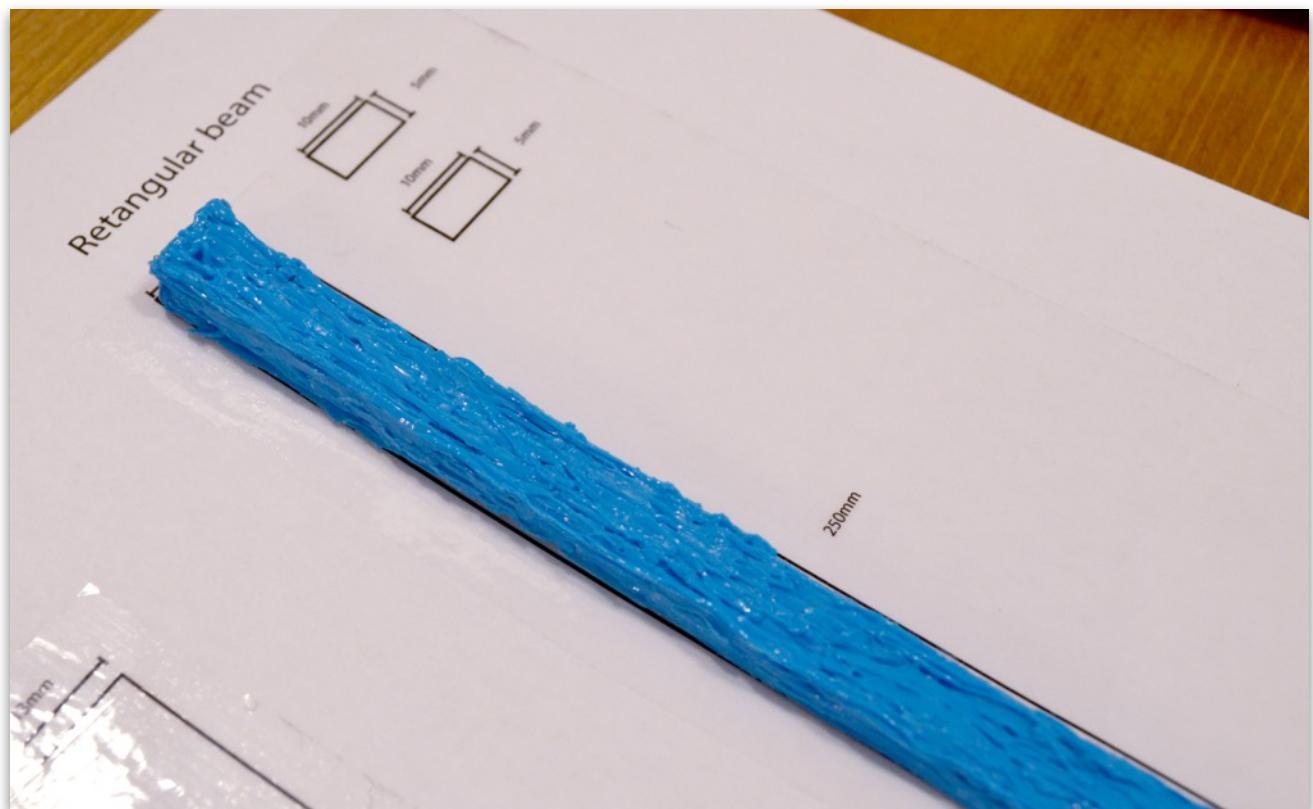
### Materials needed

For this activity, you will need the following items:

- 3Doodler
- Beam stencil
- Dial Caliper
- Blocks or pencils
- Plastic cup
- Sand
- String
- Paper clip

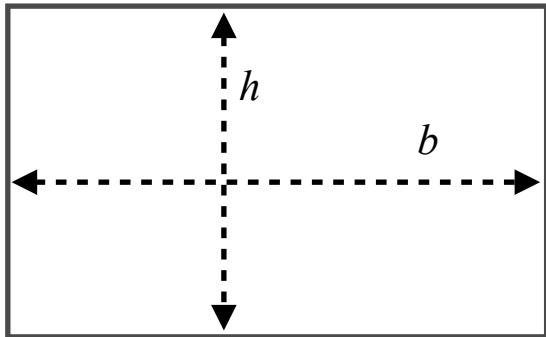
Begin with the 3Doodler and create a rectangular beam that is  $5 \times 10 \times 250$  mm.

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 or moment of inertia is a number that can be used to predict the strength of the shape. With a simple shape such as ours we can utilize a basic formula to calculate this value.

$$MI = \frac{bh^3}{12}$$



Where:

$MI$  = area moment of inertia

$b$  = width of the base

$h$  = height

Deflection is how much the beam will bend in the middle. We use the formula

$$\text{Deflection } \Delta = \frac{L^3 \times F}{48 \times E \times MI}$$

Where:

$\Delta$  = deflection

$L$  = length

$F$  = force in kilograms

$MI$  = moment of Inertia

$E$  = modulus of elasticity

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. However, in our case we will be using the 3Doodler to create the beam. Due to the layered nature of Doodle, the plastic it will not be completely consistent and uniform. Accordingly, we will take actual measurements to determine what value we should use for the **modulus of elasticity** in future calculations.

In order to do this, the above formula for **deflection** is rearranged and the values of the base and height are used to provide us with the missing information.

$$E = \frac{L^3 \times F}{4 \times \Delta \times b \times h^3}$$

Where:

$E$  = modulus of elasticity

$L$  = length

$F$  = force in kilograms

$\Delta$  = deflection

$b$  = width of the base

$h$  = height

What the formula tells us is the longer the beam being tested the more deflection you will have from the same force. It is a geometric relationship so the length is very important.

## Testing

Use two pieces of same-height furniture (such as desks or lab stools) as supports for your beam by separating them about 20 cm apart.

Use masking tape to fix a pencil at the surface edge of each furniture. This will provide a stable point of contact for your beam.

Measure the distance between the two pencils and record this data in your Engineering Notebook.

Place the sample beam that you have Doodled on the top of two pencils so there is a known distance between the pencils, and so the beam is adequately supported.

Measure and place a mark on your beam at the center of the span.

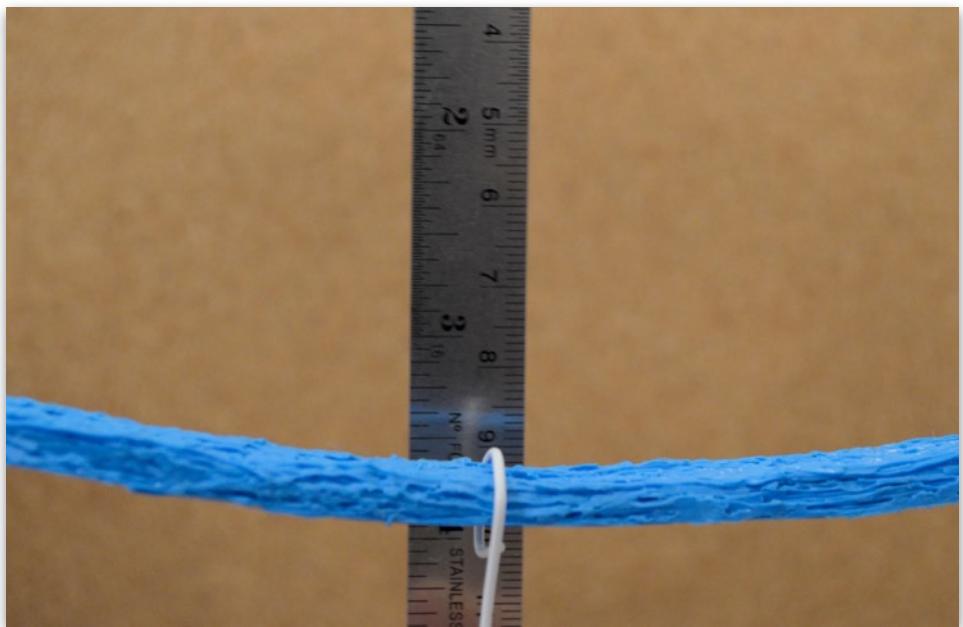
Measure the distance from the floor to the beam center mark. Record this measurement in your Engineering Notebook. This will be the original measurement of the distance from the floor to the beam center mark.

Measure the mass of plastic container with string on the triple-beam balance. This mass will be the initial weight, and should be recorded in your Engineering Notebook.

Hang the plastic container from the center point of the beam that you marked, and measure how much the beam deflects. Record this in your Engineering Notebook.

Add sand to the plastic container a little at a time. The deflection will increase. Each time you add sand to the container, record the weight of the container and the sand in your Engineering Notebook.

Each time you add sand to the container (after you have weighed it), measure the distance to the floor. The difference between the original measurement and the new measurement is the displacement and is represented by the term  $X_D$  in the diagram below.

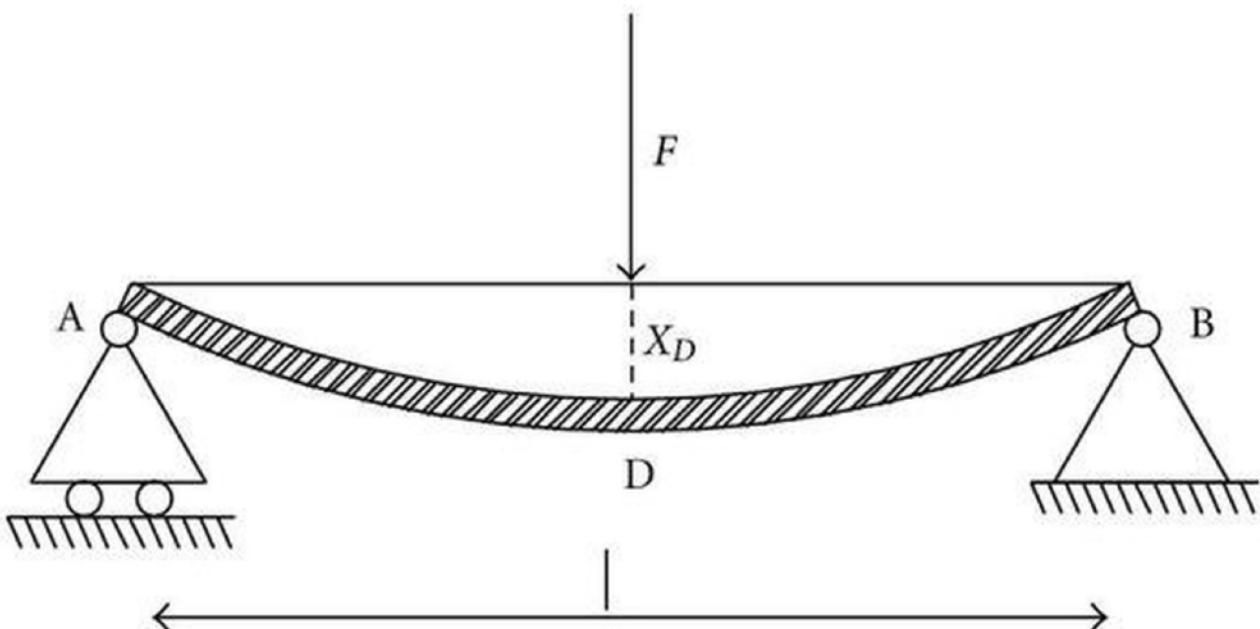


Weigh the plastic container, string, and sand. This will give you the total weight in kilograms (kg) for your force, represented as  $F$  in the diagram below.

In your Engineering Notebook, plot the values of the weight of the plastic container, string and sand ( $F$ ) with the corresponding values for displacement ( $X_D$ ) as points on a graph.

As an alternative, create a spreadsheet (using Excel, Google Sheets, Numbers or similar) and record the same values, which can then be used to create a graph.

What can we observe about the relationship between the weight of the plastic container and the displacement?



## Testing with a Torque Wrench

A torque wrench is often used to apply a specific torque to a fastener, such as a nut that is being tightened onto a bolt. Torque wrenches are used extensively in the assembly of all kinds of mechanisms. Assembly manuals will frequently provide a specific torque that should be applied to a particular fastener. In the picture below a mechanic is tightening a bolt to a specified torque.



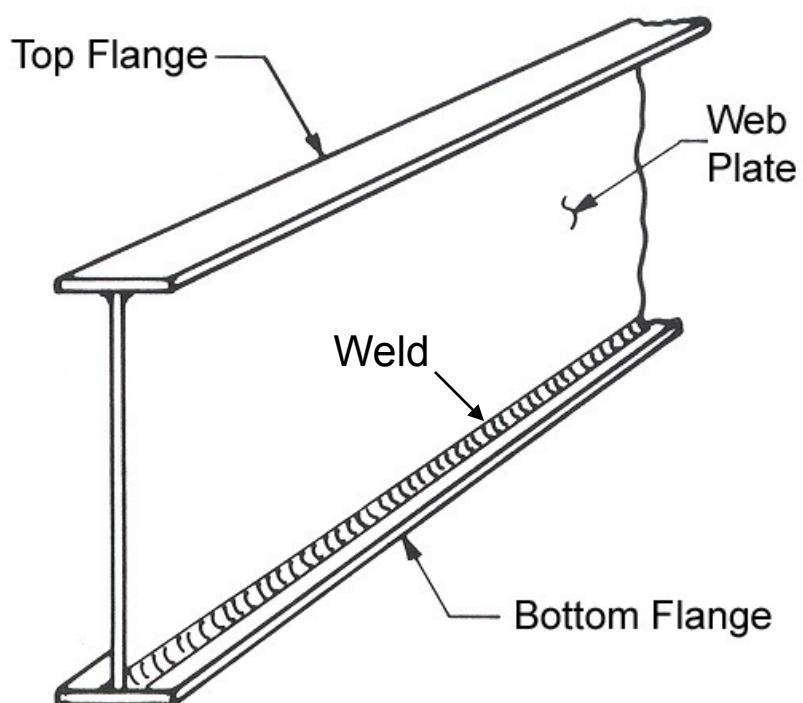
In beams, we see moments caused by the loading of a force. This load creates a twisting force at the end where beam meets the support. Eventually it will cause failure if the force is more than the structure can stand. Clamp the end of the beam in a vise so a small portion is protruding from the vise. 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 3Doodler, 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.

## Building I-Beams with 3Doodler

In the Forces activity, you found that turning the plank on its edge resisted the downward force much better than when it was flat. You also found out that doubling the width doubles the strength. You probably discovered that the plank wanted to rotate when you pushed down on the edge. Engineers have taken those concepts and combined them into shapes that resist forces in a couple directions. They also noted that the farther out from the centroid they keep the mass of the shape the stronger it is.



Engineers discovered they could take a plank on edge which was very strong and add a top and bottom flange to it. The flange adds stiffness top to bottom but more importantly, the flanges resist forces from the side. When a structure is hit with wind it has to resist the force to keep from falling down. This also reduces the weight of the structure meaning it can be smaller as it doesn't have to hold up its own weight.

Creating an I-beam is relatively simple. If you look at the picture above you can see the pieces were "welded" together. We can do this same operation with the 3Doodler. Before you begin you need to have a plan for how to make the pieces. In the picture below you can see some of the pieces are cut to a curve.

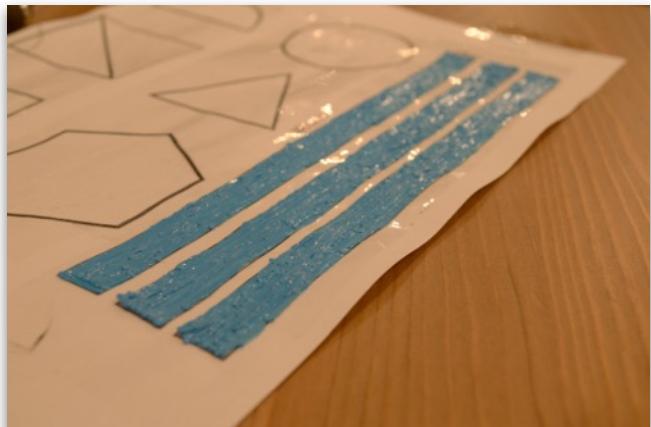


By shaping the material before being formed into an I-beam you can change the shape.



Start with a straight I-beam before getting fancy. Begin with two planks that you had 3Doodled earlier. When arranging the pieces and welding, have your partner help you, but be careful of your fingers.

Arrange the two parts in the form of a T. While you hold the parts in the correct position use the 3Doodler to **tack weld** the two together. A tack weld is a small dot of molten material spaced every so often. This will hold the pieces in the correct position and not distort the pieces the way a long bead of melted material would. Tack both sides and let them cool. Then go back and run down each side with a fresh layer of plastic.





Once you have the two pieces joined together you will then go back to put the other piece on. Have your partner keep the top lined up and tack the end. The picture below shows the tack weld at the end of the beam. Once that is done go and tack the other end. Once those cool you can flip the part over and tack along the length as you did in the first step.



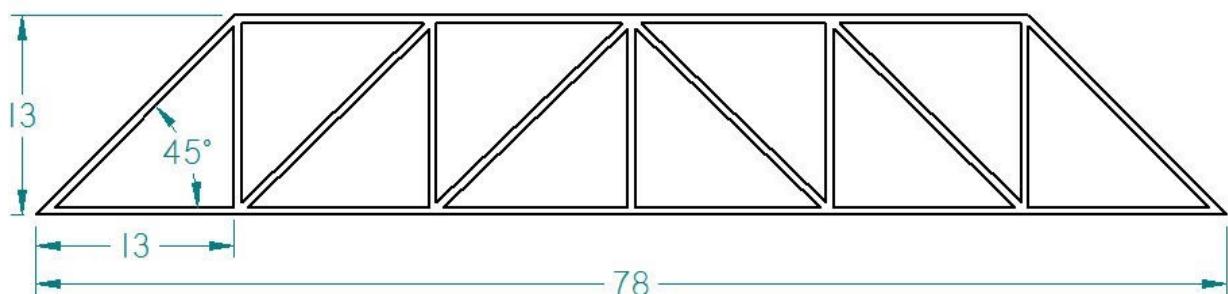
Place the finished beam on blocks so you can test its performance.

Push down lightly in the middle. Record what happens in your Engineering Notebook.



## Trusses

To truly understand how trusses work you need to create one. The plan for this Howe truss (originally designed by William Howe in 1840) is below.

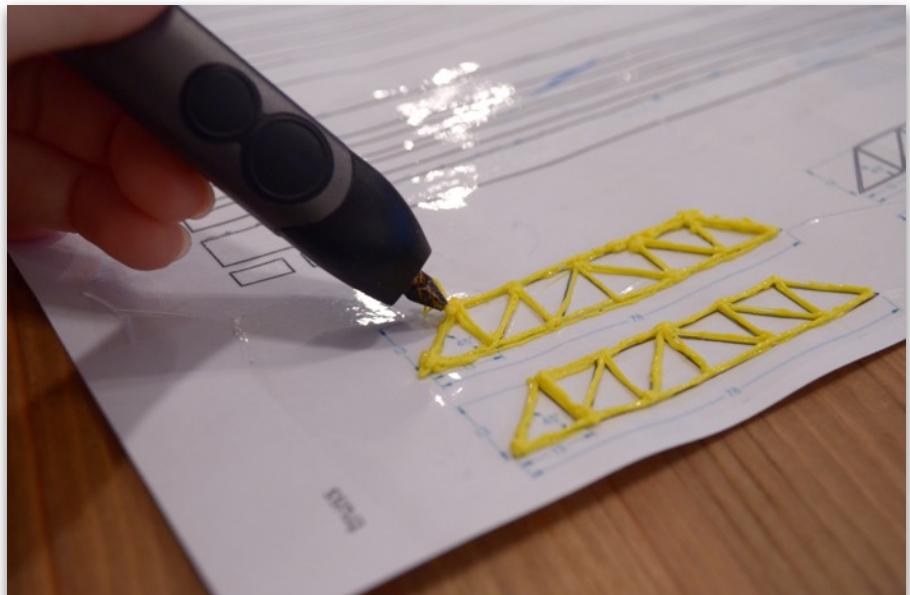


You can print the provided stencil of the Howe truss and then use it to guide the creation of the truss.

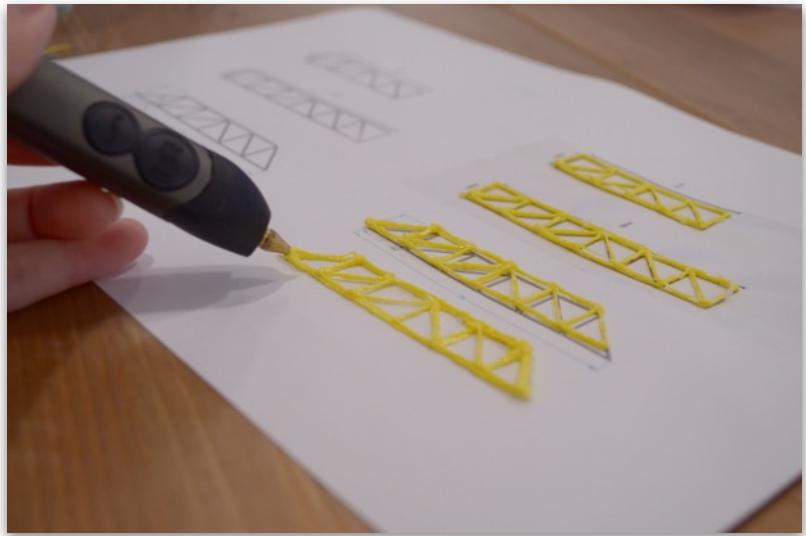
**3Doodler Pro Tip:** Cover the stencil with masking tape before 3Doodling. This will make it easier to peel the Doodled truss off the page.

Once you have Doodled the components of the truss, you can apply force to them with your hands to understand how they respond to loads.

If you press down from the top you will see how strong it is in the vertical direction. Side to side it is very flexible.



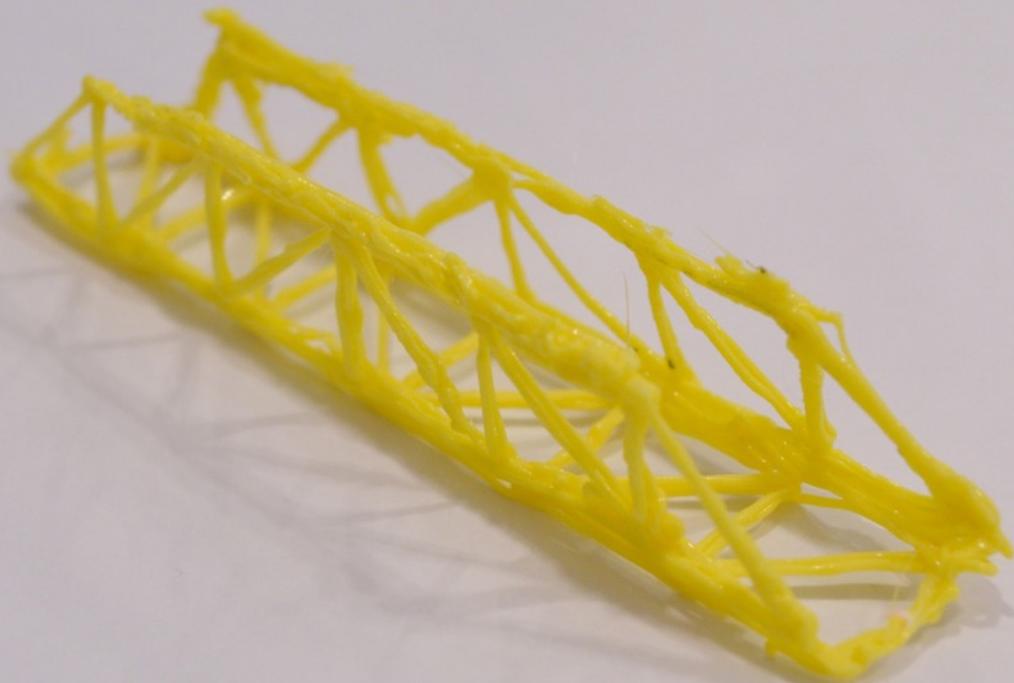
Trusses are made from a series of triangles. Triangles are a shape that cannot change without lengthening one side. When forces are applied to a truss, some of the members (called **webs**) act in **compression** and some act in **tension**. These forces balance each other and the shape is maintained. This is why the truss is so rigid when a force is applied from the top — the webs balance the force that is being applied to the truss.



You will notice all the webs that make up the truss are the same size. As a practical matter, this is convenient if you want to use only one size of material. On real bridges you will see all different sizes of materials used.

If you think about the material and when you held a plank in your fingers and pushed the ends together causing compression, the component buckled easily. When you tried to pull the ends placing it in tension it was very resistant to tension.

If you can examine the truss you want to build you can put more material in the components that will be in compression to help withstand the stress. Your tension members can take advantage of the properties of the material and be made lighter.



## Sample Outline for Final Presentation

- I. Design Brief
  - A. Design objectives and goals
  - B. Scope of the project
  - C. Problem statement or description
- II. Summary of Design Process, to include:
  - A. Preliminary sketches
  - B. Design testing methods and protocol for testing critical assumptions
  - C. Review of prototypes, discussion of iterative process
  - D. Discussion of challenges faced
- III. Present final design
  - A. Scale model
  - B. Discussion of how final design meets design objectives and goals
- IV. Questions and answers

## Web Resources

<http://partners-ink.net/pghbridges//basics.htm>

A look at different types of trusses that are found on bridges

[https://www.youtube.com/watch?v=2uSQPm3\\_4mY](https://www.youtube.com/watch?v=2uSQPm3_4mY)

Truss analysis using sections video

<https://bridgecontest.org/resources/file-folder-bridges/>

Excellent resource on bridge and truss design.

<http://www.learnengineering.org/2013/08/truss-analysis-method-of-joints.html>

Truss analysis using joints

<http://www.conteches.com/knowledge-center/pdh-article-series/design-considerations-for-pedestrian-truss-bridge.aspx>

Design considerations for pedestrian truss bridges

<http://www.permatrak.com/news-events/bid/93919/Pedestrian-Bridge-Design-7-Considerations-for-Architects-Engineers>

Pedestrian bridge design: 7 considerations for architects

<https://www.ipfw.edu/dotAsset/239460.pdf>

Design for a pedestrian bridge

<http://3dprint.com/31075/tethers-unlimited-trusselator/>

Commercial printing of carbon fiber trusses for space

[https://owl.english.purdue.edu/media/ppt/20070511105150\\_665.ppt](https://owl.english.purdue.edu/media/ppt/20070511105150_665.ppt)

PowerPoint for the Design/Engineering notebook

<https://owl.english.purdue.edu/owl/resource/647/01/>

Writing engineering reports

<https://owl.english.purdue.edu/owl/resource/563/01/>

Quoting, paraphrasing and summarizing

<https://owl.english.purdue.edu/owl/resource/561/01/>

Proofreading and revising documents.

<http://www.pbs.org/wgbh/buildingbig/bridge/>

PBS site on bridges

## Vocabulary

Abutment	The part of a structure (as an arch or a bridge) that directly receives thrust or pressure.
Arch Bridge	A bridge that uses long span arches for support.
Beam	A structural element capable of withstanding bending caused by the application of a load.
Beam Bridge	A bridge whose main structural element consists of a beam set across two or more vertical supporting members.
Buckling	Failure in a structural member caused by bending, giving way, or crumpling due to excessive force.
Cable Stayed Bridge	A bridge in which the deck is supported on either side of a central tower or towers by cables. Unlike a suspension bridge, the cables that hold the deck attach directly to the tower, rather than hanging from a larger cable running between the towers.
Centroid	The geometric center of the cross section of a shape.
Compression	The application of force on an object that would tend to reduce the size of the object in the direction of force.
Deflection	A measure of deformation of a structure due to applied loads.
Ductile	Able to be deformed without losing toughness; pliable, not brittle.
Equilibrium	A state of balance due to the equal action of opposing forces in a structure.
Forces	A push or pull acting on an object which tends to change the motion of an object.
Free Body Diagram	A diagram used to show the magnitude and directions of all the forces on an object.
Friction Force	Force resisting the sliding motion of objects.
Mass	The physical or numerical measure of the amount of matter in an object.
Moments	Measure of twisting force applied to a reference point as a product of its force and distance from the point.
Modulus of Elasticity	A number representing tensile elasticity derived from the tensile stress applied to a material and the axial strain created. (stretching caused by pulling).
Moment of Inertia	Also called Second Moment of Area. This is a measure of a shape's resistance to change.
Newton's Laws	Three physical laws that describe motion of objects.
Reaction	Forces that are induced at the supports of a structure.
Resultant	The single force and/or torque obtained by combining all the forces acting on an object or fixed point.
Scalar Quantity	A quantity that can be described by magnitude only. An example would be speed as there is no direction included.

Shear	Force acting along the surface under consideration that causes two cross sectional planes to slide in opposite directions. Looking at a sheet of paper, scissors cause a shear force that causes the paper to move down on one side and up on the other.
Strain	A measure of displacement of particles caused by the application of force. The elongation or compression of a part in comparison to its original dimension.
Stress	Force applied to an object divided by the area it is applied to (e.g., Newtons per square meter or pounds per square inch).
Suspension Bridge	A bridge having a road or deck hung from a pair of steel cables, each carried by towers.
Tension	A pulling force that stretches expands of lengthens the object in the direction of the applied force.
Truss	A shape usually comprised by triangles supported at the ends. The legs of the triangles called members are either in tension or compression so they a state of equilibrium.
Vector Quantity	A quantity that must be described by both magnitude and direction.
Weight	The force on an object due to gravity.
Yield	The stress where the material begins to deform plastically. The material will permanently change shape.

## Rubrics

### Rubric for Prototype / Engineering Design Process

	Not Yet 1	Getting There 2	Meets Expectations 3	Exceeds Expectations 4
Preliminary Research	Little evidence of research on background information and some vocabulary recorded in the Engineering Notebook	Evidence of some research on background information and some vocabulary recorded in the Engineering Notebook	Evidence of extensive research on background information and some vocabulary recorded in the Engineering Notebook	Evidence of fully researched background information and acquired dependent vocabulary recorded in the Engineering Notebook
Management Plan	Little evidence of a plan with some documentation for the creation of the design and prototype. Team members are not assigned roles	Evidence of a plan with some documentation for the creation of the design and prototype. Team members are not assigned roles	Some evidence of a well thought out and documented plan for the creation of the design and prototype. Roles are loosely assigned to team members.	Evidence of a well thought out and documented plan for the creation of the design and prototype. Roles are assigned to team members.
Design Brief	The problem statement doesn't exist or is not applicable to the problem. No resources are identified and the schedule is incomplete. Criteria and constraints are incomplete and incorrectly identified	The problem statement exists and makes some sense. Resources are identified but incomplete and a schedule is proposed. Criteria and constraints are confused and limited.	The problem statement is thought out and is understandable. Resources are identified and schedules are proposed. Criteria and constraints are mostly complete	The problem statement is well thought out and presented. Resources are identified and schedules are proposed. Criteria and constraints are complete

Brainstorming	A single idea is presented on a rough thumbnail sketch. Little or confusing annotations are included.	An approach with some design factors included. Ideas are sketched out and annotations limited	Evidence of some different avenues of approach with different design factors included. Ideas are sketched out and annotations are sufficient	Evidence of multiple avenues of approach with different design factors included. Ideas are sketched out and annotations comprehensive.
Testing Protocol	Testing is done without a protocol established	Testing protocol thought out with descriptions of what will be tested	Testing protocol is well thought out with descriptions of what will be tested and criteria established for most areas	Testing protocol is well thought out with descriptions of what will be tested and criteria established for each area
Optimization Matrix	Decisions are made with no structure or evidence	Optimization matrix in evidence for difficult decisions with some elements labeled	Optimization matrix in evidence for difficult decisions with most elements labeled and assigned a value to the final decision.	Optimization matrix in evidence for difficult decisions with each element labeled and assigned a value to the final decision.
Project Documentation	Sketches and drawings are kept in a pile. There is disorganization in the design documentation and the plan is difficult to understand.	Sketches, drawings, plans are completed. Some annotation is present and communicates components of the design.	Sketches, drawings, plans are organized and sufficiently annotated to communicate the essential components of the design.	Sketches, drawings, plans are organized well annotated and communicate the essential components of the design.
Prototype	The prototype/model is lacking scale and it is difficult to determine what the purpose is.	The prototype/model is lacking scale and provides a basic understanding of the project	The prototype/model is mostly to scale and presents a clear vision of what will be created when the proposal is accepted.	The prototype/model is scaled properly and presents a clear vision of what will be created when the proposal is accepted.

Testing	Evidence of testing is lacking.	Testing was conducted and the results are kept in a suitable location.	Testing was conducted according to the testing protocol. Data is organized and preserved for future use.	Evidence of testing is clear and was conducted according to the testing protocol. Data is organized and preserved for future use.
Analysis	Evidence of the analysis is not present.	Evidence from the testing has been analyzed by the creation of simple graphs and graphics. Some organization is evident.	Charts and other graphics have been created from the data. Evidence is organized.	Charts and other graphics have been created from the data. Evidence is organized and is easily understood by an outside observer.
Refine and iterate	Little evidence of refinements to the design exist.	Little documentation of changes made to the design as a result of the analysis conducted is present. Design changes as a result are problematic to understand	Some documentation of changes made to the design as a result of the analysis conducted is present. The thought process is evident.	Clear documentation of changes made to the design as a result of the analysis conducted is present. A logical thought process is evident.
Finalize documentation	There is little or no final design documentation.	Final design documentation is somewhat disorganized but presents the project. Some elements are included.	Final design documentation is present and presents the project in a good light. Most elements are included.	Final design documentation is organized and presents the project in a good light. All elements are included.

Communication	Communication is disorganized and difficult to understand. Little evidence of preparation is present.	The communication of the project through the use of models; design documentation and presentation are disorganized but could still be understood.	The communication of the project through the use of models, design documentation and presentation are organized and can be understood by most observers.	The communication of the project through the use of models, design documentation and presentation are well organized and easily understood.
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## Literacy Rubric for Argumentative or Persuasive Project

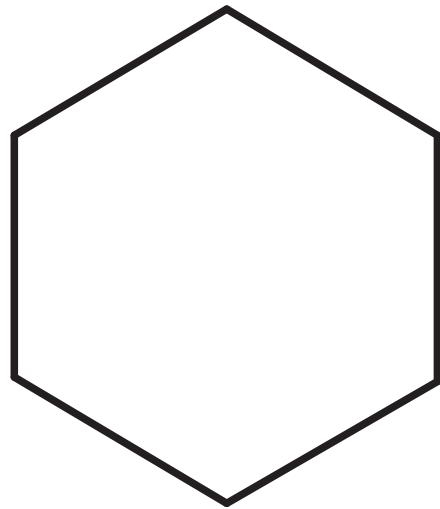
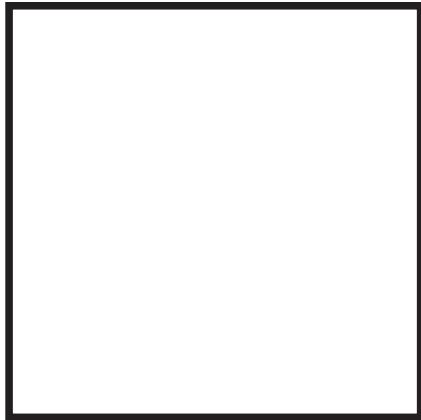
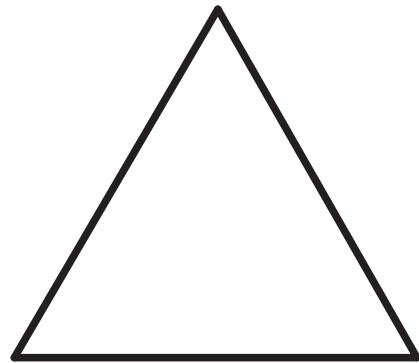
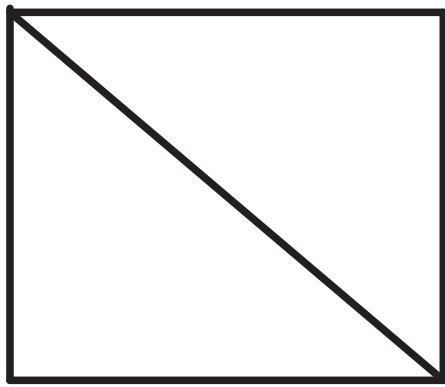
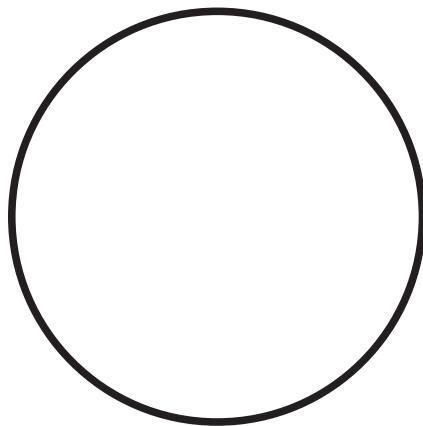
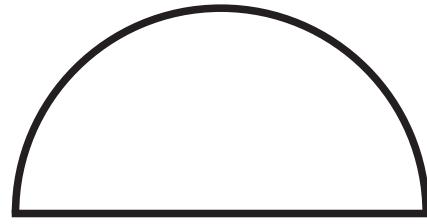
	Not Yet 1	Getting There 2	Meets Expectations 3	Exceeds Expectations 4
<b>Focus</b>	An attempt to answer the problem, but the response lacks focus.	Answers the problem and states a position but the focus is varying or weak.	Fully answers the problem keeping a clear focus. Argument is generally convincing.	Fully answers the problem keeping a very clear focus and strong, convincing argument.
<b>Main Idea</b>	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.
<b>Reading &amp; Research</b>	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.
<b>Development</b>	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.

<b>Organization</b>	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.
<b>Conventions of English</b>	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.
<b>Understanding of Content</b>	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.

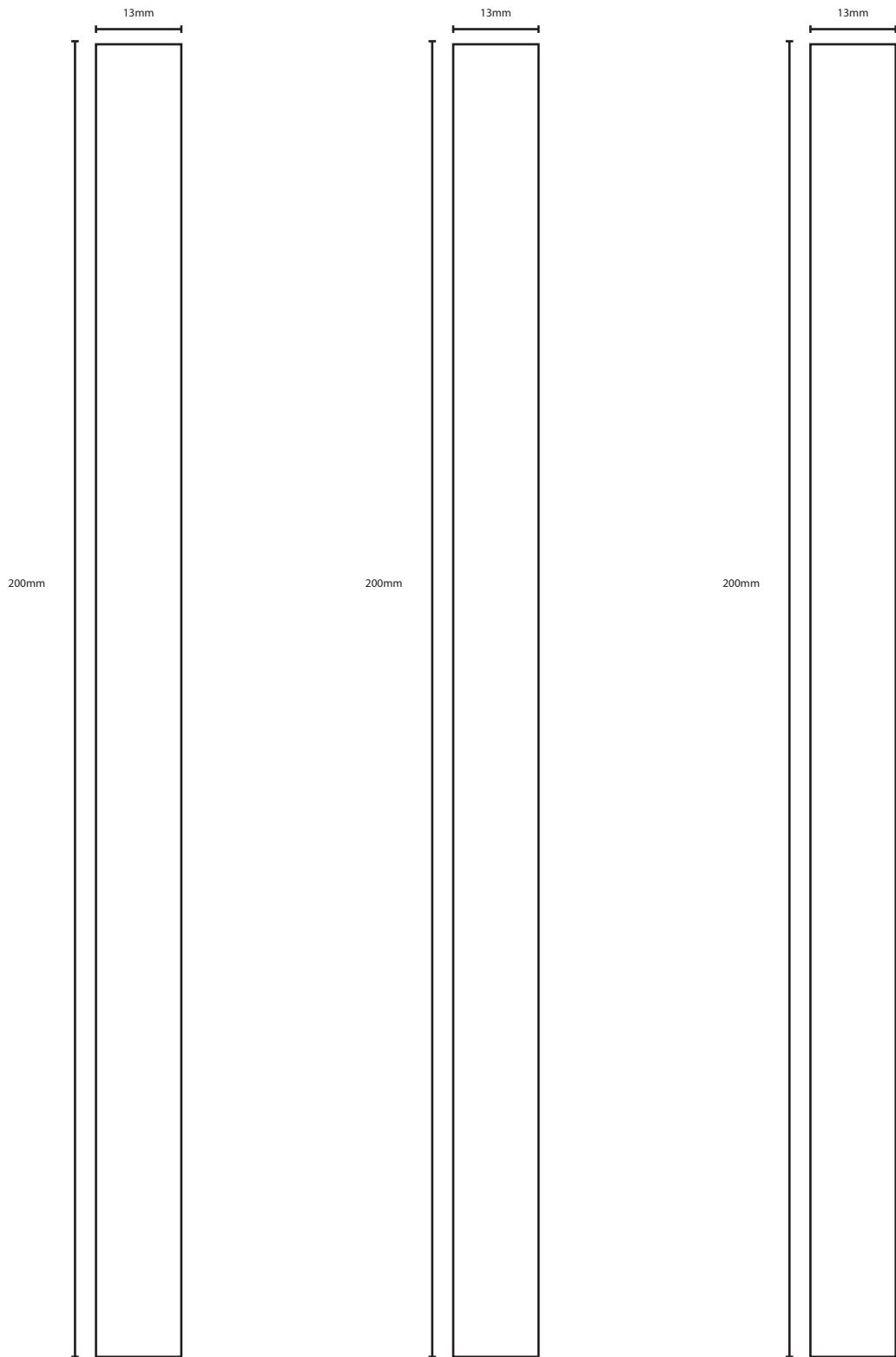
## Stencils

The following pages contain stencils used throughout the unit.

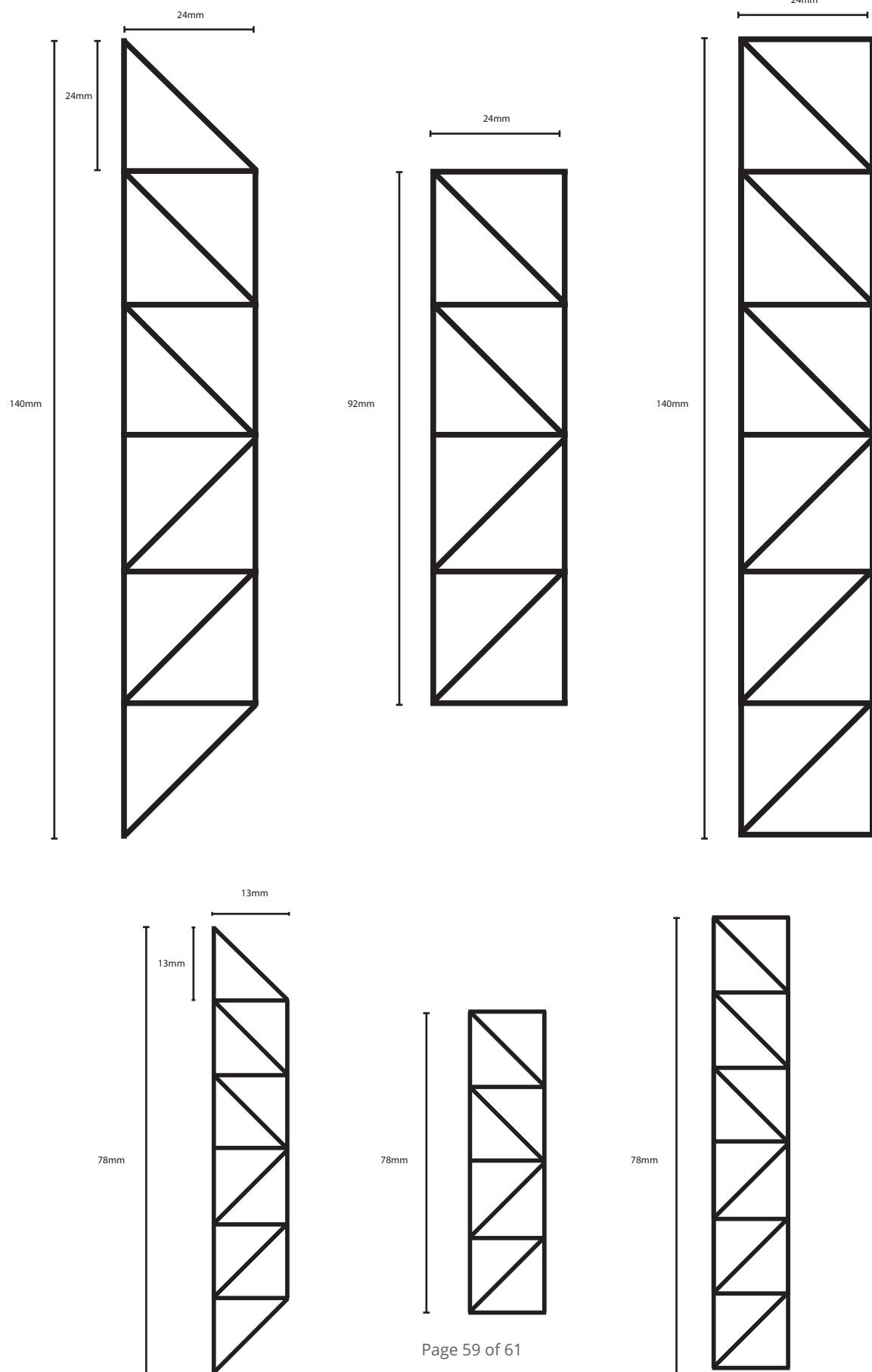
# Shapes with 3Doodler



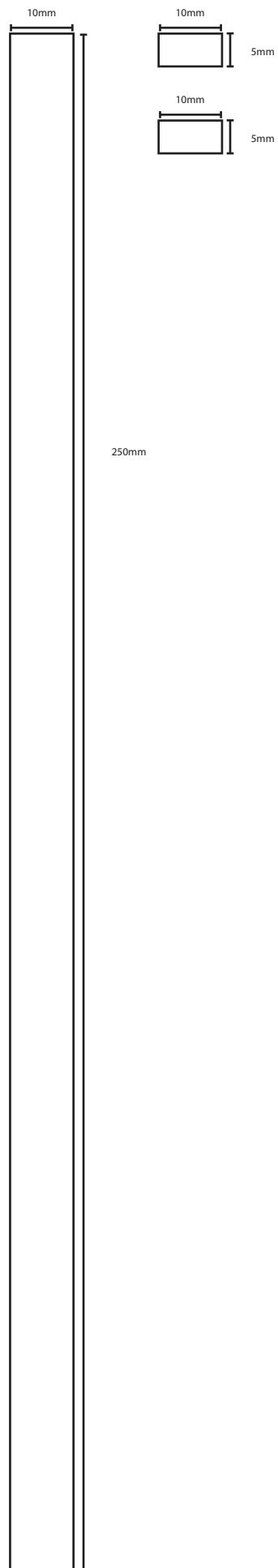
# Forces / Building I-Beams with 3Doodler



# Trusses



# Testing Beams



# Thank you.

Thank you for welcoming the 3Doodler into your classroom. We are constantly striving to improve our curricular offerings, and we need your feedback to do so. If you'd like to share feedback on your experience with this unit, or to show off your students' amazing creations, please reach out to us at [education@the3Doodler.com](mailto:education@the3Doodler.com).

Similarly, our community thrives on educators sharing their ideas and creations. If you would like to contribute your lesson plans, worksheets, stencils or ideas to the 3Doodler EDU community, please contact us at [education@the3Doodler.com](mailto:education@the3Doodler.com)!