MESA USA
Prosthetic Arm Challenge 2.1
INSTRUCTOR MANUAL

Contents

Module 0: Paper Tower Challenge

In this challenge split up into teams of four. The main challenge is to build a structure that holds a weight at the highest possible height without falling over. The weight will be an object that is provided by your instructor. You can use up to 10 sheets of $8.5'' \times 11''$ paper. You are allowed to cut, bend, fold, or roll the paper. When you are finished with your design, measure the height of your suspended object.

The following procedure should be recorded in your engineering notebook that was given to you by your instructor. Communicate as a group to work through each of the questions and procedure provided below. When each group is done with their design, your instructor

will go over each question and procedure as a class. This challenge will be performed twice. The second time this challenge is run through, address all the flaws from your first design. After the second run through, as a class discuss what obstacles each team faced.

Pre-Activity Questions:

1. What is the main goal of this challenge?
2. What are you trying to accomplish?
3. What materials are you limited to?
4. Are there any design constraints in this challenge?
5. What are the independent variables and dependent variables?
6. What are the main obstacles to overcome within this challenge?

7. How do you plan to address those problems?
8. What are some possible solutions?

Procedure:

1. As a group, brainstorm three different possible designs for your paper tower.
2. How are you going to manipulate the paper to create the tallest structure to hold an object?
3. Sketch all possible solutions in your engineering notebook as a team. You will need to present this to the class.
4. Make sure step of your design process is documented.
5. Make sure you team is communicating! Communication is key for this challenge!
6. Pick a design and build your first prototype.
7. Re-visit your design. Fix any flaws that you just encountered. Make sure that all flaws are documented in your engineering design notebook.
8. What are the current flaws within your design?
9. How many sheets of paper did you use?
10. Did you use the maximum amount of supplies that were provided?
11. Build second prototype.

Module 1: The Engineering Design Notebook and the Engineering Design Process

Learning Objectives:

1. Understand and demonstrate the steps of the Engineering Design Process.
2. Discuss the challenges that engineers face when creating a new product.

The Engineering Design Notebook

Purpose:

An Engineering Design Notebook contains documentation of a design projects from start to finish. It is a place to record ideas, research, observations, sketches, comments, and questions during the design process. Towards the end of the Engineering Design

Process, the notebook becomes the main reference for communicating results. Whether writing an engineering report, preparing a presentation, or creating an academic poster, the key information should already be part of the engineering notebook.

Content:
Your design notebook starts with the first step of the Engineering Design Process, “defining the problem.” An Engineering Design Notebook is a clear and detailed description of your team's design process so that someone unfamiliar with your work could take over the project without additional information.

Your Engineering Notebook Should Include:

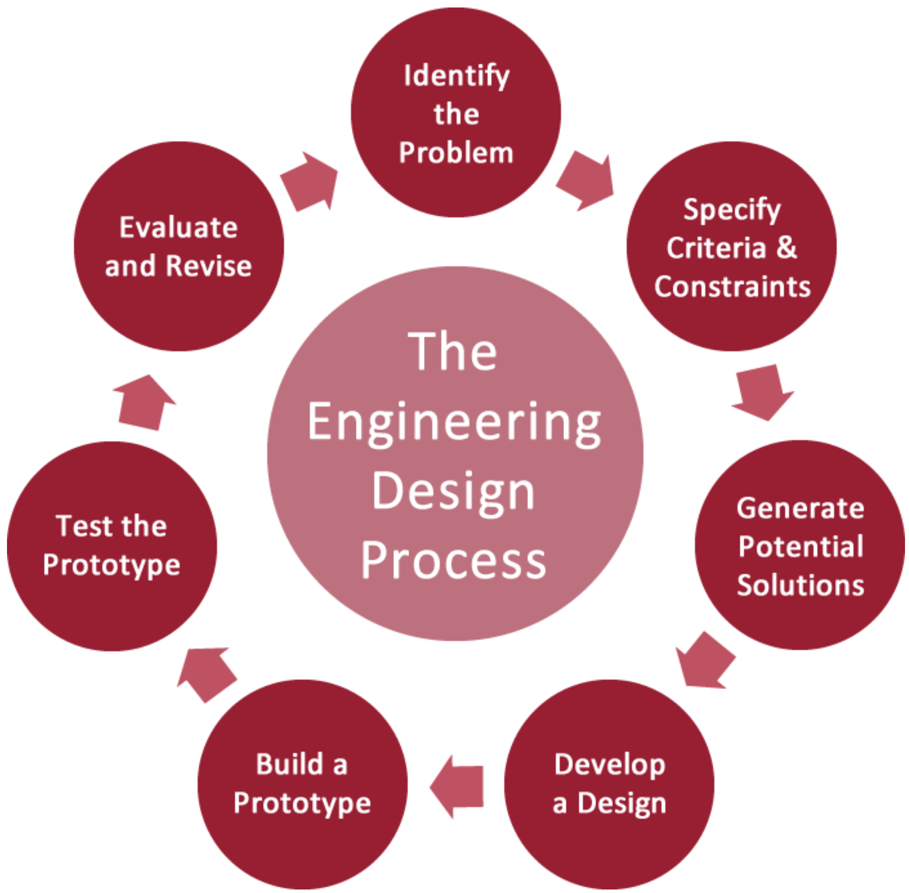
- Notes on background research
- Problem definition
- Lists of criteria and constraints
- Information received from experts
- Drawings, sketches, and photos
- Questions or issues
- Mathematical calculations
- Data tables, charts, and graphs

Formatting:
Engineering notebooks are bound numbered pages; either lines or grid format. For the MESA USA competition your team can either buy, make a notebook or one will be provided for you.
Write in pen, no erasing. It is important to document what did not work as well!
Number the pages if you are making your own notebook
Document in chronological order- Start and date a new page each day.
Tape printed information in your notebook. (Pictures, etc.)

Example of a Properly Formatted Engineering Design Notebook:

MESA Engineering Design Process

The engineering design process is a series of steps that engineers use to create functional products and processes that solve problems. While the engineering design process can be defined in multiple ways, all versions of it have the same general structure. MESA's engineering design process is shown below and will be referred to throughout your competition. The process is iterative, meaning it is repeated, so that changes and refinements can be made to the solution. Each iteration is intended to improve the quality and functionality of the design. Utilizing the engineering design process will help you better develop, design, and communicate your solution for the competition.



Throughout the following breakdown of the engineering design process each step will be applied to an example engineering problem that focuses on the design of a cell phone case.

Step 1: Identify the Problem

The Engineering Design Process begins with the identification of the problem that must be solved. By defining the problem, and more importantly understanding it, an engineer can ensure that the functions, attributes, and specifications of the solution properly address all aspects of the problem. To define the problem an engineer asks the following questions:

What is the problem or need?

Who has the problem or need?   Why is it important to solve?

Once these questions have been answered a problem statement can be written. A problem statement is simply a brief description of the issues that need to be address and will include the answers from above. Due to the amount of effort that an engineer will input throughout the design process, it is extremely important that the problem being addressed is actually the problem that is important to the potential users of the solution.

Cell Phone Case Design - Problem Statement:

A cell phones is an expensive, delicate device that users need to protect from damage without compromising the device's functionality and portability.

Step 2: Specify Performance Criteria and Design Constraints

Performance criteria are statements that define what specifications and standards the design must meet in order to be successful. These criteria help to outline what features should be incorporated into the design and provide objective guidelines for the proposed solution's functionality. The performance criteria focus on the operational requirements of the intended solution and simply stated they *describe what the solution must do*.

Cell Phone Case Design - Performance Criteria:

The case must protect the phone from a four-foot drop.

The case must be removable without tools.

All buttons, charging ports, and audio jacks must be accessible while the case is attached.

Design constraints, or limitations, are restrictions that the design must meet in order to prevent failure. These factors limit the engineer's flexibility in providing a solution. These constraints might include, but are not limited to, cost, time, knowledge, and manufacturing techniques available.

Cell Phone Case Design - Design Constraints:
The case must cost less than $2.00 in raw materials.
The case design must be completed in one month.
The design must be capable of being mass produced.

Step 3: Generate Potential Solutions
Once the problem statement has been drafted and the performance criteria and design constraints have been identified, an engineer will begin to work towards generating potential solutions to the problem. These initial ideas are concepts that may only meet some of the criteria and constraints, but possibly they can be modified or combined to provide a complete solution. Techniques for generating possible solutions include:

Breaking the Problem into Subproblems:
If the design problem is complex, it can be helpful to divide the main problem down into subproblems that can be solved more easily.

Search Externally for Ideas:
Researching what solutions currently exist can provide inspiration for a new design. Analyzing the strengths and weaknesses of existing solutions can be accomplished by comparing the designs to the recently drafted performance criteria and design constraints. Disassembling a current solution to see how it works, or *reverse engineering,* can provide useful information on how to further enhance and improve it.

Search Internally for Ideas:
Brainstorming is a great way to search internally for creative new solutions to a problem that exists. While brainstorming there is no incorrect answer and it is best to record all ideas, including ones that seem farfetched, as they may provide additional insight. In other words, focus on the quantity of ideas and not quality while initially brainstorming.

Cell Phone Case Design - Potential Solutions
A one-piece case that is made of a flexible material like silicone.
A hard plastic case that has two halves that snap together.

Four rubber bumpers that are placed on the corners of the phone.
A wooden case that has a front and back panel.
A multi-level case: Hard plastic exterior, rubberized interior, and a screen protector.
After a large number of concepts have been proposed, the engineering team works together to select the best idea(s) that have the greatest potential to be successful. A decision matrix is a tool that can be used to provide each idea with a score relative to how well it meets the performance criteria and design constraints that were previously defined.

Cell Phone Case Design: Decision Matrix

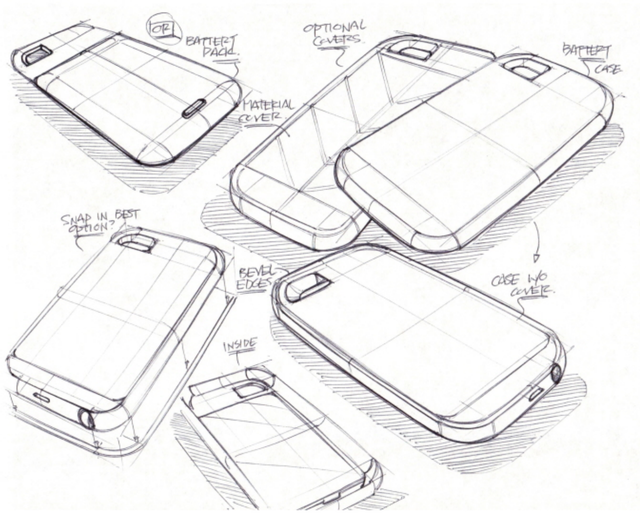
Cell Phone Case Concepts	Protection	Removability	Accessibility	Cost	Manufacture	Portability	Total
Flexible Silicone	7	9	8	7	7	7	45
Hard Plastic Halves	6	7	7	8	8	8	44
Rubber Bumpers	4	2	9	9	8	9	41
Wooden Panels	5	6	7	7	4	7	36
Multi-Level	9	5	7	4	5	6	36

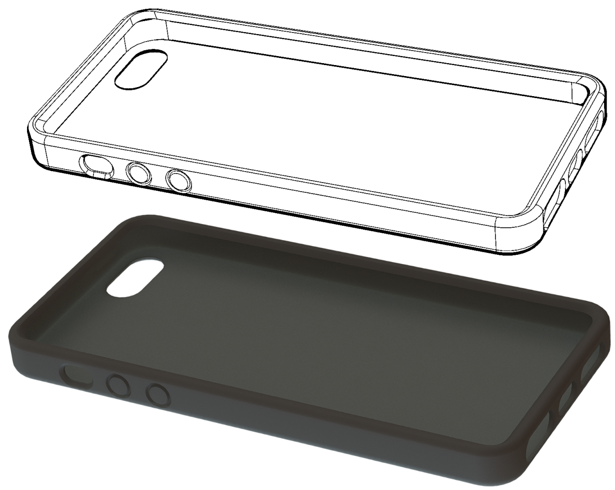
Step 4: Develop a Design
Once an initial concept has been chosen it is time to create a more detailed design. Sketches and detailed drawings of the design provide a blueprint that can be used to build a working model. Additionally, a materials list must be compiled that outlines the different components that are necessary to build the prototype.

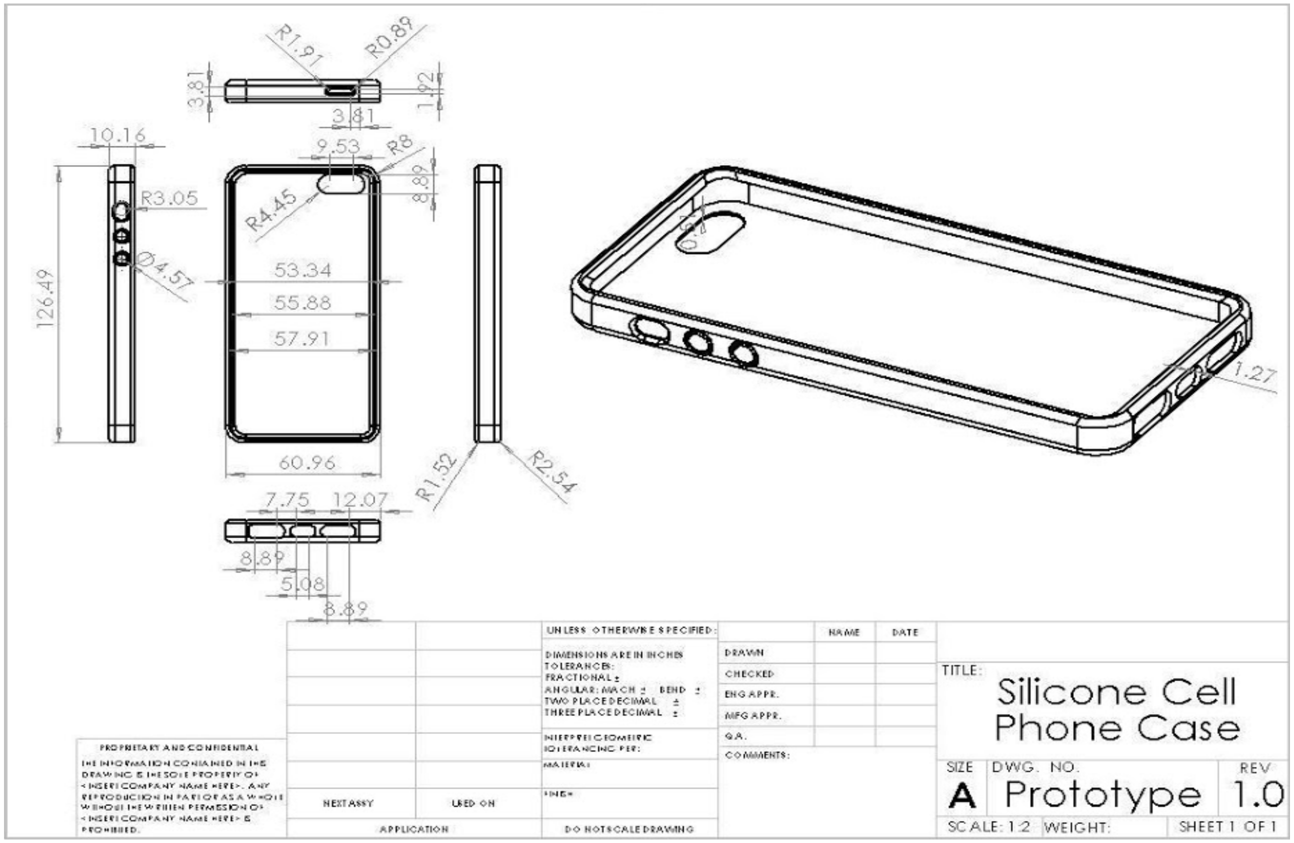
As the design is refined it is important to consider how the prototype will actually be manufactured. There may be limitations on what is possible relative to the tools and machinery that are available.

In early iterations of the design process sketches may be sufficient for initial prototyping, but as the design is continually improved better drawings will be required. More complex prototypes will require computer-aided design (CAD) models that perfectly define the geometry of the design so that 3D printer and automated machinery can be used.

Cell Phone Case Design: Initial Sketches, CAD Models, and Plans







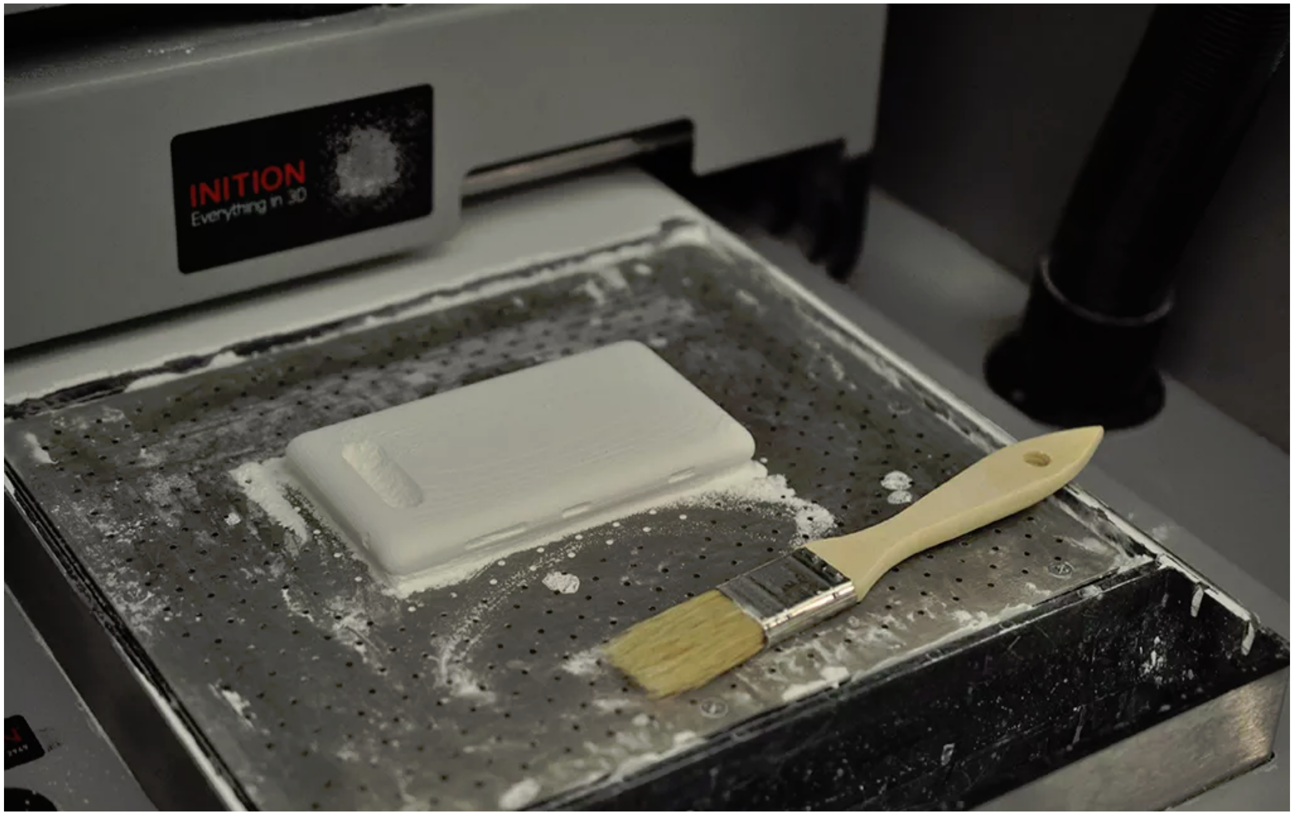
Cell Phone Case Design: Materials
Starch (base material for pliable silicone)
Silicone caulk (binding agent for pliable silicone)
Sculpey® SuperFlex Bake & Bend Clay
Two part silicone rubber (liquid casting agent)
Aluminum block (mold)

Step 5: Build a Prototype

Once a design has been drafted the next step is to build a prototype. Before a prototype can be fabricated the necessary parts and tools must be acquired. For initial prototypes simple materials such as cardboard, tape, glue, and other craft supplies can be sufficient.

For later iterations of the prototype specialized parts and materials can be used to produce a higher quality model. 3D printers are a great tool for rapid prototyping as they use inexpensive filament to print the parts and can do so in a relatively short amount of time.

Cell Phone Case Design: Prototyping



Step 6: Test the Prototype

Once a prototype has been built it is time to test it relative to the performance criteria and design constraints that were developed earlier. Specific, quantifiable tests for each criteria and constraint need to be developed. Multiple trials can be run to provide more accurate data on the prototypes performance. This is also time to think of the ergonomic, social, and aesthetic aspects of the design.

Cell Phone Case Design: Prototype Testing

Place a test phone or a substitute in the prototype. Drop the device from increasingly higher heights and record the resulting damage on the test phone. Is the phone capable of surviving a four-foot drop as per the performance criteria? How frequently does it survive this fall? Place the test phone into the prototype. Are all of the ports still accessible? Is the case removable without tools? Have multiple new users attempt to try to remove the case. How fast can they remove it? What are their comments and reactions in terms of the difficulty?

Step 7: Evaluate and Revise

After the prototype has been tested it is time to evaluate the data gathered to determine the success of the device. Analyze what aspects of the design failed to meet the necessary performance criteria and design constraints. Did the prototype sufficiently solve the design problem and what were its shortcomings? Share the information gathered with others to receive input and work as group to determine what needs to be redesigned. Perhaps a new problem has presented itself and thus the engineering design process can now be applied more directly to that aspect of the prototype. Learning from the failures of early prototypes is the greatest way to improve future prototypes. Suggest potential improvements and then begin to define the problems that the device still encounters.

Cell Phone Case Design: Evaluate and Revise

Testing showed that the majority of the damage occurred when the phone fell on a corner. Increasing the thickness of the case at these points could help improve the design.
The original concept of using corner bumpers could be combined with the current design to further help this problem. The silicone ripped during testing. Perhaps a hard shell case could be used in combination with the silicone.

Multiple prototypes will have to be developed before the best design has been produced.

Module 2: Identify the Problem and Specify Criteria & Constraints

1. Communicate with local experts to obtain support for engineering problems.
2. Scan STEM textbooks with attention to precise details and potential questions.
3. Scan a client profile and develop a design plan focused on the needs of a client.

Activity 2.1: Problem Statement Identification

Directions: Read the MESA Prosthetic Arm Challenge 2.1 Rules with your team. Clearly define the problem statement in your own words based on your understanding of the MESA USA National Engineering Specifications and the Engineering Design Process.

Problem Statement:

Activity 2.2: Identification of Performance Criteria and Design Constraints

Review of Concepts:

1. Performance Criteria: guidelines that are set by which the competition is evaluated on
2. Design Constraints**:** limiting factors

Directions: Using the MESA Prosthetic Arm Challenge 2.1 Rules, identify the performance criteria and design constraints involved in the design of a prosthetic arm. To aid in this answer the following questions with your team members. When answering the questions below, keep in mind the Engineering Design Process and your problem statement.

What is the maximum cost that the prosthetic arm needs to be?

What is the optimum size and weight expected?

What is the minimum number of fingers the prosthetic arm must have?

What are the power requirements?

What are the functions of the unencumbered hand?

What are the user requirements for the prosthetic arm? (ex: size, ease of use)

How is immobilization integrated?

List the basic functions of the artificial fingers.

Performance Criteria What is Required?	**Design Constraints** What is NOT Allowed?

Module 3: Generate Potential Solutions and Develop a Design

1. Apply reflections from simulation activities to design approach.
2. Articulate to their peers, with specificity, how they revised their design approach based on this simulation.
3. Explain how prosthetics enable completion of complex and everyday activities.

Generating Potential Solutions

With the performance criteria and design constraints now defined for the problem the engineering design team is now prepared to begin to consider potential solutions. The techniques for generating concepts are discussed in the first section of this workbook: break the problem into subproblems, search internally for ideas, and search externally for ideas. These techniques will be elaborated on and activities will be provided so that they can be directly applied to the production of the first prototype.

The technique of breaking the problem into subproblems can be applied during any stage of concept generation or design development. Sometimes it helps to focus on a specific aspect of the design as opposed to coming up with a general solution. For the prosthetic arm challenge this step may involve focusing on how the prosthetic is attached to the user's limb, figuring out the mechanics of the fingers, or determining a force will be applied to produce movement in the prosthetic.

Brainstorming:

Provide descriptions of three possible solutions to the problem. Do this prior to exploring existing options that may limit creativity by influencing your opinion of what the design should look like.

Activity 3.1: Initial Brainstorming

Make the following table in your design engineering notebook and fill in the results. Work by yourself to describe or sketch your initial design ideas.

Potential Prosthetic Arm Concepts
1.

2.
3.

The next step is to search externally for existing solutions to the problem. This can mean you reverse engineer a current product that solves the problem and determine how it works or you simply use an image database to find pictures of other designs. This allows the design team to understand what has worked in the past and may reveal where issues could arise in the design process. Additionally, it provides inspiration for concepts that may not have been considered.

Activity 3.2: Research Existing Concepts
Make the following table in your design engineering notebook and fill in the results:

Current Solution	Strengths	Weakness	Key Features
	*Simple part geometries* *Affordable manufacturing* *Adjustable socket* *Parts easily replaced* *Strong construction* *Uses standard hardware*	*Comfortability* *Adjustable height* *Aesthetics* *Rigid right angle design* *Socket does not form to leg*	*Hinged knee joint* *Toe attachment provides better fit for shoes* *Materials are affordable* *Parts can easily be modified*

Use the internet and other research resources to discover existing solutions to the problem. Outline the strengths and weaknesses of each design and determine how well each existing solution meets the performance criteria and design constraints that have been identified. Determine the key features or elements of each design that could be implemented in the prototype.

Activity 3.3: Group Brainstorming Using IDEO Technique

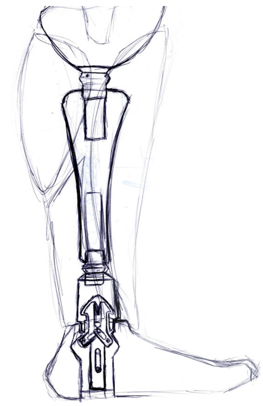
Use the following rules and table to have a brainstorming session with your engineering team. Each team member should create as many concepts as possible as this will help find the ideal solution. During the brainstorming process it is important to record all ideas within the engineering design notebook. It may help to first record each idea on an index card so that the ideas can easily be shared amongst other members. Index cards can then be taped or pasted into your engineering design notebook.

Rules of Brainstorming:

1. Defer judgement. You never know where a good idea is going to come from. The key is make everyone feel like they can say the idea on their mind and allow others to build on it.
2. Encourage wild ideas. Wild ideas can often give rise to creative leaps. In thinking about ideas that are wacky or out there we tend to think about what we really want without the constraints of technology or materials.
3. Build on the ideas of others. Being positive and building on the ideas of others take some skill. In conversation, we try to use “and” instead of “but.”
4. Stay focused on the topic. Try to keep the discussion on target, otherwise you can diverge beyond the scope of what you're trying to design for.
5. One conversation at a time. Your team is far more likely to build on an idea and make a creative leap if everyone is paying full attention to whoever is sharing a new idea.
6. Be visual. In live brainstorms we write down on Post-its and then put them on a wall. Nothing gets an idea across faster than drawing it. Doesn't matter if you're not Rembrandt!
7. Go for quantity. Aim for as many new ideas as possible. In a good session, up to 100 ideas are generated in 60 minutes. Crank the ideas out quickly and build on the best ones.

An example of a concept generated during the brainstorming phase:

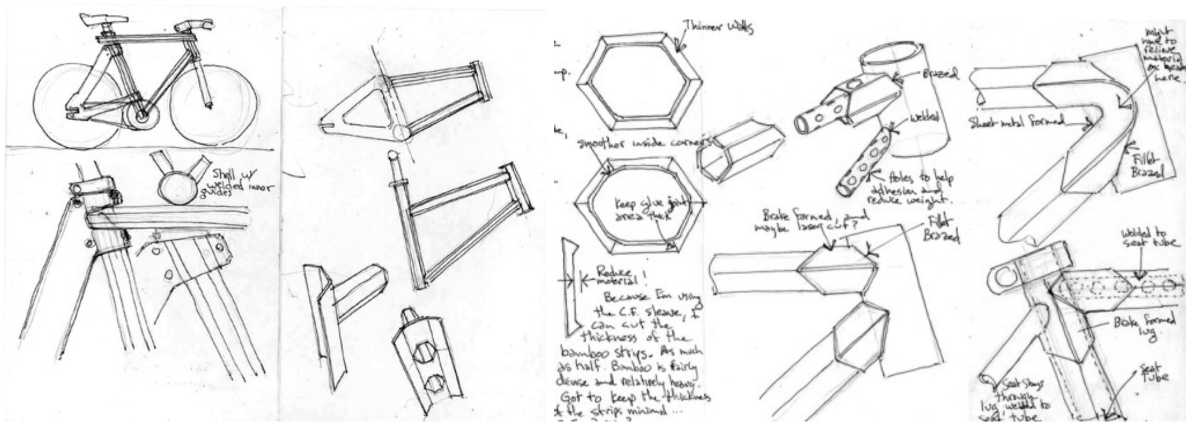
Name of Idea: Detachable Foot w/ Custom Shells	Simple Conceptual Sketch of Idea:

Description/Features: Interior main chassis allows for rigid construction and support for the prosthetic. Custom 3D printed shells can be attached to the interior frame. Provides better aesthetics and customization for the user. Detachable foot makes dressing easier.	

Once a large number of ideas have been generated the team must work together to select the best idea. This is accomplished with the completion of a feasibility analysis, which is a stage where the engineering members discuss the practicality of each concept. Take the list of ideas that have been generated and ask yourself how well each idea has the capacity to meet the performance criteria and design constraints.

One way to accomplish this task is to use a decision matrix such as the one shown in section one. It is shown again below:

Once the best idea(s) have been selected it is time to start refining the design so that it can be built during the following prototype process. Before building a prototype a detailed drawing or sketch must be drafted with general dimensions and descriptions of features. Additionally, a materials list should be compiled. For the first round of prototyping craft supplies can be used and the drawing does not need to be as detailed. Later prototypes will require an orthographic drawing and specialized parts that may need to be ordered. It is also important to discuss how the design will be fabricated and assembled during the prototyping stages. There may be certain building steps that must occur before others, so it is important to discuss the proper build order and to write out a general plan for the prototyping process.



Activity 3.4: Produce a Detailed Sketch
Have the team work together to create a parts list and more detailed sketch of the selected design. As a group have a discussion about the design and plan for building the prototype. This will make sure that the parts that have been designed can actually be built and assembled without running into compatibility and clearance issues.

Design Efficiency: Greatest ratio of performance score to device mass plus greatest ratio of performance score to total cost of materials.

Prototype

1. Construct a mechanical, fo ical design.
2. Identify the basic physics t
3. Apply logic processes to eva
4. Reach a consensus on which design is best suited for the challenge of which they will construct at least one prototype.

Now that all of the designs are finalized, it is now time to build a prototype. A prototype is an operating version of a solution. Often a designer makes a prototype with different materials than the final version, and generally it is not as polished. A prototype is classified as a model of a product used to explore test concepts and ensures that the product is safe and user-friendly. It is a design that is created and built to test a theory. It is important to realize that the goal of building a prototype is to work through the design flaws. The CEO of the design firm IDEO approaches the engineering design process with the mantra: “fail often to succeed sooner.”

Prototypes are important because it is key to the development of the final design. Prototyping allows you to fix any flaws or imperfections with the design. Prototypes can help you develop the structure, function, and appearance of your potential solution. Occasionally, designers will prototype pieces of their final solution early in the design process and sometimes they will make several iterations.

There are four different types of prototypes; visual, proof- of- concept, presentation, and pre-production. A visual prototype is a product that does not have all the working parts but represents all overall shape and dimensions. Proof-of-concept prototype showcases the core functionality of the product with all the technical aspects. Presentation prototypes are products that are only used for demonstration purposes and are not the final product. Pre-production prototypes build on the presentation prototypes design such that it can be mass produced.

Initial prototyping for the Prosthetic Arm Challenge should focus on the construction of a proof-of-concept prototype. There are lot of complex parts involved in a prosthetic arm and it is important to determine how each of the components will function.

Activity 4.1: Build a Simple Mechanical Finger

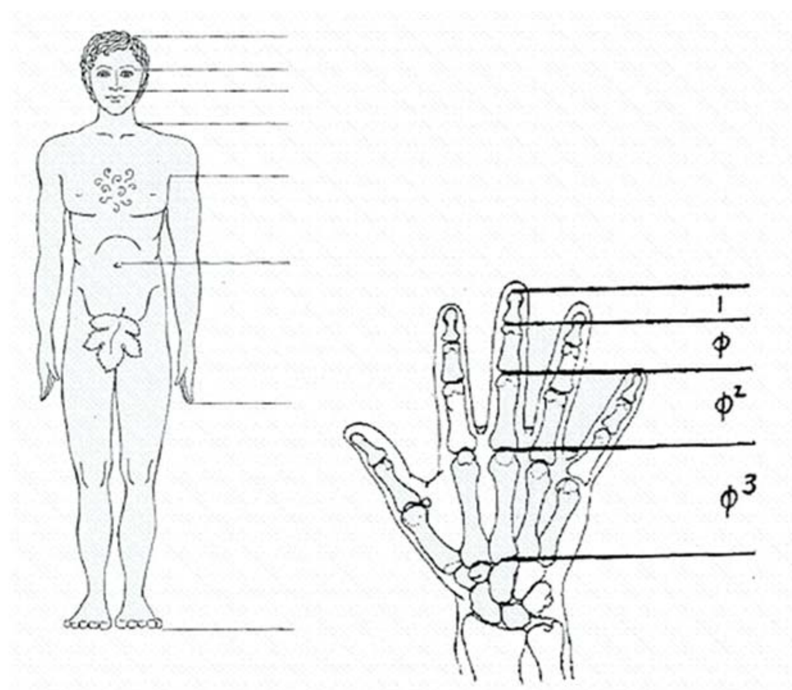
Work individually to create a mechanical finger using the supplies listed below. Use the process listed as a guideline. You may find that there are certain elements of the design that you feel can be improved. Take a note of these flaws and potential improvements. If you have time after completing the finger, apply these modifications and see if they improve the performance.

Materials List:

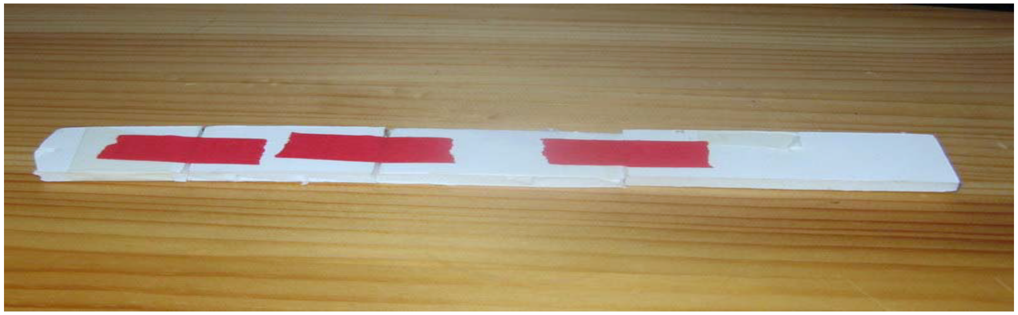
1. Bone material: wood tongue depressors, foam core or equivalent rigid material (2 cm x 40 cm x thickness).
2. Muscle material: rubber bands, cut once
3. Ligament and tendon material: electrical or masking tape
4. String, 40 cm
5. One drinking straw

Procedure

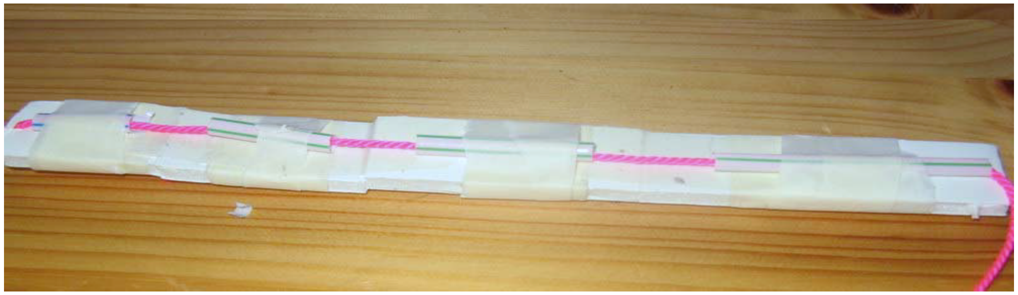
1. Measure the length of each joint of one finger starting from the fingertip:
    a. Length from fingertip to knuckle #1: ____________________
    b. Length from knuckle #1 to knuckle #2: ____________________
    c. Length from knuckle #2 to knuckle #3: ____________________
    d. Length from knuckle #3 to wrist: ____________________



2. Cut the bone material into the four lengths you just recorded.
3. Cut the straws into pieces about 6/10 the length of each piece of bone material.
4. Use the ligament material (tape) to connect the bone pieces together in the proper order.



5. Turn finger over and attach the muscle material (rubber bands) with the tendon material (tape). At each end of rubber band fold over the bit rubber band and tape down to provide a stronger anchor.
6. Turn over again and tape straws to the middle of each section and insert the string.



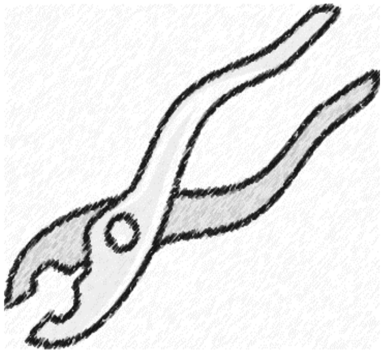
7. Anchor the string at the tip of the finger cutting a notch in the bone material for the string to wedge into. Apply tape over the string after it has been placed in the notch.
8. Pull the string to actuate the finger. Note: you will need to hold parts of the finger steady to make the finger work.

Question Your Design:

Discuss how your design worked with the other members of your team. Did any of you attempt to modify the design? If so what did you do, why? If not, what would you suggest to improve the functionality of the finger?

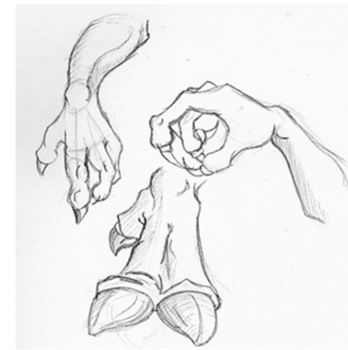
1. Would this finger design work in the MESA competition?
    a. If so, how many “fingers” would you need to complete the challenges?
    b. How would they be oriented?

2. In the neutral or “relaxed” position, this mechanical finger is “open” or pointed. Can you build a device that is “closed” in the relaxed position (no external forces applied)? Would this be better for the MESA challenge?
3. Take a look at the pictures on the next page. Would these work better in your design? How about a combination of these?



Activity 4.2: Build a Prototype

With your designs in mind, now begins the building process of the engineering design process. Use the materials that are readily available. Depending on the given class size, the overall goal is to create two prototypes per team.



Potential Materials List:

Cardstock	Rulers	Paper clips
Wooden or metal dowels	Hot glue	Empty water bottles
Duct tape	Cotton balls	Empty soda bottle
Popsicle sticks	String	Rubber bands

As you build the prototype you may find that certain elements of the design are flawed and must be revised. Record issues that arise in your engineering design notebook, and then use the earlier steps of the engineering design process to develop new solutions. During the prototyping process it will become clear why breaking the problem into subproblems can make the design process easier.

Each team will determine their own method for immobilization and must demonstrate this for the judges during specification check and impound.

Module 5: Test

1. Identify independent and dependent variables.
2. Determine how many different tests are needed to describe all variable's impact.
3. Design data tables and use data from tables to create correctly labeled charts that depict the significance of the data.
4. Statistically analyze the results of a dataset to derive meaning from an experiment.

Once a working prototype has been developed it can be tested to determine its effectiveness. The performance criteria and design constraints have already been developed and will serve as benchmarks. The objective of the testing process is to develop procedures that will analyze the degree to which the prototype is capable of meeting these standards. This task is called 'engineering validation testing' (EVT) and it evaluates the functionality of the prototype. There are multiple verification methods that can be used:

Demonstration: Demonstrations are conducted in the actual environment that the design would be used, or a simulated environment that mimics actual conditions.
Example - Performance Criteria: The cell phone case must be removable without tools. The simplest method for verifying this requirement is to have someone actually attempt to remove the cell phone case from a phone without the help of any tools. To document the testing, it can either be witness or recorded with a camera.

Inspection: Inspection is used to verify requirements related to physical characteristics.
Example - Design Constraint: The cell phone must not increase the dimensions of the phone by greater than .5” in any dimension. In order to verify this constraint, the prototype can be measured and the results documented. This is one of the least expensive verification methods.

Analysis: Analysis can be used if testing is not feasible, possibly as a result of being cost prohibitive, and the risk of using it is low. For example, analysis can be used to support the argument that a product has the durability to survive its desired lifecycle. If the lifecycle of a product is 25 years, it would take too long to completely test these criteria.

Similarity: If a design has features or materials that have been proven on a similar product to meet or exceed specifications, then an analysis to illustrate this similarity can be used as verification that the performance criteria has been met. For example, if a specification requires a product to be water resistant, and a material has proven to be water resistant in other applications, then an analysis of similarity can be used.

Testing: Testing is the most time, and cost, intensive verification method, but sometimes it is the only acceptable way to verify that requirements are met. Testing involves developing a procedure that can collect data to verify that a criteria or constraint has been met. Example - Performance Criteria: The case must protect the phone from a four-foot drop. In order to test this the case could be placed around an old phone and dropped repeatedly from a height of 4'. If the case protects the phone from multiple falls of this height across many trials than the performance criteria can be verified.

It is important to properly test a prototype because it helps to identify design problems as early as possible in the design process. Poor testing can allow design flaws to remain latent: the flaws exist, but they have not been revealed yet, and thus cannot be resolved. When the testing process does expose issues in the design the engineering team must revert to an earlier stage of the design process to develop a solution.

For the Prosthetic Arm Challenge many of the performance criteria and design constraints can be verified using the demonstration and inspection methods. It is good to verify these simpler tasks first because the testing process takes more time and we only want to test the prototype once we know it at least meets the general criteria.

Activity 5.1: Plan Engineering Verification Testing

Compare the list of EVT techniques above to the list of performance criteria and design constraints developed earlier in the engineering design process. For each criteria and constraint determine which engineering verification testing technique will be applied. Make notes regarding how the testing process will be used and outline the necessary procedure.

The following table should be made in your engineering design notebook:

Performance Criteria / Design Constraint	EVT Method	Description
The case must protect the phone from a 4' drop.	Testing	The case and phone will be dropped from 4' multiple times and damage to the phone will be determined.
The case must be removable without tools.	Demonstration	A user will try to remove the case. The trial will be timed so that the ease of removability can be compared to future iterations.
The design must be able to be mass produced.	Analysis	An analysis of various manufacturing techniques will show that the case can be made through injection molding and the geometry does not prohibit the use of this method.

Activity 5.2: Demonstration/Inspection/Analysis/Similarity Verification
Use the table generated in the previous step to verify any criteria/constraints that can be evaluated using demonstration and inspection. Write down the criteria or constraint and document the verification process.

Additionally, use the Inspection and Performance Datasheet to verify that the prototype passes the inspection list. Record the inspection list in your engineering design notebooks to provide documentation that the design is meeting these mandatory qualifications. This list is as follows:

INSPECTION LIST:	YES	NO
Device is a generalized tool and includes all parts necessary to accomplish all tasks	☐	☐
Includes at least two artificial fingers that open and close	☐	☐
Fingers grab and release the specific objects for each task	☐	☐
Fingers are controlled by Arduino programming and components	☐	☐
Team has demonstrated immobilization of the wrist, hand and fingers separate from the device	☐	☐
The team provided a complete itemized budget with references and documentation	☐	☐
Device does not exceed the $80 pre-tax price limit	☐	☐

Use the analysis and similarity verification techniques if you identified that they were necessary. These may be needed for evaluating design durability.

If the prototype does not pass these initial verifications, then it will be disqualified at the competition. The engineering design team must revert to an earlier stage in the engineering design process to resolve any issues that arise from this initial evaluation.

Activity 5.3: Testing the First Prototype
Finalize the testing procedure for any performance criteria or design constraints that were found to need testing. Determine the variables that you are attempting to test and establish controls in the experiment. Record the testing process in your design notebook.

Example: Testing the ability of a cell phone to survive a 4'drop using the case prototype.

Cell Phone Drop Test Results – Prototype v1.0		
Trial	Drop Height	Damage
1	4'	Survived fall with no observable damage.
2	4'	Survived fall with a .0625” deep dent to the corner of the case.
3	4'	Survived fall with no observable damage.
4	4'	Case fractured but the phone remained undamaged.

For the Prosthetic Arm Challenge one of the best ways to test the effectiveness of the prototype is to determine how well it completes the competition tasks. The tasks for the competition are as follows: distance accuracy, object relocation, dexterity, and design efficiency.

Take some time to review these tasks that are outlined in the MESA National Engineering Design Competition Prosthetic Arm Challenge 2.1 Rules.

Activity 5.4: Mock Competition
Have a different member of your team focus on each task. Their goal is to become an expert on the particular challenge in terms of the rules that are involved. The team will then compete in each challenge and use the Inspection and Performance Datasheet to record each trial score. Each team member should complete multiple trials of each task so that scores can be compared. Scoring and observations on the performance of the device should be recorded in the engineering design notebook by members of the team that are not actively participating in a test trial.

At this point the team should have gathered data and observations about the prototype. With the first iteration of the prototype it is likely that there are many flaws that have been discovered. The prototype may have outright failed to meet certain performance criteria and design constraints. The next stage in the design process will take this information in to consideration and determine what changes must be made to the prototype.

The device MUST incorporate an Arduino microprocessor which is programmed with the Arduino language.

Teams MUST submit a completed itemized budget sheet for their device and MUST provide documentation to support each and every price listed.

Module 6: Evaluate and Revise the Prototype

1. Critically analyze initial designs using design constraints and performance criteria, and as a result choose the best design option.
2. Apply logic and statistical processes to evaluate the effectiveness and merit of a design.
3. Come to a consensus on which design is best suited for the challenge and which they will begin to construct in the next lesson.

After the design has been tested and the performance criteria and design constraints have been verified the engineering design team is tasked with evaluating what changes must be made to the design. The team must analyze the data gathered in any tests to reveal where the prototype failed.

Activity 6.1: Individual Analysis of the Verification and Testing Process

Compare the data gathered directly to the performance criteria and design constraints. Write a statement that records your conclusion on the prototypes ability to meet each criteria/constraint. Did the prototype fail the verification process? What solutions can you brainstorm to resolve this issue? A table similar to one used earlier can be employed:

Devices must be in testing condition prior to device inspection before competition. If devices do not meet specification check, design changes will not be allowed.

Performance Criteria / Design Constraint	EVT Method	Conclusion
The case must protect the phone from a 4' drop.	Testing	The phone and case survived 80% of the drop trials from 4'. The greatest damage occurred when the phone fell directly on a corner. 60% of failure trials resulted in only the phone case breaking while the phone remained undamaged. Can the case be designed to purposely divide into halves upon impact without breaking?
The case must be removable without tools.	Demonstration	The phone case could be removed in an average of seven seconds, but required the use of the user's nails to pry the case off. Could the case be redesigned so that it can be removed more easily and in under five seconds?
The design must be able to be mass produced.	Analysis	The analysis and discussion with experts determined that the case at this point can be easily injection molded and thus can be mass produced quite easily.

Activity 6.2: Group Evaluation of the Testing Process

Selecting one criteria/constraint at a time, each member of the engineering design team should share their opinions on how well they felt the prototype met the requirement. The team should discuss how the design failed, why it failed, and possible solutions. Record any additional conclusions gathered through group discussion.

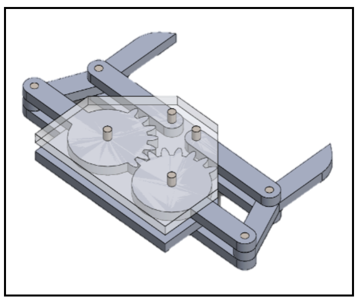
It is important to recognize that the engineering design team is now defining how the prototype has failed. Essentially the team is at the first stage of the engineering design process again: Define the Problem. What caused the prototype to fail? Where is the prototype surpassing expectations?

By redefining the problem with the existing solution the engineering team can now focus on subproblems that have arisen. The design team can now work to brainstorm potential solutions to each of the newly identified flaws in the prototype. From the example above it was determined that the cell phone case survived most falls, but ran into issues when the prototype landed on a corner. A possible solution to this might involve adding more material at the corners of the device or including a different type of material as an additional layer of protection at the corners of the device.

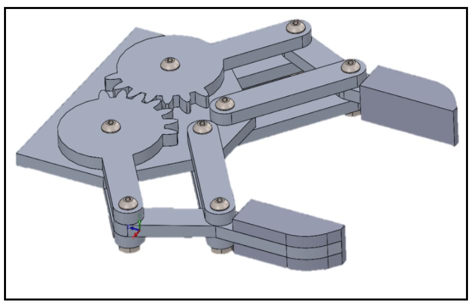
As a team, brainstorm potential solutions to the newly discovered flaws in the device. It is important to determine when a design is a complete failure and an entirely new solution should be generated. However, sometimes a few small design changes can be employed that resolve the issues and produce a working prototype. Often the initial solution may be overly complicated and perhaps a simpler design solution could have been employed.

Activity 6.3: Redesign and Reiterate the Engineering Design Process
Each team member should develop a new design solution and determine what the next course of action is. Discuss as a group the best solution and next course of action that should be taken place by the design team. The goal is to iterate the design process again to either improve an existing prototype or to develop an entirely new solution.

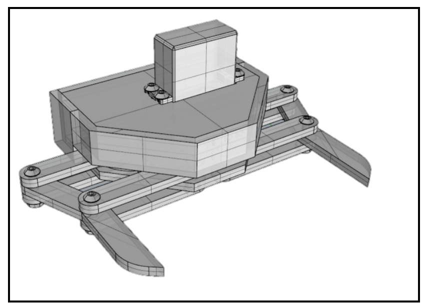
When engineering design teams work on prototypes it is important to name the prototype version effectively to keep track of design changes. This name should be applied to designs and documentation for each prototype as it is being developed. The first prototype bears the name 'v. 1.0' (version 1.0). Minor design changes increment the number to the right of the decimal. Major design changes increment the number to the left of the decimal.



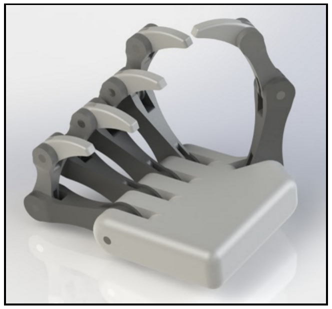
V 1.0: *Initial Parallelogram Design Concept*



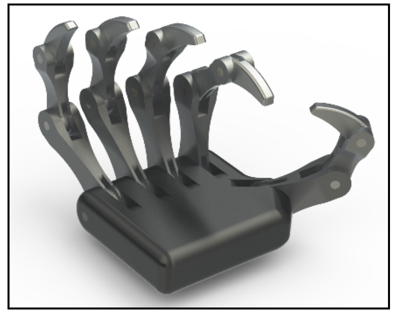
V 1.1: *Parallelogram with Increased Gripper Surface Area Design Concept*



V 1.2: *Parallelogram with Case and Motor Design Concept*



V 2.0: *Initial Five Finger Design Concept*



V 2.1 *Shortened Thumb Five Finger Design Concept*

Module 7: Introduction to the Arduino Electronics Prototyping Platform

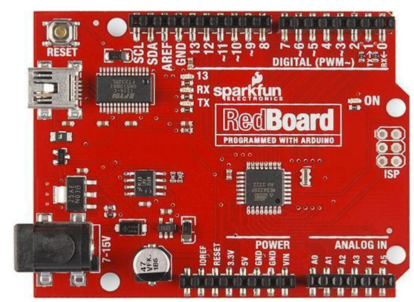
1. Differentiate between Arduino hardware and software components by name and functionality.
2. Use simulator software or actual hardware to wire simple circuits, including: a power source, one button, LED, support wiring, and necessary resistors.
3. Code basic functions in Arduino to produce a desired result.

In this module you will learn the basics of wiring and coding an Arduino, this will allow you to create the electronic system that will power your Arduino. The module starts by providing some background on what Arduino is, the parts that are involved, and how the electronics are coded. You will then use a simulator to work through multiple activities that will show you how to progressively produce more complex circuits.

Terminology

Software: the programs used to direct the operation of a computer and perform certain functions
Hardware: the machines, wiring, and other physical components of a computer or other electronic system
Open-Source: denoting a product or system whose origins, formula, design are freely accessible to the public to modify and use
Microcontroller: a smaller computer consisting of one circuit
Output: power leaving the system
Circuit: a path where a current source flows through
Schematic: a diagram that shows how an electronic circuit is wired

What is Arduino?

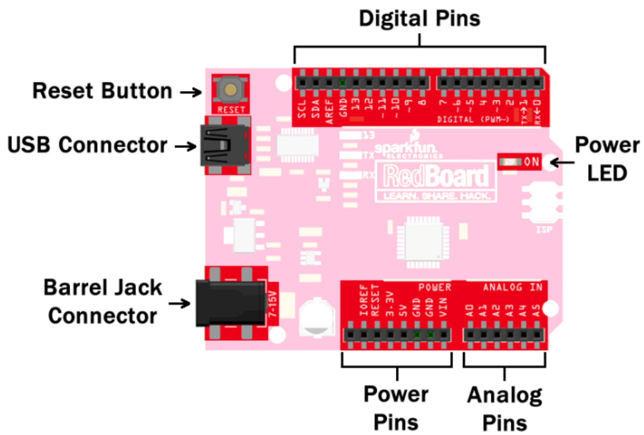


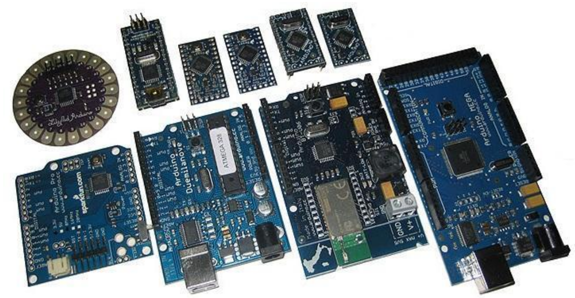
Arduino is an open-source family of **microcontroller** boards used to easily design, prototype, and experiment with electronics. Arduino consists of both **hardware** and **software** components.
Hardware: the machines, wiring, and other physical components of a computer or electronic system
Software: the programs used to direct the operation of a computer and perform certain functions

The main hardware element of an Arduino system is a physical programmable circuit board, often referred to as a **microcontroller**. A microcontroller is classified as an Arduino board if it can be programmed using the Arduino software.

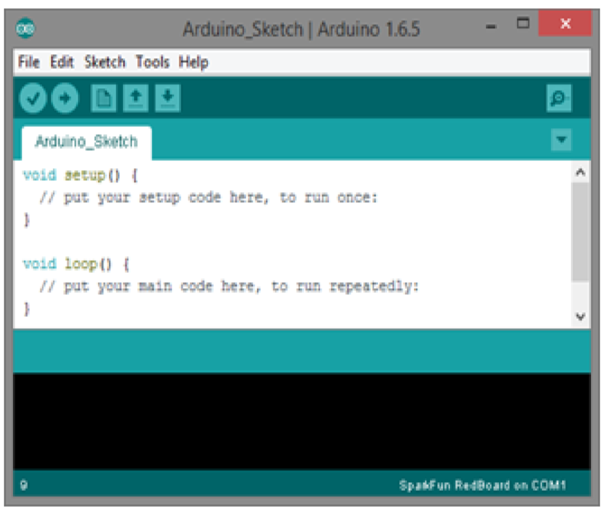
Microcontroller: a compact computer (SoC: system on a chip) present in a single integrated circuit which is dedicated to perform one task and execute one specific application. It contains memory, programmable input/output peripherals, and a processor.

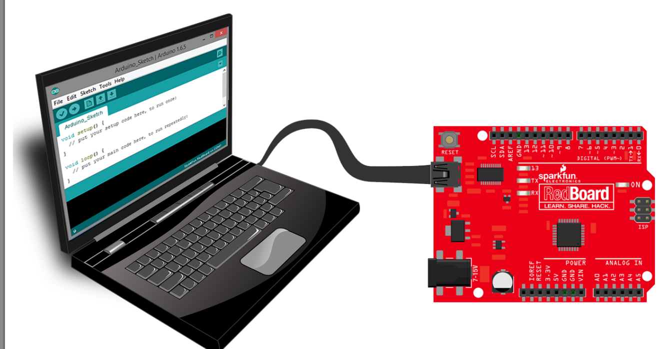
There are a variety of Arduino boards available depending on the needs of the user. The boards have varying sizes, components, and capabilities. Some examples of Arduino microcontroller boards are shown in the picture to the right. The board that you will be provided with, the Sparkfun RedBoard is shown below:





The m he Arduino Integrated Development Environment (IDE), which runs on a computer and is board. It can be used to program any Arduino microcontroller using a compatible data transfer cable, which depends on the specific board, but is usually a USB cable.

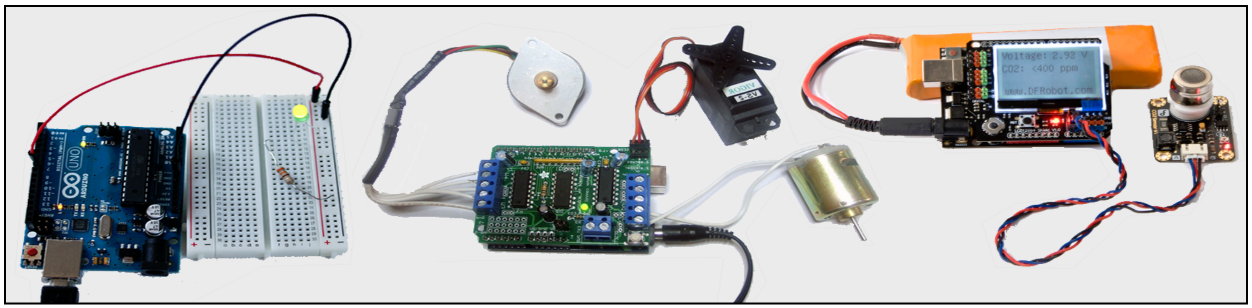




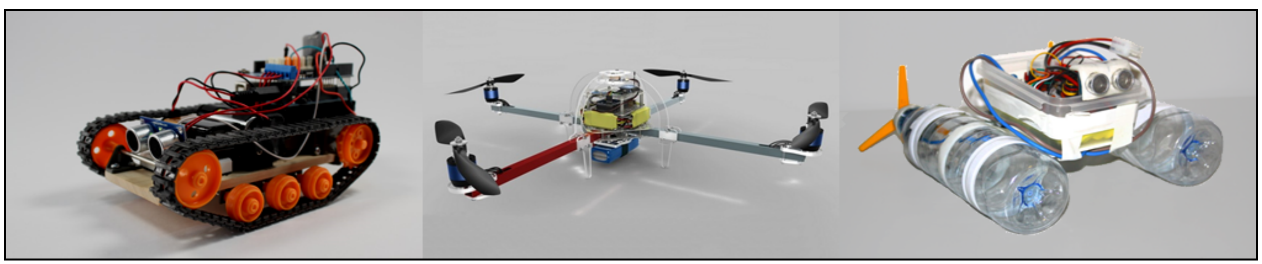
The Arduino IDE is designed to introduce programming to newcomers unfamiliar with software development. It includes a code editor that is used to write a program called a “sketch”. The sketch is written in the Arduino language which is mainly a set of functions from the language C/C++. Functions are bodies of code that receive input data and

What does Arduino do?
The Arduino hardware and software works together to create electronic projects that are capable of interacting with the world through the use of sensors, lights, motors, and other devices. It does this through the use of its input and output pins. Input pins receive information from hardware components that can include: cameras, buttons, switches, motion sensors, light sensors, proximity sensors, etc. Output pins send signals from the Arduino to hardware components that can include: motors, LEDs, speakers, solenoids, relays, etc.

Example Arduino Projects:



Simple projects for the Arduino involve controlling a single LED light, driving various types of motors, and programming sensors. The sensor in the picture above is able to determine the quantity of the greenhouse gas carbon dioxide that is in the air.



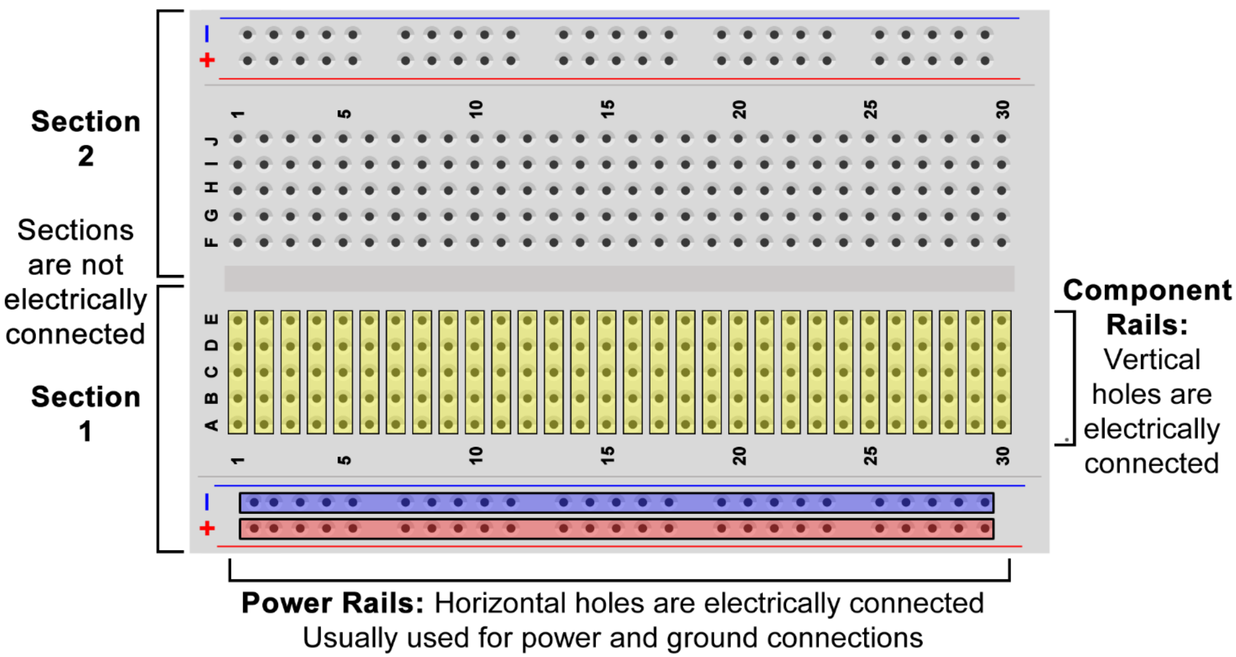
More complex projects for the Arduino can involve designing vehicles and robots. These can be vehicles that operate in the land, air, and water. They can be made to move using a remote controller or they can be programmed to move autonomously through the use of sensors that allow the vehicle to avoid obstacles.

Other Arduino projects can augment existing technology and automate processes that had to previously be done manually. Some of these projects include: adding robotic control to devices, monitoring and adjusting the growing conditions of plants, and automating the motion of a camera so that it can capture panoramic time-lapse footage.

Basic Electrical Component Overview:

Breadboard:

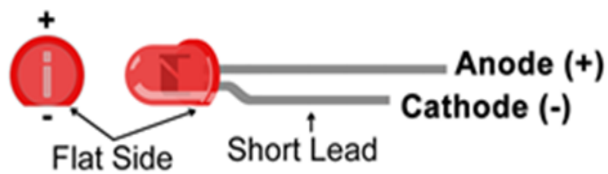
Breadboards are perforated plastic blocks that allow for solderless prototyping of electrical circuits. The holes in the breadboard contain metal contact points that can hold electronic components and connect them with an underlying strip of metal.

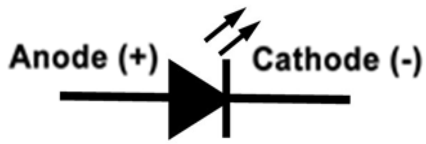


Understanding the layout of the underlying connections of a breadboard is essential for successful use. The diagram above shows how the contact points are connected. It is important to note that the two halves of the board are not connected.

LED:

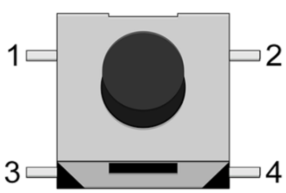
A light emitting diode (LED), is a semiconductor light source. LEDs can produce light of multiple wavelengths: visible, ultraviolet, and infrared. Visible light LEDs can come in a variety of colors and are often used as visual indicators. Infrared LEDs can be used to transmit signals remotely.

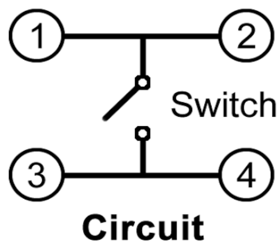


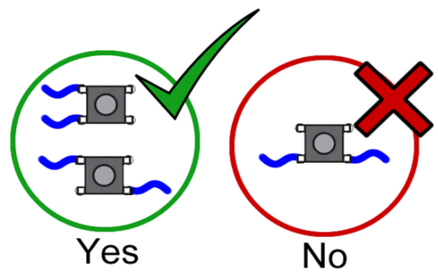


Tactile Switch:

A tactile switch is an electric switch that controls the flow of electricity through a circuit. It is different from other switches in the sense that it is momentary, meaning the switch is only activated while it is pressed. As soon as pressure is removed the switch goes to its default state of being open. A tactile switch acts as a button. It is important to learn the proper wiring of a tactile switch, as can be seen below:

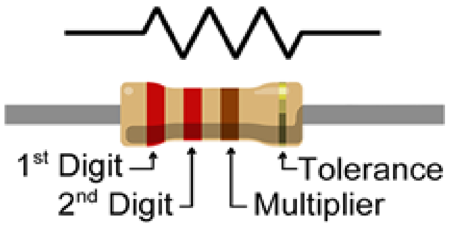


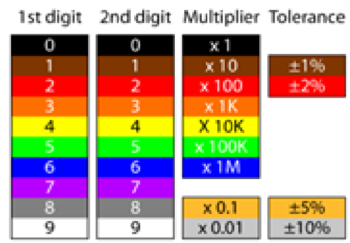




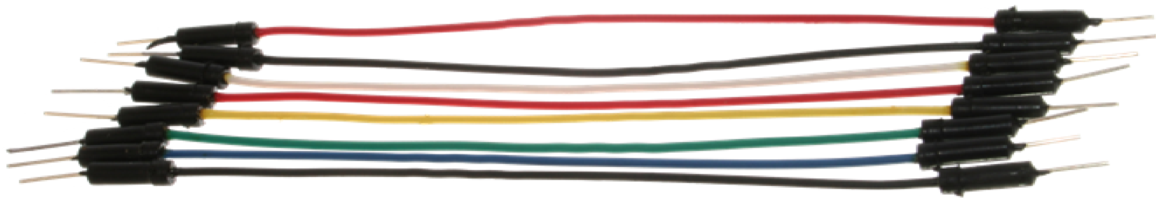
Resistor:

A resistor is an electrical component that limits or regulates the flow of electricity, which can be for the purpose of reducing current in a circuit or lowering voltage levels. Certain components are rated for specific voltage, and thus resistors are necessary to prevent the destruction of these parts. Resistors are measured in ohms, the unit of electrical resistance. The colored bands on a resistor indicate its resistance.





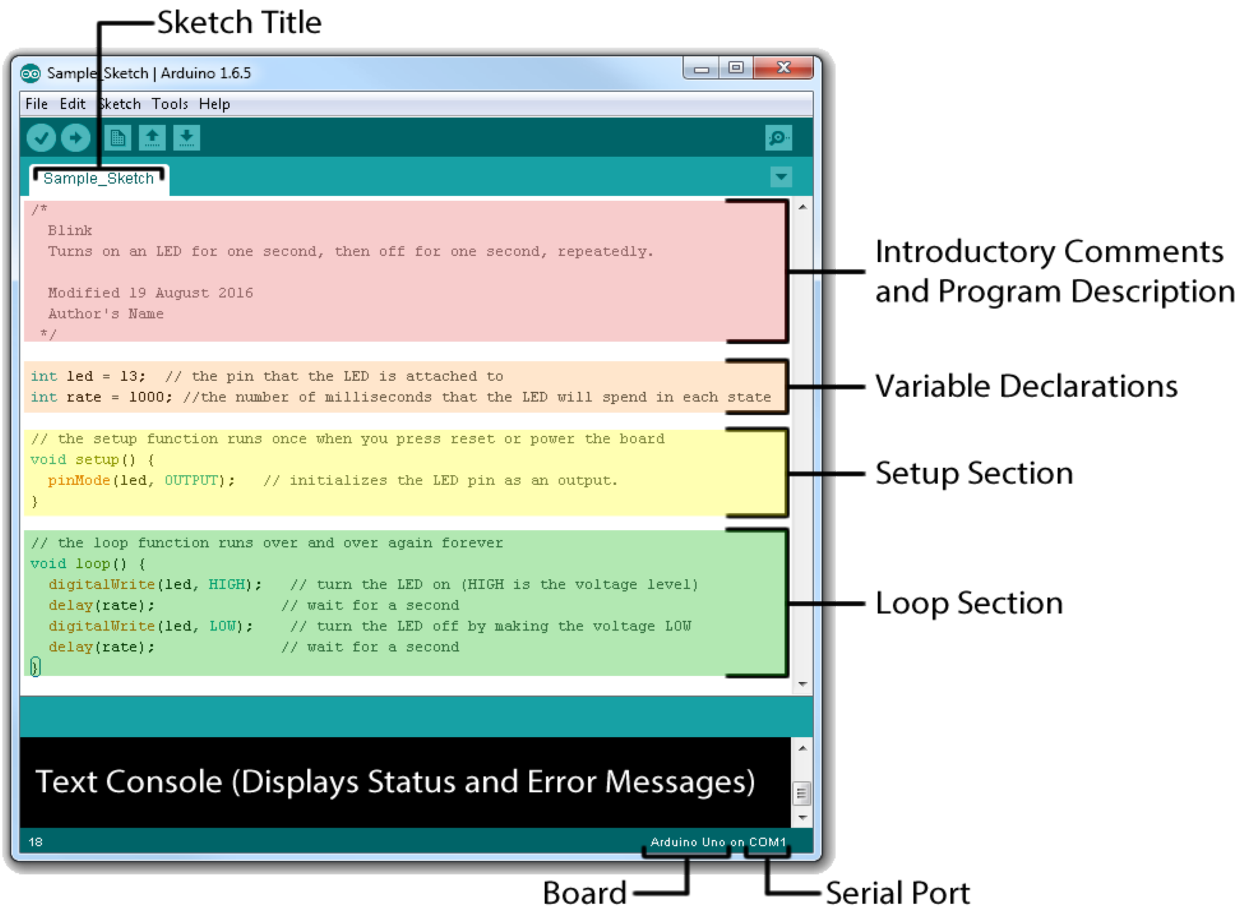
Jumper Wires:
Jumper wires are short wires that are used for prototyping circuits in combination with a breadboard. These are what you will use to connect the various components electrically to your Arduino. The rubber ends help insulate connections.



Programming Overview:
The most effective way to learn programming for Arduino projects is to actually start to attempt to build and program projects. Actively working through progressively more difficult projects will gradually add skills and coding ability as it is applied to a circuit. However, a little background information that outlines some key vocabulary and components of the software elements of the Arduino system can be helpful.

The important thing to realize when writing code is that the Arduino knows nothing to start, and it must be told everything when trying to complete an action. However, the Arduino also is unaware of what is plugged in to the board, so the code must define what component is placed in each input or output pin on the board prior to telling these components how to interact.

A basic Arduino sketch is shown and annotated with the proper way to structure the code:



Arduino Prototyping and Tutorials

Using the **circuits.io** integrated prototyping development software platform to test and learn Arduino circuits. Virtual simulation of the Arduino systems is a great way to design a circuit without having to spend money on parts that are used for initial prototyping that may not be needed in the final design.

Getting Started with Circuits.io

1. Go to the website: circuits.io
2. Create an account: in the top right corner click the 'Sign up for Free' button
3. Follow the steps to sign up a new account or login using a Facebook account
4. Create a new simulation: Select the 'New' button in the top right corner of the screen and then click 'New Electronics Lab'

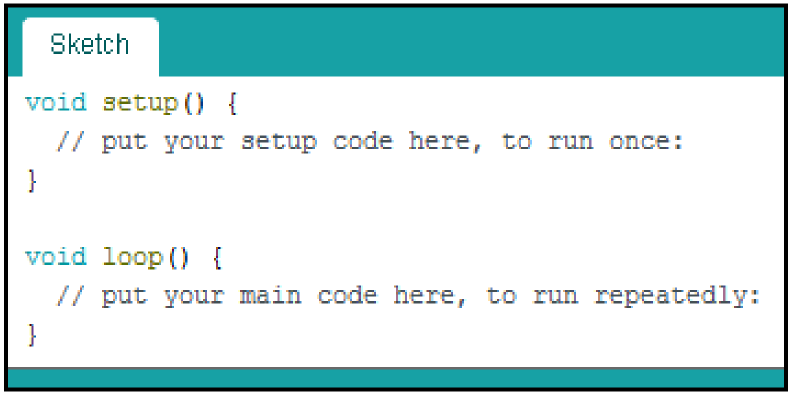
You are now prepared to start working through the following activities that will progressively teach you how to create a circuit. Additionally you will learn how to program the circuit with the internal code editor. This code editor emulates the Arduino IDE that was discussed earlier. Any code that you write in the code editor will work exactly as it would if it were to be copied into the Arduino IDE.

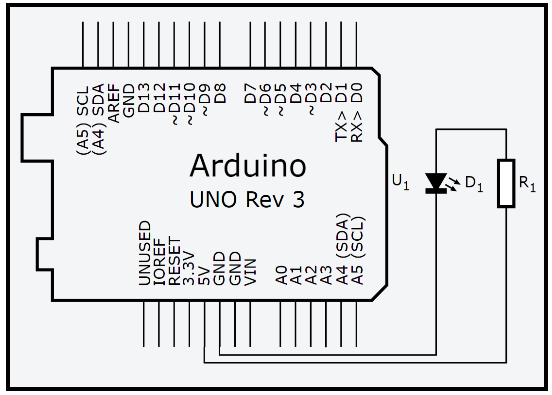
Activity 7.1: Turning on an LED
The objective of this first activity is to understand how to source power from the Arduino board. The first thing to notice about this activity is that the sketch file does not contain any code within its setup and loop sections. This is because power can be sourced straight from the power output pins on the Arduino board. These pins provide a constant 3.3 volt and 5 volt source of power. So we can always supply power to an LED if our only goal is to keep it on constantly.

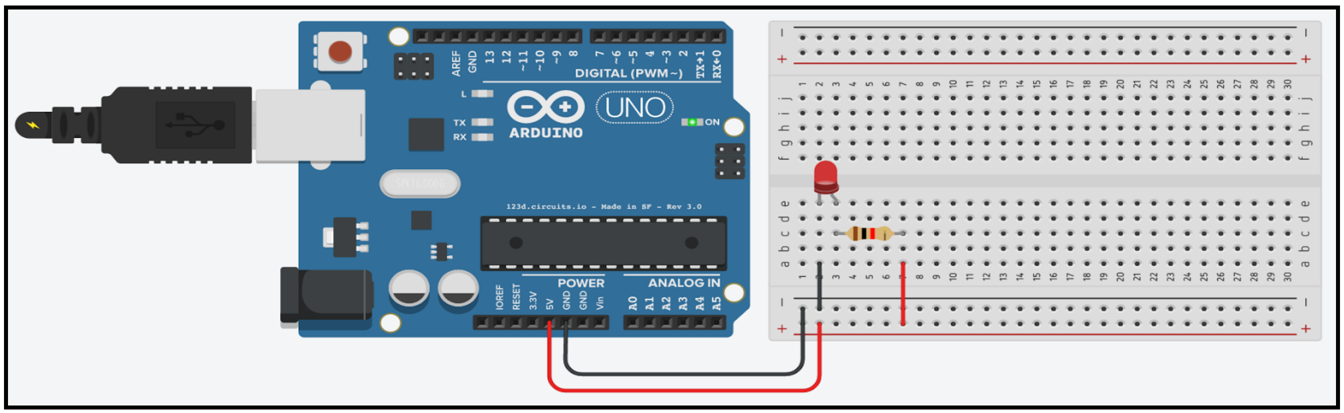
Procedure:

1. Select the components button in the upper right corner of the screen
2. In the search box type 'Arduino' and then click the component labeled 'Arduino Uno R3'
3. Click in the workspace to place the Arduino board next to the breadboard.
4. Click the first dot in the bottom left of the breadboard to place a wire in the positive power rail that is labeled with a red plus sign
5. Connect the other end of that wire to the 5V input pin on the bottom of the Arduino board
6. Create another wire that connects the negative power rail (the row of dots directly above the positive power rail) to the GND pin on the Arduino
7. Create a wire that connects the negative power rail to the 2nd component rail
8. Create a wire that connects the positive power rail to the 7th component rail
9. In the components panel search for 'Resistor' and then click the resistor part
10. Hover the mouse over the breadboard and press the 'R' key three times to rotate the resistor so that it is horizontal
11. Place the resistor so that one end connects to the 3rd component rail and the other end connects to the 7th component rail
12. In the components panel search for 'LED', and place the LED so that the straight terminal (cathode) connects to the 2nd component rail and the bent terminal (anode) connects to the 3rd component rail.
13. Click the 'Start Simulation' in the top right of the screen. If you wired the circuit properly the LED should appear to turn on.
14. If the LED failed to turn on then the circuit is not wired properly. Check to see that your circuit matches the wiring diagram shown below.

To understand how this circuit works it's helpful to think of electricity like water flowing through a pipe. The electricity flows out of the 5V pin and into the resistor, which reduces the 5 volts to a lower voltage that is necessary for the LED (typically 1.8-2.2 volts), into the positive terminal of the LED, and out the negative terminal of the LED to the ground (GND) pin.







Activity 7.2: Blinking an LED

This activity expands upon the last activity by modifying the circuit and adding code so that the LED will blink. In this activity you will first want to create your circuit. To do so use the techniques learned in the last activity to create a circuit that looks like the circuit in the picture below. Notice the difference in this wiring diagram compared with the previous activity. For this activity the electricity is going to flow out of the #8 digital pin instead of the 5V pin. The digital pin can be controlled using code that will tell it when to output 5 volts and when to output 0 volts, which will turn the LED on and off.

1. To write the code to blink the LED:
2. Click 'Code Editor' in the top right of the screen

3. Select any existing code in the code editor panel and delete it
4. Declare an integer variable 'led' and set it equal to 8:
5. Type 'int led = 8'. This tells the Arduino that we have created an integer variable. That variable is called 'led', and it has a value of 8.
6. Create a setup function:
7. This is a function that runs at the start of every Arduino sketch and is used to initialize variables, pin modes, etc. Essentially it is the portion of the code that will allow the board to understand where components are connected to the Arduino, what type of component is connected at that spot, and whether we are receiving a signal from that component (INPUT) or sending one out to it(OUTPUT).
8. Type ‘void setup() { }’.
9. Initialize the digital pin that is being used (#8) as an output:
10. Inside the brackets (not the parenthesis) of the setup function type: ‘pinMode(led, OUTPUT);’
11. This uses the function ‘pinMode’ which configures a pin that you specify as an input or an output. You already told the IDE that the variable ‘led’ is equivalent to the number 8. So the code reads what is entered as ‘pinMode(8, OUTPUT);’. This tells the Arduino that you will be using pin number 8 as an output pin.
12. Create a loop function:
13. This is a function used in every Arduino sketch file. This is the section of code that the Arduino will continuously cycle through.
14. Type: “void loop() {}”
15. Write the code that will be looped continuously inside the brackets of the loop function that you just created above:
16. Two functions will be used to tell the Arduino how to blink the LED:
17. digitalWrite(pin, value): this function writes either a HIGH or LOW value to the pin specified. HIGH outputs 5 volts. LOW outputs 0 volts.
18. delay(ms): this function pauses the program for the amount of time (in milliseconds) specified by the parameter (1000 milliseconds = 1 second)
19. Type: “digitalWrite(led, HIGH);” : this will turn on the LED
20. Type: “delay(500);” : this will delay the program for half of a second
21. Type: “digitalWrite(led, LOW);” : this will turn off the LED
22. Type: “delay(500);” : this will delay the program for half of a second
23. At this point your code is complete. Press the 'Upload & Run' button and the code will be uploaded to your virtual Arduino and start to run

Troubleshooting:

If you receive an error message or your LED fails to blink do the following:

- Error Messages:
  1. Check the text console (black box) to see where the program encountered the error and what it was expecting.
  2. Did you forget to include a semicolon (;) or a bracket {} when one was expected?
- No error message, but the LED doesn't blink:
  1. There may be an error in your circuit. Check to see that it matches the wiring diagram for this activity.
  2. Check your code to see that each function is referencing the correct pin and you are outputting the type of signal you want to output (HIGH vs. LOW)

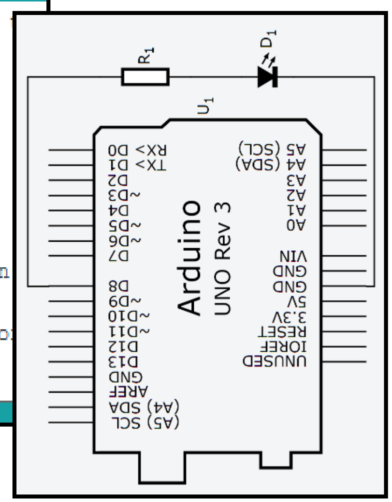
Further Your Understanding:
What would you do to make the LED blink faster?

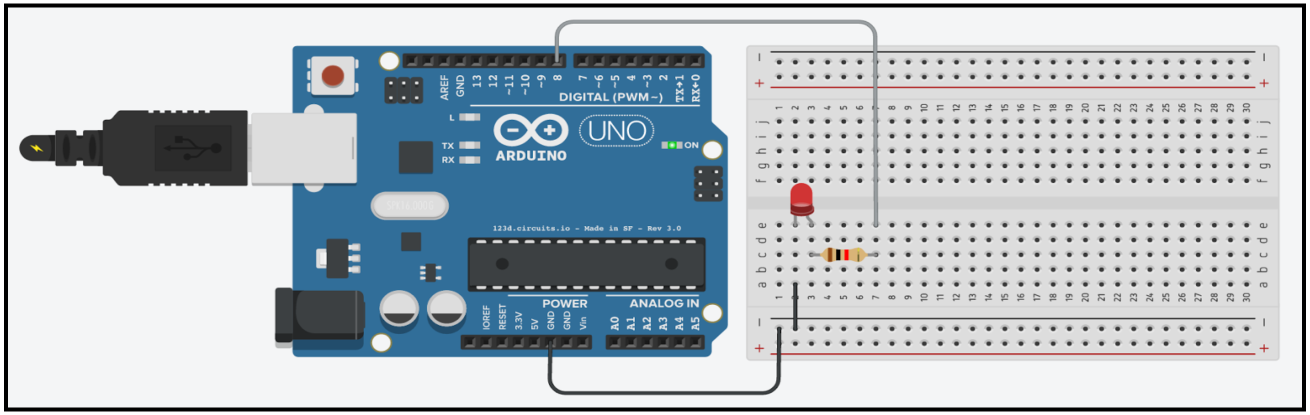
If you wanted to use a different output pin on your Arduino, what would you change?

How would you approach blinking multiple LEDs?

LED_Blink

```
int led = 8; // create variable for the digital pin the LED is attached t

void setup() { //This code runs once
  pinMode(led, OUTPUT); //Initializes the led pin as an output
  }

void loop() { //This code runs continuously
  digitalWrite(led,HIGH); //Sends 5 volts to the LED to turn it on
  delay(500);  //The progam delays for half a second while the LED is on
  digitalWrite(led,LOW);  //Sends 0 volts to the LED to turn it off
  delay(500);  //The program delays for half a second while the LED is o
   }
```





Activity 7.3: Fading an LED

In this activity you will make a few modifications to your circuit and code from the previous activity so that the LED will gradually fade on and off instead of blinking. A digital pin that is capable of simulating pulse width modulation (PWM) must be used instead of a standard digital pin. These special PWM pins are marked with a tilde operator (~) next to the pin number.

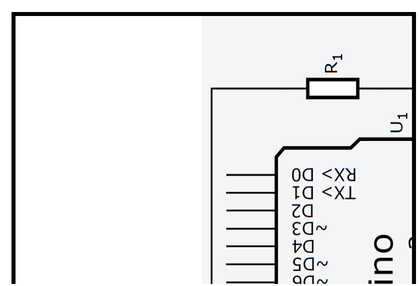
You will create two additional variables: brightness and fadeAmount. Additionally, an 'if statement' is going to be used in the loop section of the code. This is a programming control structure that acts as a conditional statement. It looks like this: if(conditional statement){ }. If the conditional statement is evaluated as being true, then the program will run whatever code is in the brackets.

For this activity, each time the Arduino cycles through the loop function it increases the brightness of the LED by the fade amount. When the program cycles through the loop function and determines that the LED is as the highest level of brightness (255), it will make the fade amount negative. This allows the fade amount to be subtracted from the brightness on progressive cycles which effectively starts to dim the LED. When the LED reaches its lowest level of brightness (0) the fade amount reverses again and the LED will begin to fade to full brightness again. This process continues forever.

The device must NOT be controlled by the team member's own wrist, hand, or fingers on either hand.

...ng an LED with a Button

In this activity you will learn how to turn an LED on or off with the press of a button. You will need to



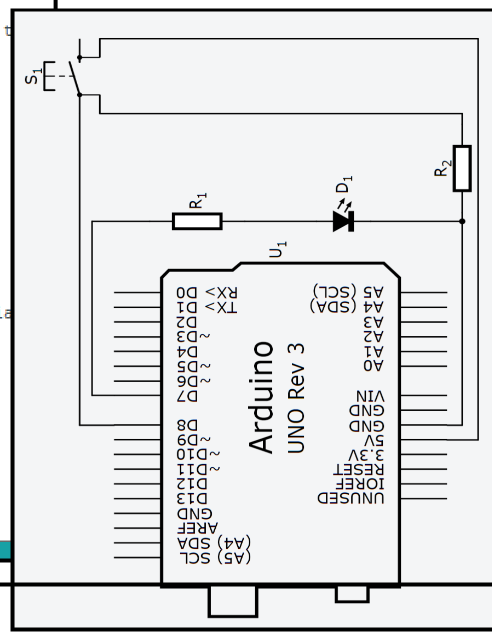
declare three variables: the pin the LED is attached to, the pin the button is attached to, and the state of the button (either pressed or unpressed).

Also you will expand upon the if() conditional statement by using an if() else() conditional statement. This statement does whatever is in the if statement brackets should the conditional be true. Otherwise, if the conditional statement is false, it executes the code in the else() statement.

At this point you should be able to look at the code and follow what the code is telling the Arduino to do. This code is commented using two backslashes followed by text. These comments are invisible to the Arduino, but serve the purpose of telling the programmer what the purpose of the code is and how it works. Use the wiring diagram and code below to build the circuit and program the LED to turn on with a button press.

LED_Button

```
int led = 7; // create variable for digital pin LED is attached to
int buttonPin = 8; // create variable for digital pin button is attached t
int buttonState = 0; //create variable to store the state of the button

void setup() { // this code runs once
  pinMode(buttonPin, INPUT); // initialize the button pin as an input
  digitalWrite(buttonPin, LOW); // pull the button pin to a low voltage
  pinMode(led, OUTPUT); // initalize the LED pin as an output
}

void loop() { // this code runs continuously
  buttonState = digitalRead(buttonPin);
  // ^ reads whether the button is pressed and sets the button state varia
  if(buttonState == HIGH){ // if the button is pressed
    digitalWrite(led,HIGH); // then turn the LED on
  }

  else{
    digitalWrite(led,LOW); // otherwise the LED is off
    }
}
```



Module 8: Using Arduino to Actuate a Prosthetic Device

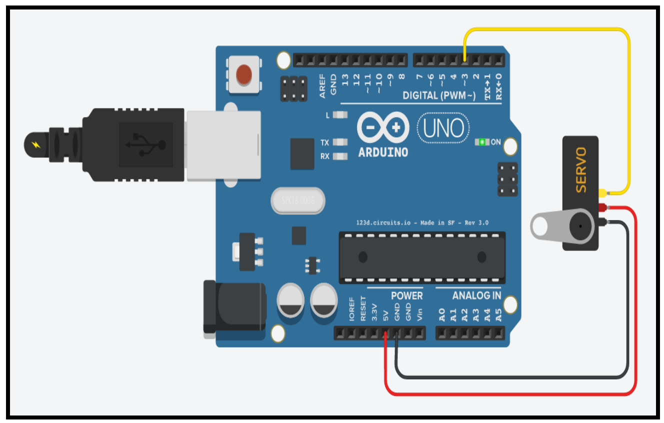
1. Apply previously obtained understanding of Arduino circuits to include at least one servo motor.
2. Provide code in order to command at least one servo motor.
3. Apply automation to their prosthetic arm by wiring and coding at least one servo motor and control.

In the previous module the basics of Arduino were taught with the help of various activities that use an LED and a few other components. Now it is time to apply those same concepts to a motor, called a servo, so that you can build an electronic system that can provide power to your prosthetic device.

Servo motors typically have a limited range of motion, meaning they can only turn a certain amount before their movement is physically restricted by the mechanics of the motor. Simple servo motors typically only turn 180 degrees (a half rotation). We will assume that this is the range of motion of the servo motors in this program, although it is possible to buy servo motors that are capable of making a full rotation or spinning continuously.

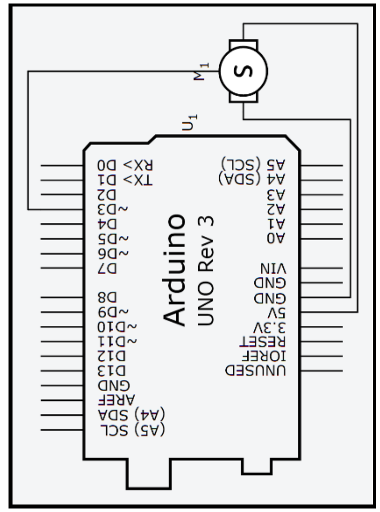
Activity 8.1: Sweeping a Servo

In this activity you will produce a circuit that is able to sweep a servo motor back and forth. At the start of your program you need to include something called a library. A library provides additional functions for the Arduino to use that increases its capabilities. For this activity you will include the servo library so that the Arduino knows how to use the servo motor. It is important to note that a servo must be controlled using a PWM pin. Use the code and wiring diagrams provided to simulate this circuit.



Servo_Sweep_Full_Speed

```
#include <Servo.h>  // include servo library

Servo servo1;  // create servo object to control a servo

void setup() {  // this code runs once
  servo1.attach(3);  // attaches the servo on pin 3 to the servo object
}

void loop() {   // this code runs continuously
 servo1.write(0);   // tell servo to go to position 0
 delay(2000);       // waits for two seconds for the servo to reach position
 servo1.write(180); // tell servo to go to position 180
 delay(2000);       // waits for two seconds for the servo to reach position
}
```

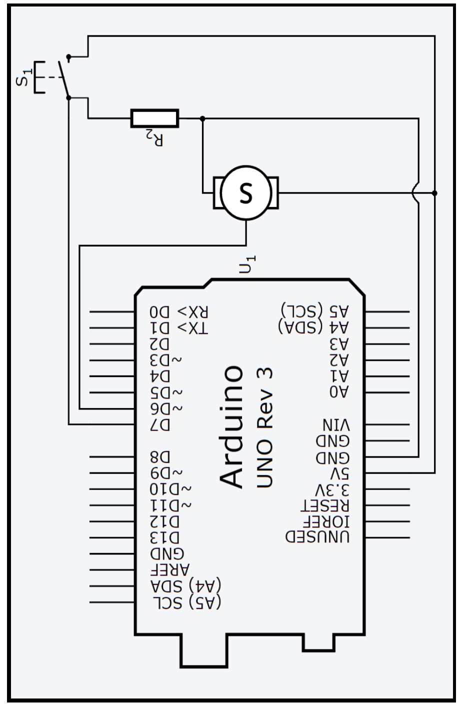


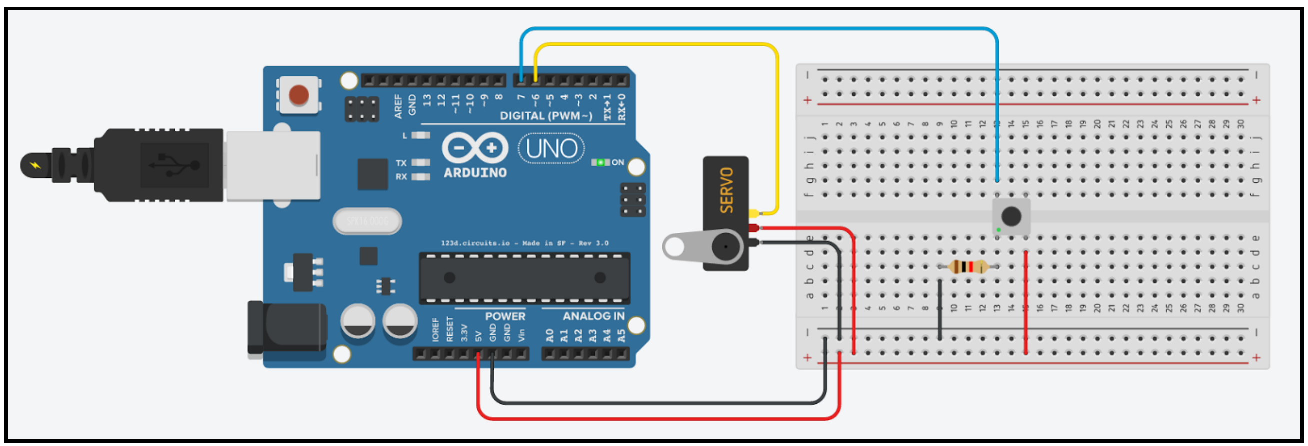
Activity 8.2: Controlling a Servo with a Button

For this activity you will be expanding upon the previous activity to allow you to control the motor with the push of a button. When the button is pressed the motor will turn, otherwise it will remain motionless. Use the code below and wiring diagram below to simulate this circuit.

Servo_Button_Controlled_Sweep

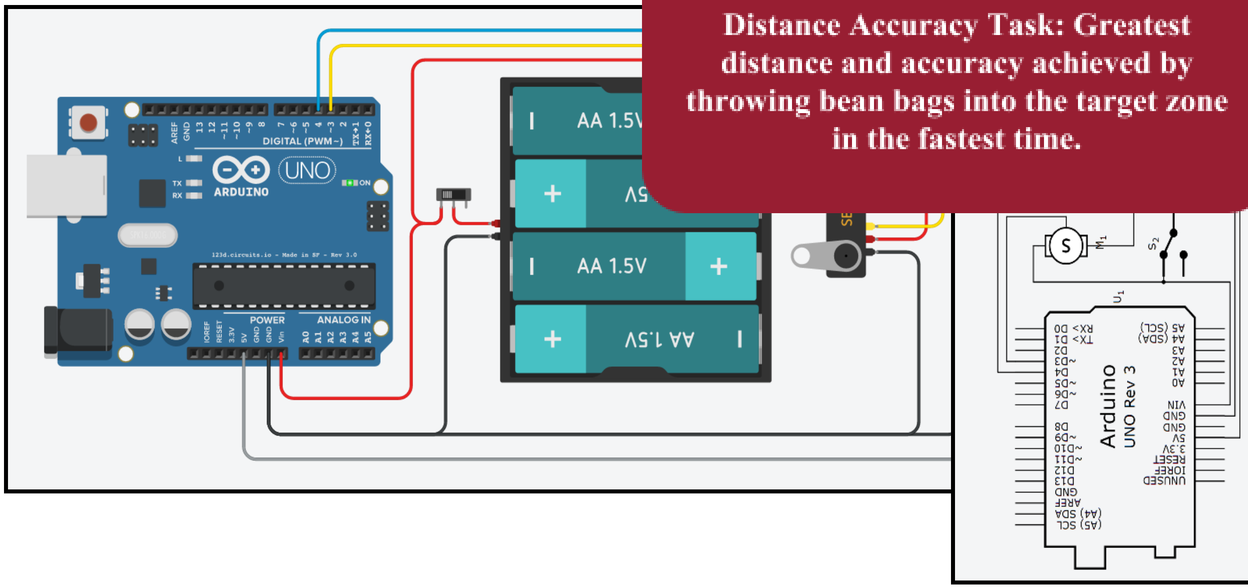
```
#include<Servo.h>

Servo servo1;  // create servo object to control a servo

int buttonPin = 7;  // create a variable for the pin the button is attached to
int buttonState = 0;  // create a variable for the state of the button

void setup() {  // this code runs once
  servo1.attach(6);  // attaches the servo on PWM pin 6 to the servo object
  pinMode(buttonPin, INPUT);  // initializes the button pin as an input
  digitalWrite(buttonPin, LOW);  // pull the button to low state initially
}

void loop() {  // this code runs continuously
  buttonState = digitalRead(buttonPin);  //read and log the state of the button

  if(buttonState == HIGH){  // if the button is pressed
    servo1.write(180);  // then turn the servo motor 180 degrees
  }

  else{
    servo1.write(0);  // otherwise the servo motor will defaul to 0 degrees
    }
}
```





Activity 8.3: Wiring Servo Circuit with Battery

In the competition you will not be able to have your Arduino always plugged into a USB port to power the board. Additionally, a servo motor uses a lot of power and it is best to power them directly from the proper voltage power source (usually 6 volts), as opposed to powering them through the Arduino. The wiring diagram below shows a setup that could be used to power your electronic system. It includes a switch that allows the user to cut off the power supplied to the Arduino board and the servo motor so that the battery is not being wasted. Try simulating the circuit depicted. The code will be the same as the previous activity as the only thing we are changing is the power source.



Distance Accuracy Task: Greatest distance and accuracy achieved by throwing bean bags into the target zone in the fastest time.

Module 9: Understanding and Applying Mathematical and Scientific Concepts

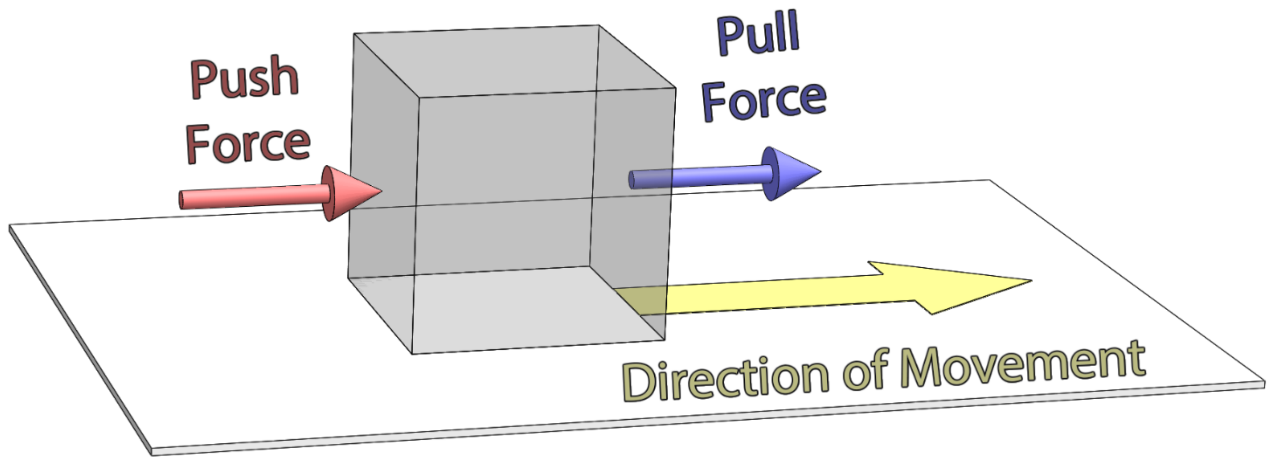
1. Define degrees of freedom of an object to determine how it moves.
2. Define and apply the concept of force to objects.
3. Demonstrate the law of levers by creating a conceptual and physical model.
4. Resolve vectors to demonstrate the concept of torque and how it can apply to their prosthetic arm.

Understanding the underlying mathematical, scientific, and physical principles involved in the design of a prosthetic device can help improve its quality and functionality. These concepts allow certain elements of the design to be optimized. For example, understanding the physics related to the application of forces can allow for motor placement that will yield the maximum possible grip strength on a prosthetic hand.

The following activity is designed to explore the law of levers, Hooke's law, and the concept of mechanical advantage, which are all principles that be can be used to optimize force output.

Terminology:
Force: A push or a pull upon an object that is a result of the object's interaction with another object
Torque (Moment of Force): A force acting on an object that causes that object to rotate or twist
Fulcrum: The pivot point, or axis of rotation, of a lever
Input (Effort) Force: The force required to actuate a lever
Output (Resistance) Force: The force generated from the operation of the lever
Effort Arm: Length of the arm of a lever from the fulcrum to the input force
Resistance Arm: Length of the arm of a lever from the fulcrum to the resistance force

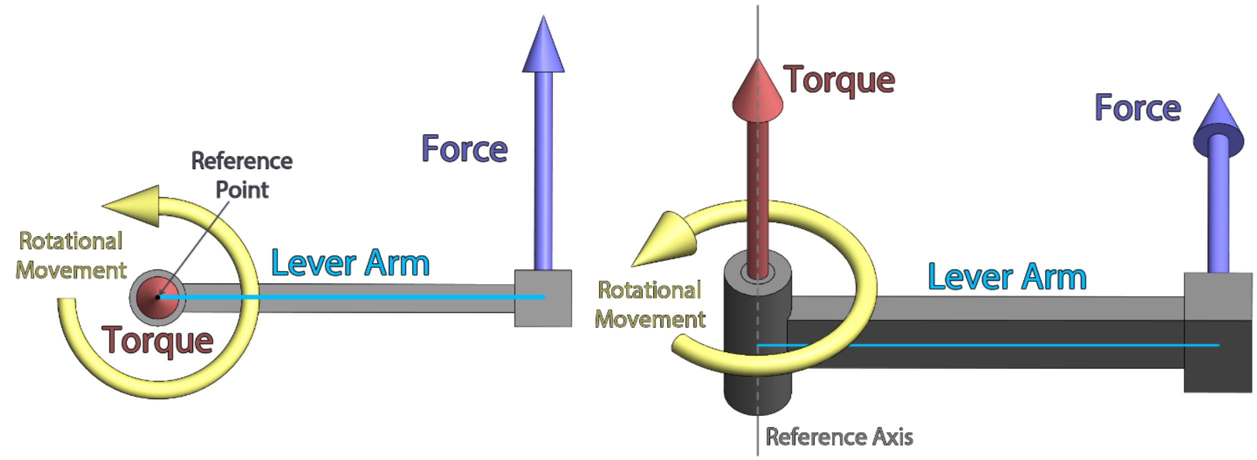
Explanation of Force:
In physics, **force** is an interaction that, when unopposed, will change the motion of an object. Force can more simply be explained as a **push or a pull on an object**. It is important to understand that force is a *vector* quantity. A vector quantity has both a magnitude, which is another term for size, and a direction. A quantity that does not have direction associated with it is known as a scalar. Scalars only have a magnitude. If two forces are of the same magnitude, and in opposite directions, they will oppose each other and produce a net force of zero, which means the object will not move.



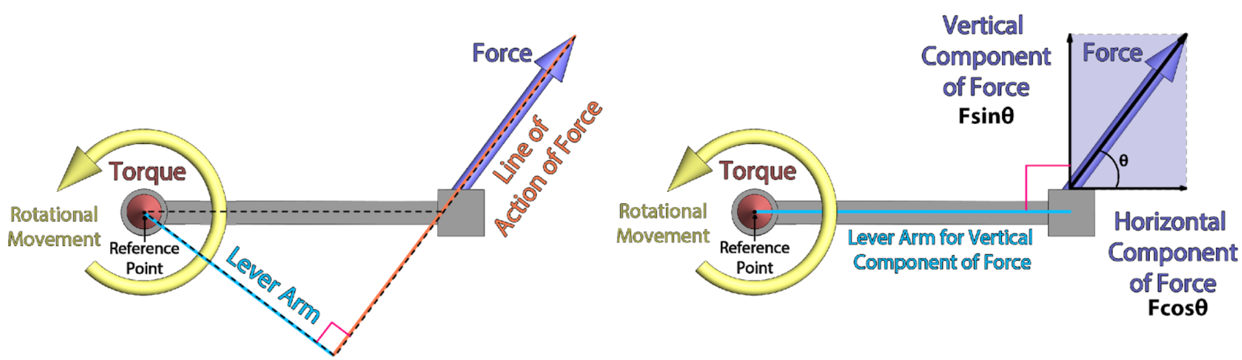
The picture above shows that a force that is a push, the red arrow, and a force that is a pull, the blue arrow, will produce movement in the same direction.

Explanation of Torque / Moment:
In physics, **torque**, is the tendency of a force to rotate an object about an axis. As explained previously, a force is a push or pull that can move an object, whereas a torque is the measure of how much a force causes an object to spin or turn. Torque, like force, is a vector quantity. It has a magnitude, and a direction that correlates to the way the object will spin.

To calculate the torque about an axis three components are needed:
A **reference point**, or axis, about which the torque is being calculated
The perpendicular distance from the reference point to the line of action of the force that is being applied, also known as the **lever arm**.
The **force** that is generating the torque. As a vector quantity this will have both a magnitude and direction.



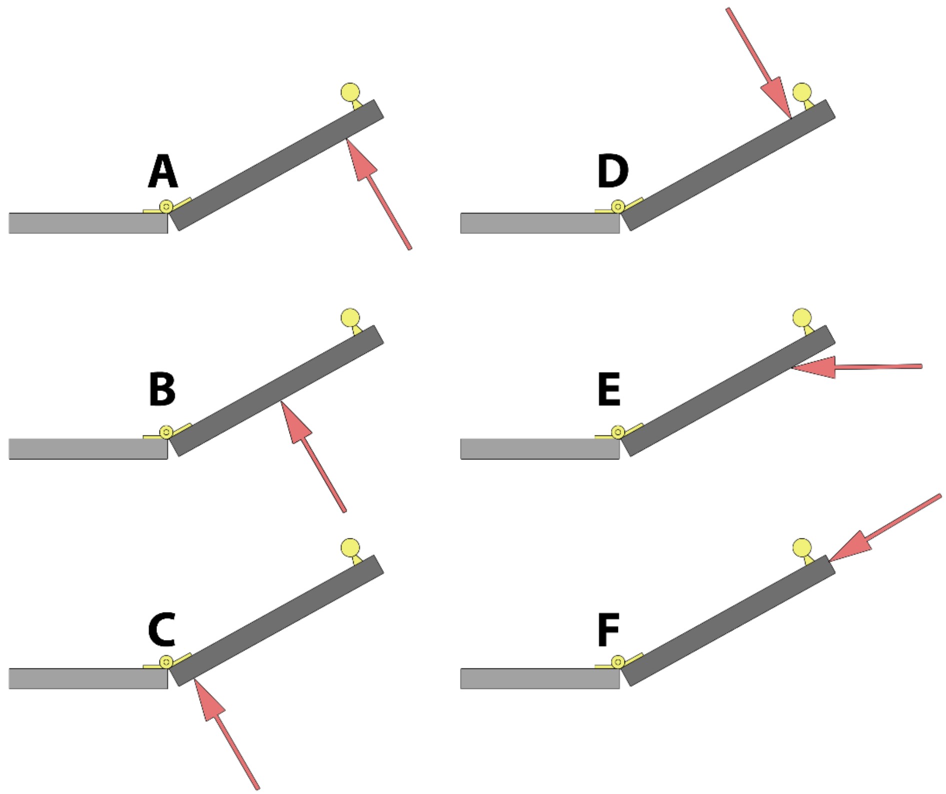
In the above image the force is being applied perpendicularly to the object and as a result the lever arm is equal to the distance from the reference point to the point at which the force is being applied. This is the most efficient angle to apply a force to an object if the goal is to generate maximum torque.



In the above image the force is applied at an angle to the object. As a result we need to extend the line of action of the force to determine the true length of the lever arm. As can be seen in the image the length of the lever arm decreases. However, the magnitude of the force remains constant. As a result of this the torque decreases relative to the previous image where the force was applied perpendicularly. Another alternative way to calculate the torque is to determine the component of the force vector that is being applied perpendicularly to the lever arm.

Activity 9.1: Understanding Torque (Moment of Force):

Attempt to open a door by applying a pushing force to the door in the locations depicted by the red arrows in the image below. Record the difficulty of your ability to open the door on a scale of one to ten for each of the scenarios below.

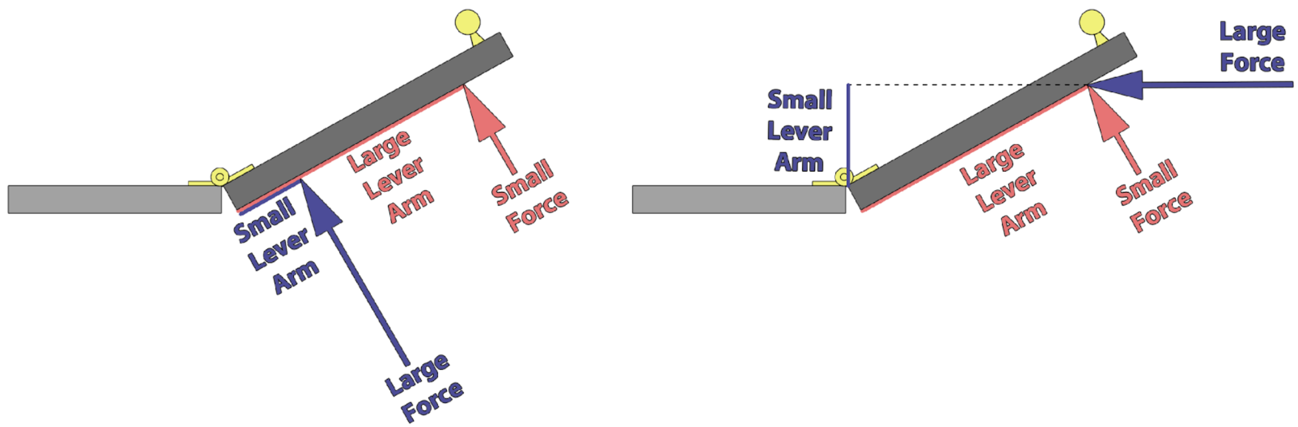


Difficulty:					
A:	B:	C:	D:	E:	F:

Circl

e.

Each device must be ready for competition when called for or forfeit that trial.



Why Torque is Important for Your Prosthetic Design

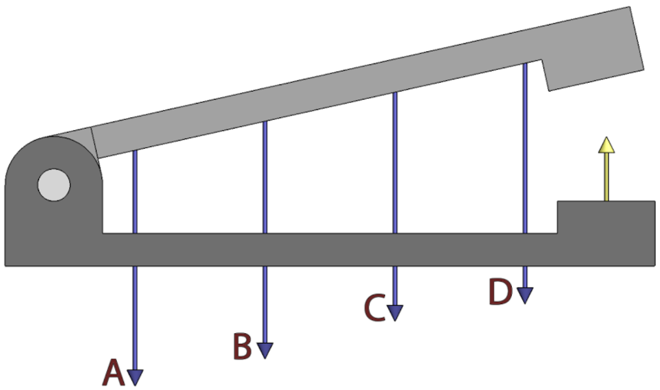
It is necessary to understand the concept of torque so that the force generated by the motor of the prosthetic arm can be optimally applied to the mechanical fingers of the device. Failure to apply the force produced by the motor efficiently will result in the need for a more expensive, higher torque motor.

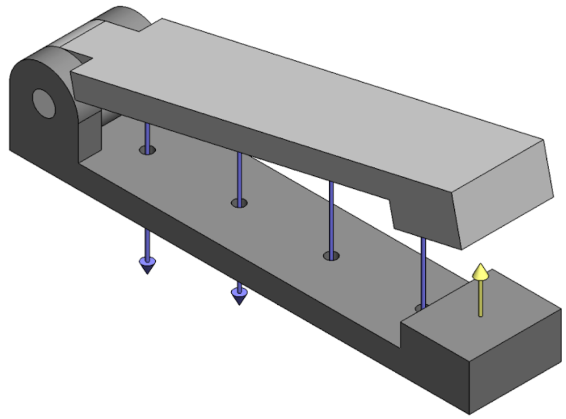
At this point the concept of torque may still be confusing, but the example that follows should provide some clarity. A simple way to think about torque is to consider the application of a pushing force to various locations on a door.

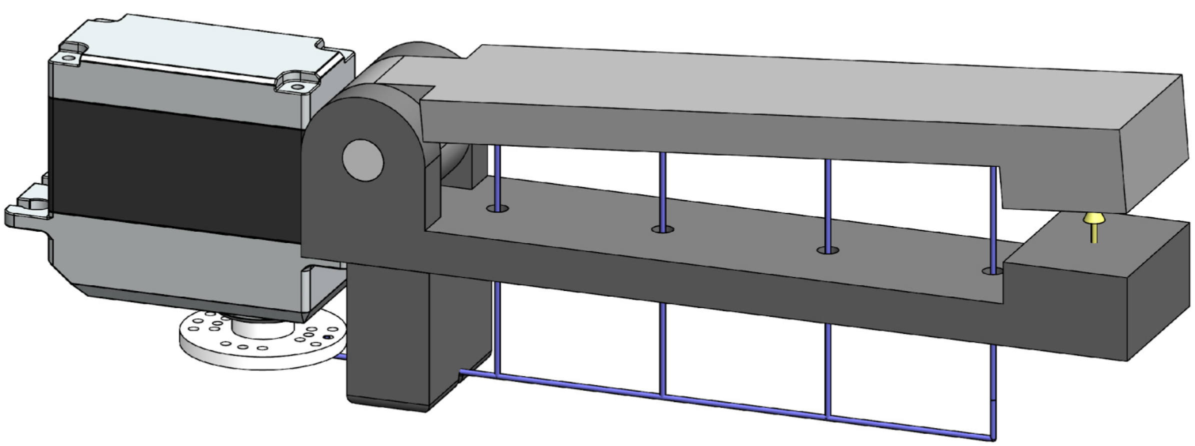
Compare the difficulty of opening the door relative to the actual torque generated in each scenario. You should find that the action of opening the door was much easier when the force is applied at a distance farther away from the hinge axis. From this activity you should observe that the best way to apply a force to a door is perpendicular to the face of the door and at the farthest possible distance from the hinge axis.

It is important to understand the concept of torque because it is the quantity that describes the strength of the motors that are used to move the mechanical fingers of the prosthetic device. The diagram below shows that in order to produce the same torque about an axis at a distance closer to the rotational axis a much larger force must be applied.

The torque provided by the servo motor used for a prosthetic device will have a fixed maximum potential magnitude. As a result, if the device is unable to turn using the torque provided by the motor then the force supplied by the motor must be applied at a greater distance from the pivot point of the finger (the length of the lever arm must be increased) or if the motor is directly driving the finger at the axis of rotation then the length of the finger must be decreased (the length of the lever arm must be reduced). Include a diagram showing these two scenarios below:







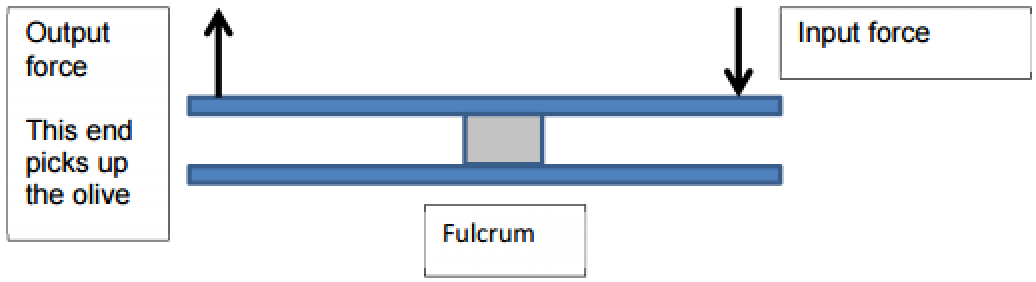
Activity 9.2: Build a Gripper

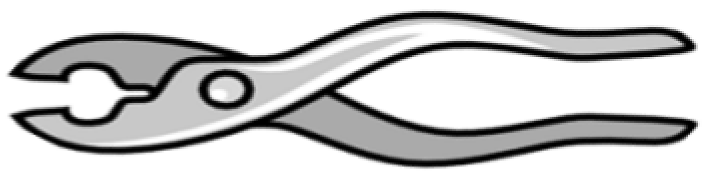
This activity will teach you the Law of Levers and will show you how to generate the maximum output force for a given input force based upon the principle of leverage and the resulting mechanical advantage that it produces.

Materials List:

- Rubber bands
- Compression springs (if possible, not necessary)
- (2) Flat pieces of wood about $\frac{3}{4}'' \times 7\frac{1}{2}'' \times \frac{1}{16}''$ (tongue depressors, popsicle sticks)
- Block of wood or plastic about $1'' \times \frac{3}{4}'' \times \frac{3}{4}''$
- A weighing scale

Procedure:
Take the two pieces of wood and the block. Assemble these components into a *class one lever*. This is a lever that has the fulcrum located between the input and output forces. It should look like this:





The gripper locks like a pair of pliers and operates on similar principles. In order to make this lever into a gripper, you will need to decide if you want to apply the input force (squeeze the handle) to CLOSE and grip an object or apply the input force to OPEN the gripper. In this activity we will wrap a rubber band snuggly around the gripper between the “output force” location and the fulcrum.

Attach a rubber band between the output force location and the fulcrum. To do this, close one end of the gripper and loop the rubber band over the wood. Additional loops may be required if the rubber band provided is too large.

In this design the rubber band acts like a spring. Hooke's Law of Elasticity provides us with a good approximation of what is happening to the rubber band when an input force, squeezing the handle, is applied to the lever.

Hooke's Law: The extension of a spring is directly proportional to the load applied to it.
Many materials obey this law within a limit. If you stretch a spring too much, beyond the ability to “spring back”, Hooke's law does not apply. This limit is called the elastic limit.

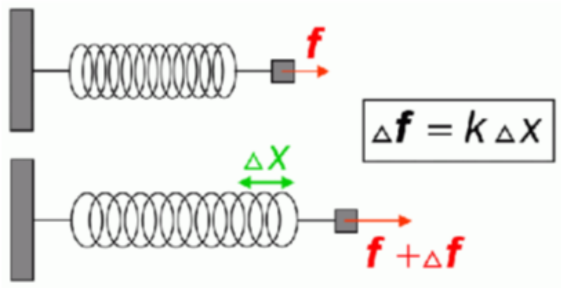
Mathematically, Hooke's Law is: $F = -kx$

x: the spring's displacement, in meters (m), from its starting point

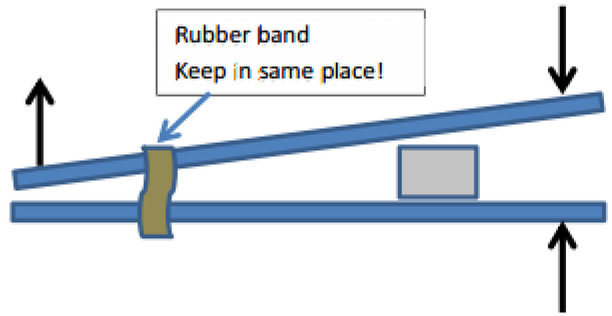
F : the restoring force, in Newtons (N), exerted by the spring

k: the spring constant, which has units of Newton/meters (N/m)

Engineers choose springs with different spring constants (k), depending on what the design needs to do.



Law of Levers and Mechanical Advantage:
Move the fulcrum to different positions and get a feel for how much force is required to open the gripper arms to parallel. DO NOT move the location of the rubber band.



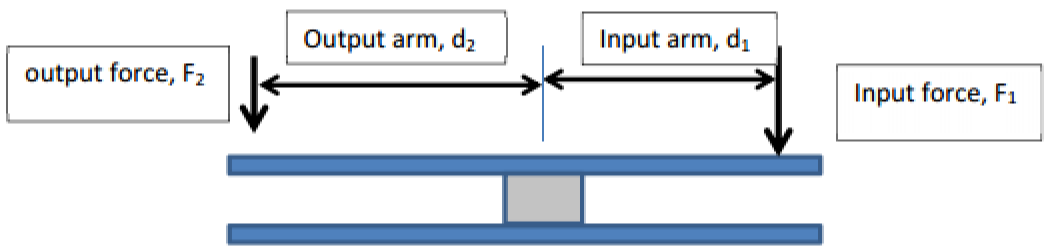
When does it require the most force to squeeze open the gripper to the 2cm width?

When the fulcrum is closer to the rubber band (output force)?

When the fulcrum is closer to the input force (the handle)?

The Law of Levers describes the relationship between the forces and the fulcrum location.

The effort arm is the distance from the fulcrum to the input force.
The output arm is the distance from the fulcrum to the resistance force.



Output arm x output force = Input arm x input force

$$d_2F_2 = d_1F_1 \qquad (2)$$

Mechanical Advantage (MA) is the factor by which the lever mechanism will multiple the input force.
Rearranging equation (2), the Law of Levers, and solving for F_2:

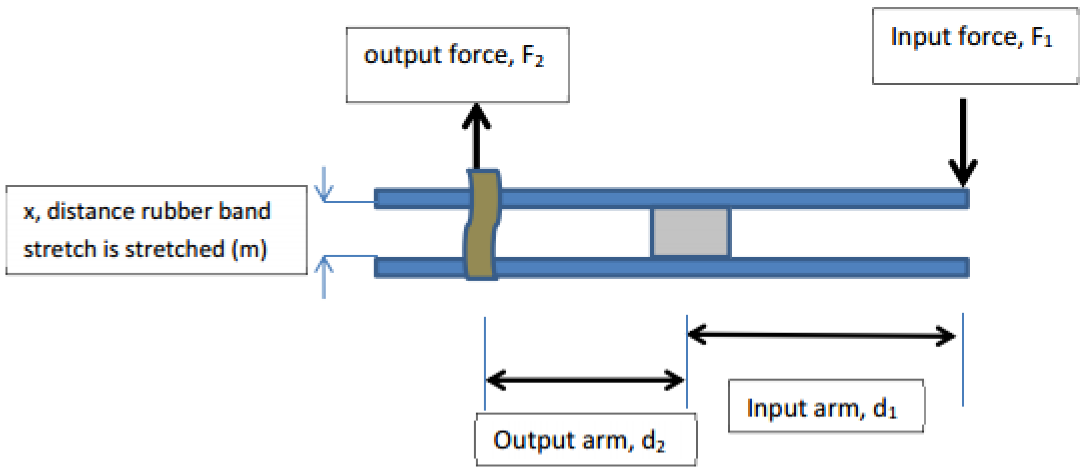
$$F_2 = \frac{d_1}{d_2} F_1$$

So for a unit input of one, $F_1 = 1$, the output force is multiplied by the factor of $\frac{d_1}{d_2}$.

$$MA = \frac{d_1}{d_2} = \frac{\text{length of input arm}}{\text{length of output arm}}$$

Putting It All Together:

Can you figure out a way to measure the spring constant, k, on your rubber band?



Take a look at the equations:

1. Equation (1) Hooke's Law: $F = -kx$
2. For the gripper above: $F_2 = -kx$
3. Equation (3) Law of Levers $F_2 = \frac{d_1}{d_2} F_1$

Substitute (1) into (3):

$$-kx = \frac{d_1}{d_2} F_1$$

Solve for k:

$$k = -\frac{d_1}{d_2} \frac{F_1}{x}$$

Measure the spring constant (k):

Set the lever on a scale and press the input arm until the rubber band is stretched a known distance. We have been stretching until the lever arms are level. You now have the x value.

x = ______________ m

Read the value from the scale. Make sure your scale is in Newtons. If your scale is in kg, then convert to Newtons (multiply by 9.8 m/sec^2)

Input force reading, F1 = _____________N

Measure the length of the input arm, d_1 , and the output arm, d_2 :

d_1 = _________________m

d_2 = _________________m

Input into equation (6) and solve:

$$-kx = \frac{d_1}{d_2}F_1$$

k = ____________________ N/m

Test Your Understanding:

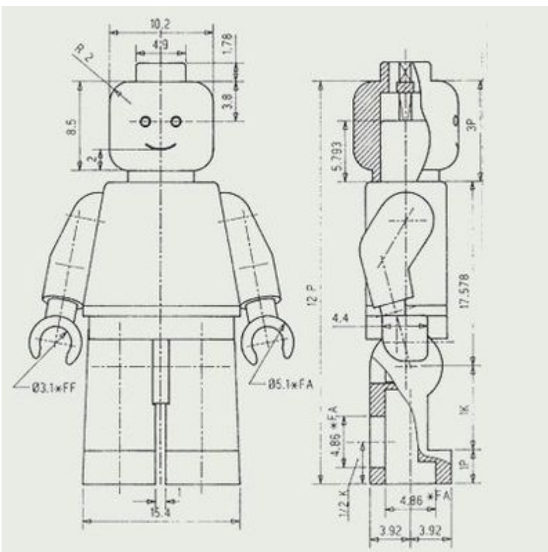
If you want to design a gripper where the output force is exactly twice that of the input force, how much longer will the input arm be?

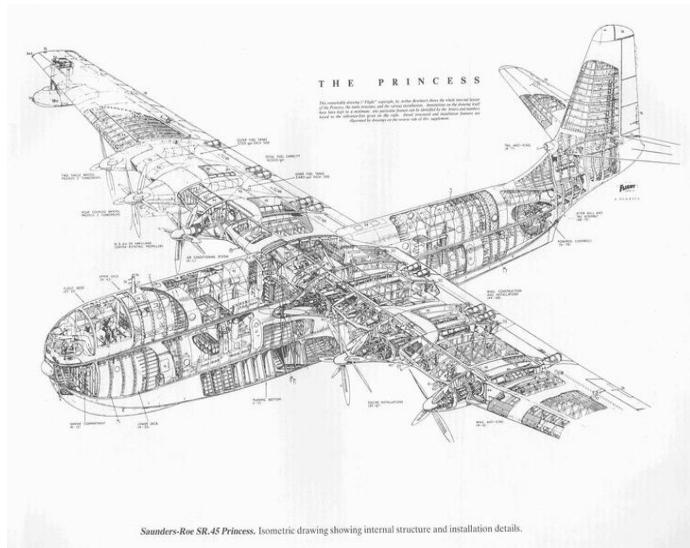
Design Efficiency: Greatest ratio of performance score to device mass plus greatest ratio of performance score to total cost of materials.

Module 10: Technical Drawing

1. Use drawings to communicate design ideas.
2. Identify and use drawing notations: construction lines, object lines, and hidden lines.
3. Identify and draw front, side, and top views of an object.

Engineers use technical drawing to visually communicate an idea or how something functions. Utilizing a type of visual language, engineers use similar notations or units of measurement to draft their ideas. This makes the drawing easy to understand and internationally accepted. Technical drawing is used in both architectural engineering and mechanical engineering.

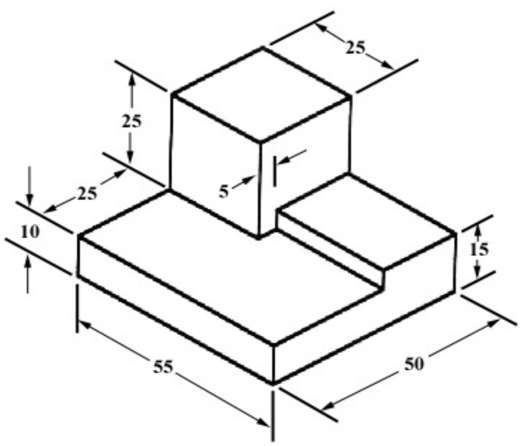


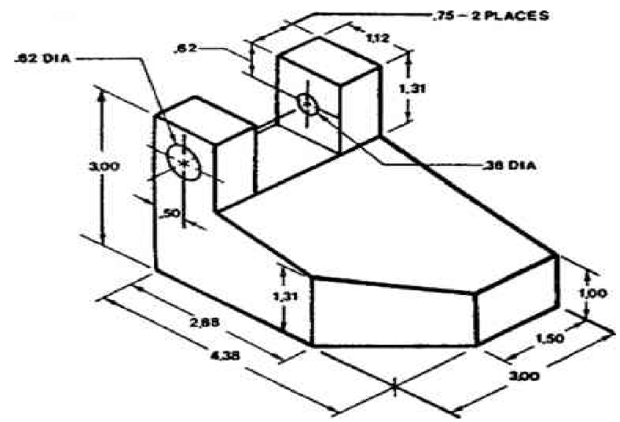


Technical drawing tools and drawing materials are used for measurement and layout of drawings. Technical drawing tools include but are not limited to: pens, drawing board, T-square, drafting machine, French curves, rules, or templates. Some technical drawing materials that engineers use are tracing tubes, tracing paper, drawing board, drafting paper, and dry transfer paper.

Terminology

Construction Line - lines that are used as guides while drawing
Hidden Line - a line that represents an edge that is not visible in the current view
Object Line - a line that represents the outline of the object being drawn
Views- there are six possible directions you can look at an object- top, bottom, left side, right side, front and back. Three views are typically in a technical drawing.
Depth- distance from the front of the object to the back
Width - distance from the left side to the right side of an object
Height - distance from the bottom to the top of an object
Edge - the line that separates two shapes in a drawing
Isometric Drawing - a three-dimensional drawing that is commonly known as a pictorial illustration





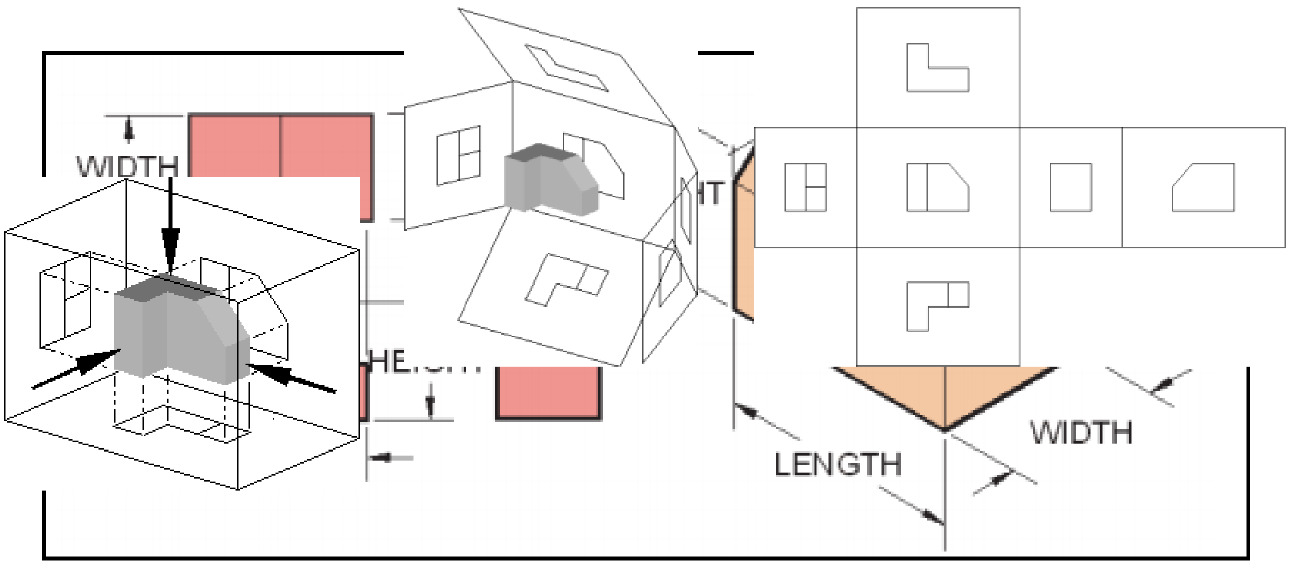
The MESA rules state that each team must prepare a three-view drawing depicting the actual device designed and built.

Front, side, and top views should be included
All parts of the device should be labeled
Photographs are not acceptable for this component
Scaled drawing may be drawn by hand or computer generated (AUTOCAD or SOLIDWORKS)
Maximum paper size shall be 11”x 17”
Orthographic projection or multi-view drawing

There are two types of technical drawing; two-dimensional representation and three-dimensional representation. A two-dimensional representation commonly uses orthographic projection where only two dimensions are represented. A three-dimensional representation is commonly known as a pictorial, which represents three dimensions of an object.

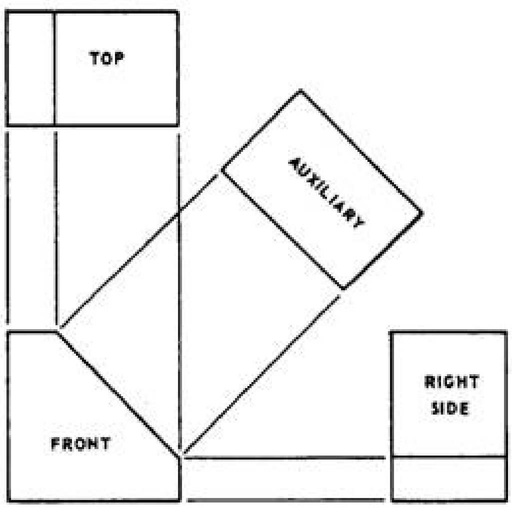
Orthographic Projection is viewing an object in different ways from three different sides; top, front, right side, left side, rear and back view. There are three common views that used which is the front, back, and side view. This type of technical drawing helps the person manufacturing the object to be able to have a good representation of the whole object.

Multi-view is a type of orthographic projection that has two conventions; first-angle and third-angle. An orthographic projection shows all of the primary views of an object. Engineers use a method called “unfolding” the box or glass box method to show all of the interior walls.



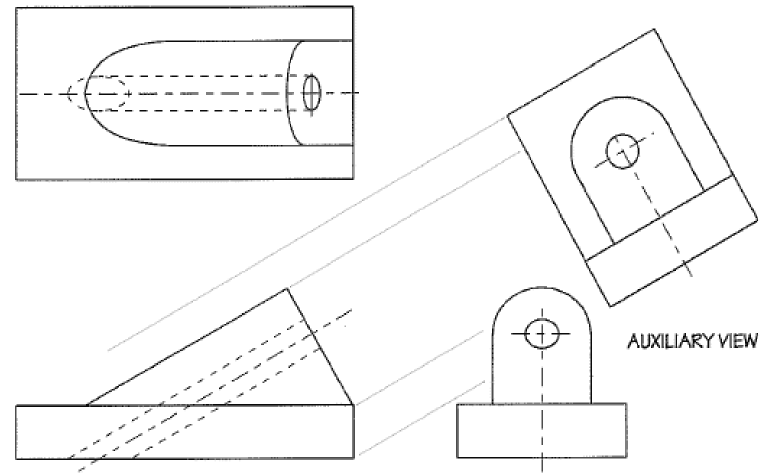
Sectional View provides a clear and detailed representation of the internal features of an object that the orthographic projection might not be able to show. This type of view can also minimize the number of projected views the drawing might have.

Auxiliary View includes any incline plans within the object. Many objects have sloping or inclined surfaces and standard orthographic views represent these surfaces as distorted and not their true shape. This is why having an auxiliary view is so important in drafting an object.

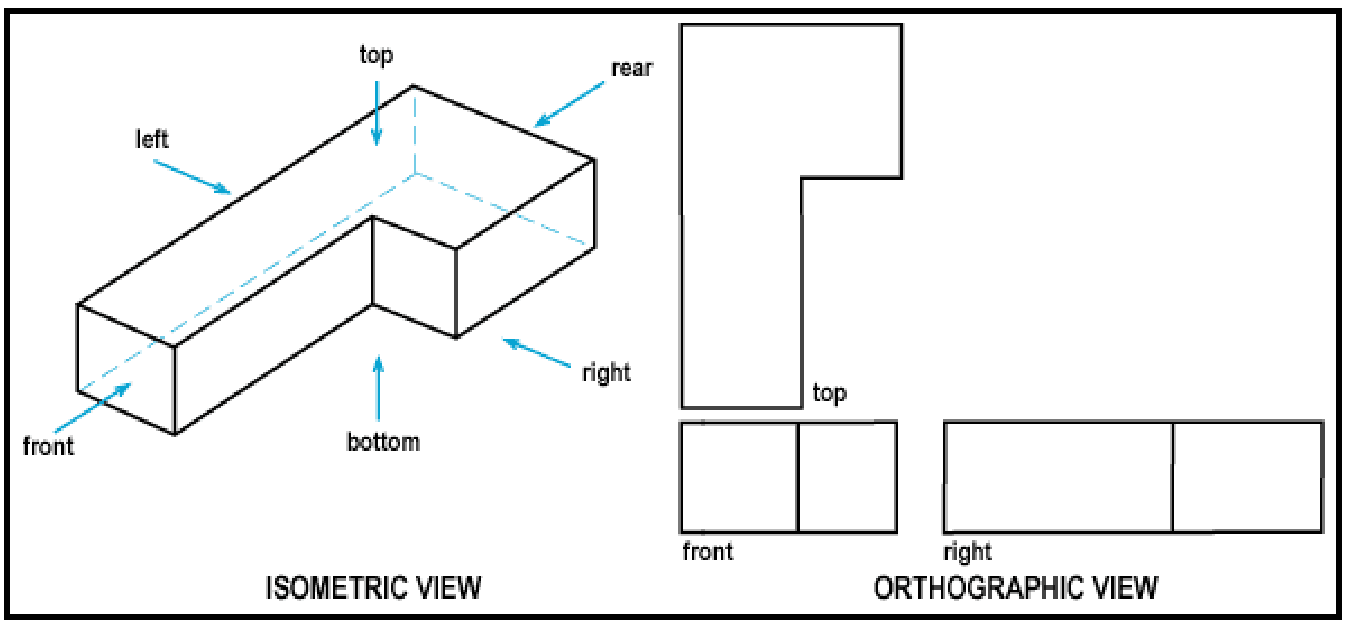


Activity 10.1: Drawing an Orthographic View Step-by-Step

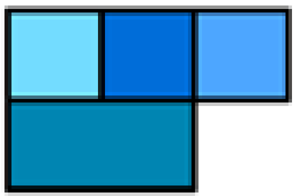
To draw a standard orthographic drawing there are three standard views that must be shown; top view, front view, and right side view. The key to drawing an orthographic drawing is to draw every face you see for each view. In the figure below, shows the isometric view and the orthographic view and the differences between them. The isometric view is 3-D whereas the orthographic view is 2-D.

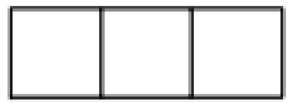


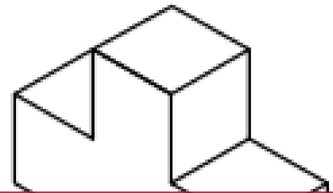
To get a better understanding of how to draw an orthographic view, the figure below is color coated to show what aspect of the object is drawn for each view. The blue shades are aspects of the object that should be included in the top view. The purple shades are aspects of the object that should be included in the front view. The pink shades are aspects of the object that should be included in the right view.



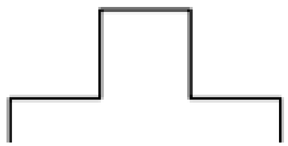
In this activity, you will follow the example on the previous page and color coat the objects below to get a better understanding of orthographic drawing. Pick a shade for each view and follow along with the example above. Once you have completed this activity your advisor will go over this as a class.

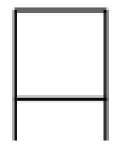






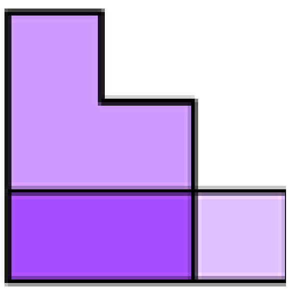
Hazardous materials may not be used in the construction or operation of the device, including, but not limited to, lead.

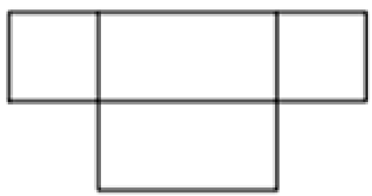


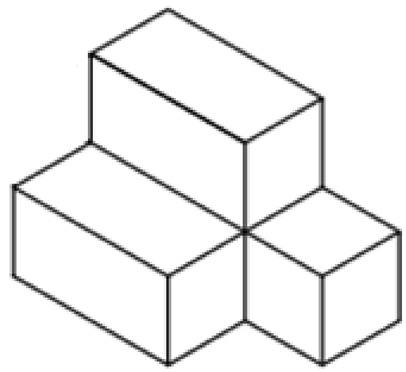


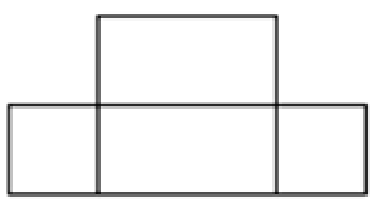
Activity 10.2: Isometric View vs. Orthographic View

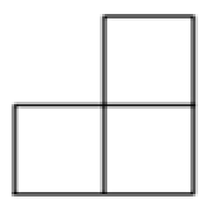
In this next activity you will be matching the isometric drawing with the orthographic drawing. Put the corresponding letter next to the associated number. Once you and your team have



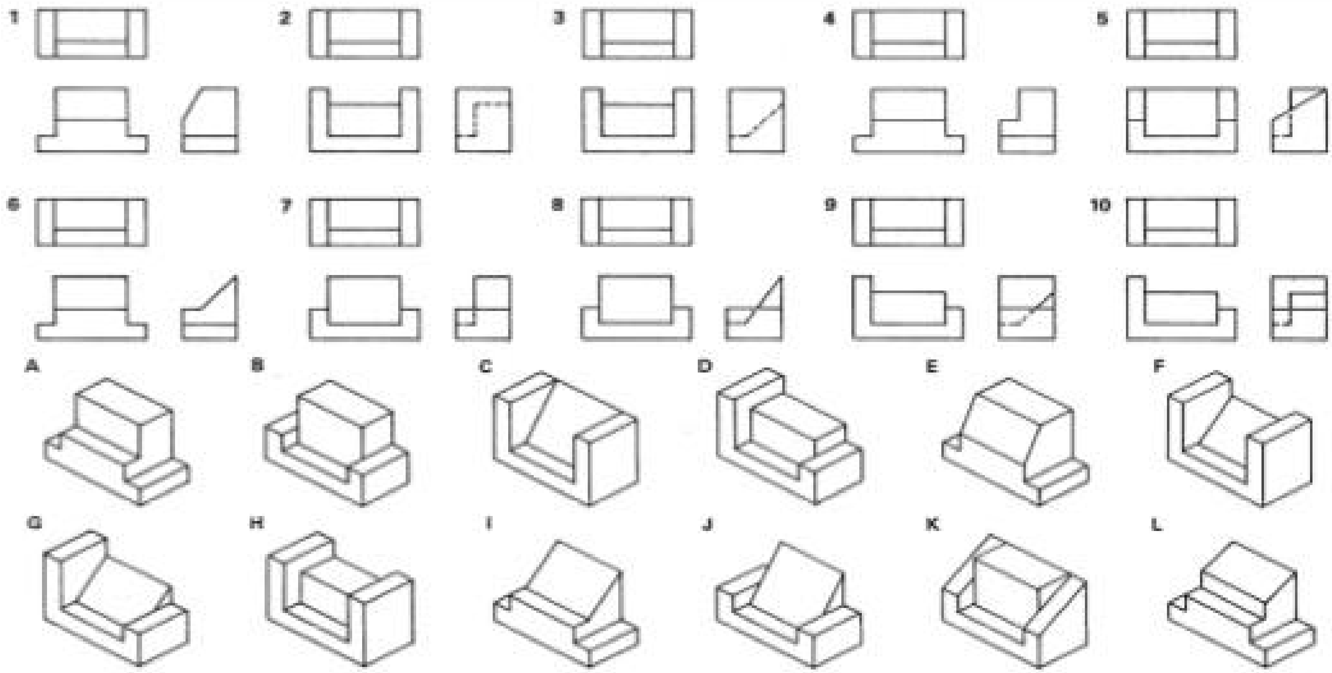








completed this, your advisor will go over this with you. This activity is made to train your brain on how to view objects in such a way to



1	2	3	4	5	6	7	8	9	10

produce an orthographic drawing. It takes a lot of practice; so don't worry if you don't get it at first!

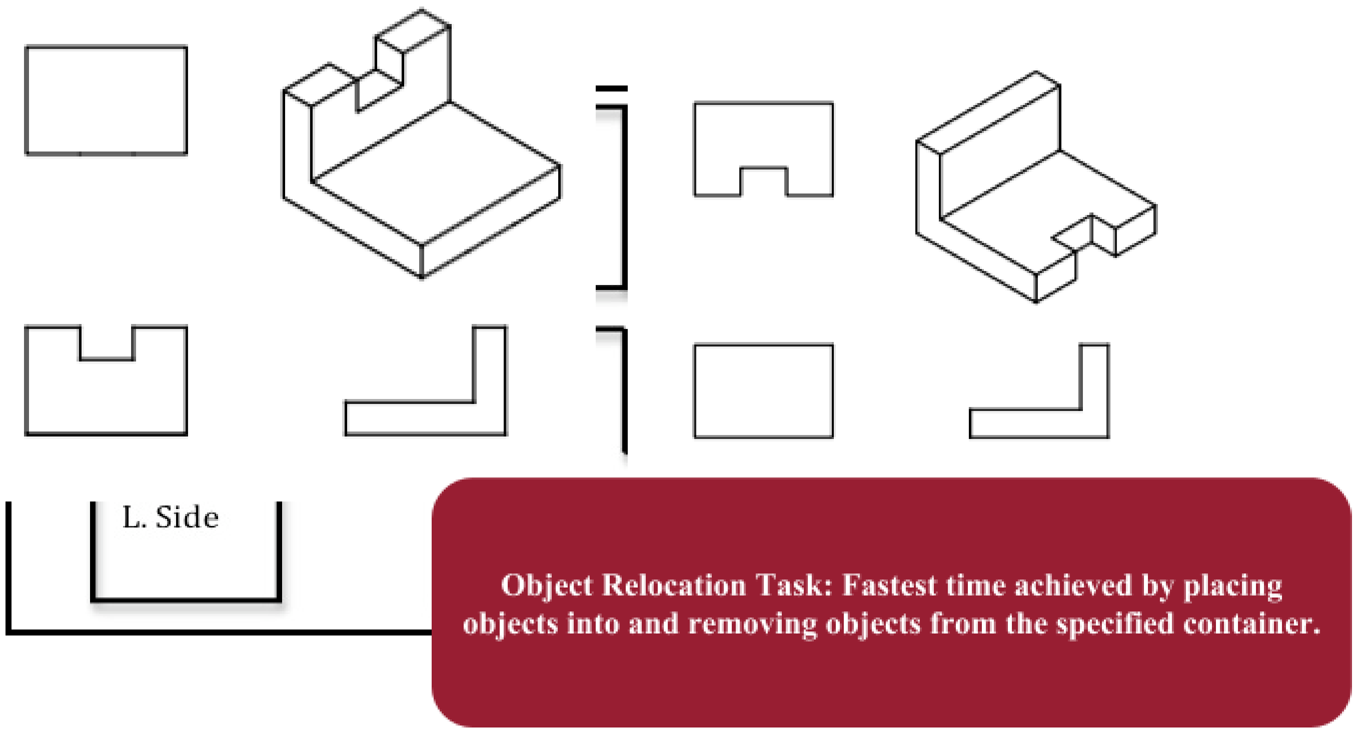
Activity 10.3: Drawing Missing Solid Lines

Now that you know which surface is drawn for each view, draw the missing lines from each of the different views.

Activity 10.4: Drawing Hidden Lines

oIn many orthographic drawings it is standard practice to use dashed lines to represent a part of an object that is hidden from different views. Without the use of hidden lines, engineers won't have all the information needed to recreate the object. The figure below shows the difference between an object line and hidden line between different views.

In the next exercise, use the above example to fill in the hidden lines in the following examples. Your advisor will go over the answers as a class.



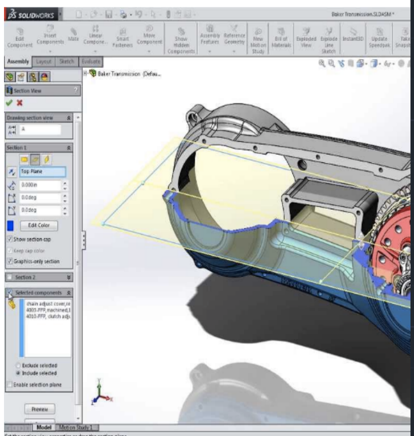
Activity 10.5: Isometric to Orthographic View

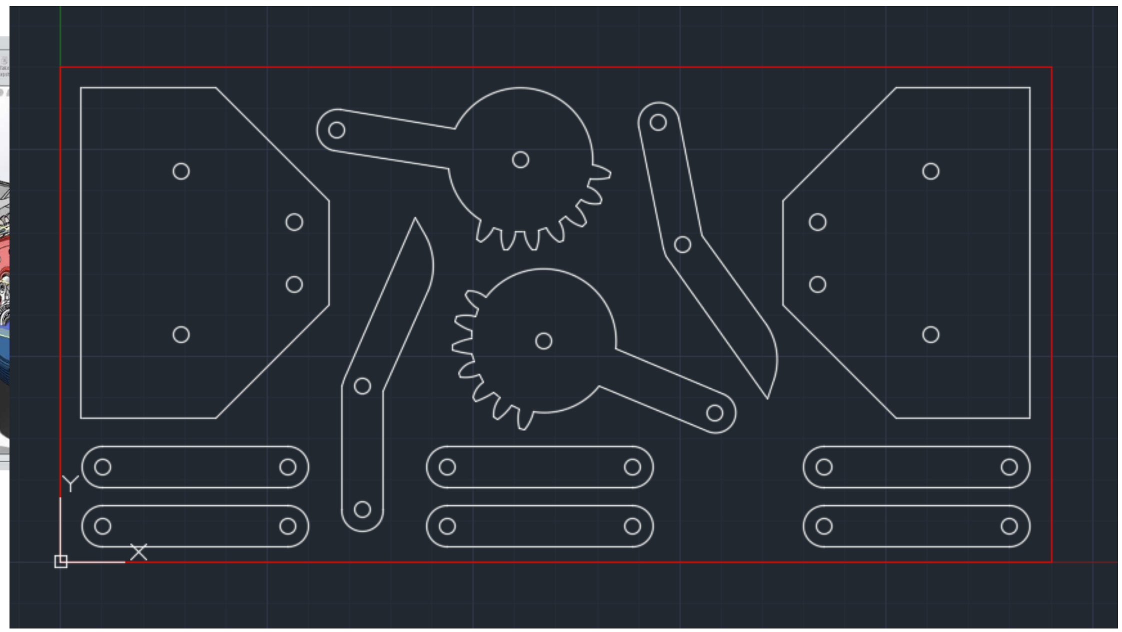
In this activity, you will utilize all the tools you have learned throughout this section. The below example is an isometric 3-D view of an object. Your task is to create three orthographic 2-D views: front, right, and top. Get into groups of four and once your group is done your advisor will go over it as a class.

Each team member must speak for a maximum of ten minutes during the presentation portion.

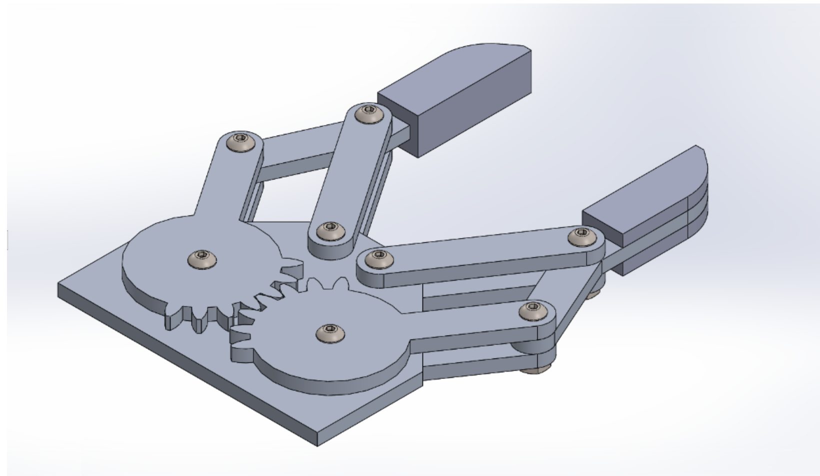
Computer Aided Design Software
There are two commonly used computer aided drafting software to help with drafting; AutoCAD and SOLIDWORKS. Computer-aided drafting (CAD) is the creation or optimization of a design through the use of a computer system. CAD software can produce figures in both two-dimensional (2D) and three-dimensional (3D). This competition does not require you to have any computer aided drafting software within your project, however it is a useful tool to know both professionally and academically.

AutoCAD is commonly used across a wide range of disciplines such as engineering, project management or graphic design. At the Temple University MESA Saturday Academy, AutoCAD was utilized to develop one version of the prosthetic arm that was laser cut from a sheet of acrylic plastic.

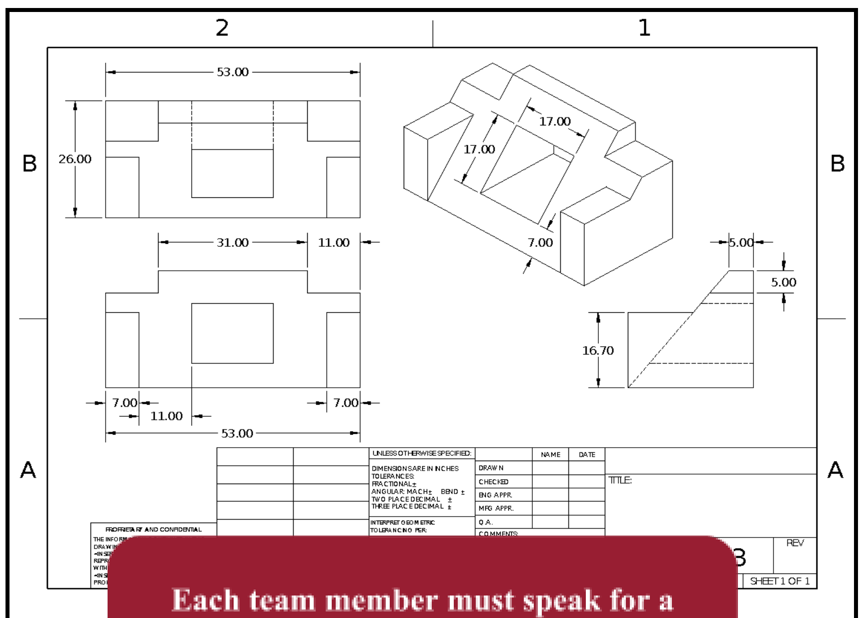




SOLIDWORKS is a solid modeling CAD software that is used by many companies that focus on mechanical design. It is a very useful drafting and designing tool. The same prosthetic arm drawn in AutoCAD could also be generated in SOLIDWORKS to represent a 3D version of the prosthetic arm.



Both software programs can produce orthographic views of an object. The example below is an object that a group of MESA students was assigned. Their task was to generate three orthographic views from the isometric view utilizing SOLIDWORKS.



Each team member must speak for a maximum of ten minutes during the presentation portion.

Module 11: Engineering Technical Aspects

1. Make a presentation outline and produce notecards.
2. Understand the guidelines for making presentation aides.

Making presentations does not have to be hard! You are the experts on all the hard work your team did in the MESA challenge. By following the following recommendations, your MESA Day presentations will be a success. In preparation for MESA USA Day, your team will prepare a research paper, an academic display poster and an oral engineering presentation.

Technical Paper:
A technical document describes the results, process, and progress of a specific scientific research concept or problem. The purpose for a technical document is to communicate your thought process and design process for designing your arm.

Items to include:

Title Page
Abstract
Table of Contents
Introduction
Discussion
Conclusion
Recommendations
References or Bibliography
Acknowledgments
Appendices (Optional)

Conventions (Format, Language, Grammar):
The length should be 5 to 15 pages that is not going the cover, title, and appendix pages
Title page should include authors/team members, school, MESA state, and date
12 pt. Times New Roman font
1" margins and double spaced
Use Spelling, sentence, paragraphing, and transition conventions
Readability will increase your score
Use computer generated graphic when possible
Paper should be typed with a cover sheet

Electronic Format and Authorship:

All technical papers must be submitted as a Portable Document Format (.PDF)
Maximum file size is 9MB
All authors should be part of the student team that are participating in the competition
Must cite any external sources that were used in the technical document

Criteria for Scoring:
Discussion of Design Process Methods / Approach (30 pts.)
STEM Concepts and Analysis (30 pts.)
Quality and Thoroughness (30 pts.)
Conventions (10 pts.)

Academic Poster Presentation:
Each team is required to have a poster presentation that will present their device as well as relevant aspects of their design from their technical paper. The poster presentation should deliver an organized and focused overview of the development of the design. The poster is worth 75 points.

Items to include:
- 36” x 48” tri-fold presentation board or 36” by 48” poster
- Title should be included on the top of their poster
- Must have the MESA logo
- Team Card should include:
- School Name
- Grade Level
- State your representing
- All the team members’ names
- Abstract, Recommendations, conclusion
- Design Features and Drawings included (orthographic drawing, Arduino block diagram, two data charts)
- Team's engineering design notebook in front of your poster representation
- NO electronic media

HINT: Practice your presentation over and over again. Make sure each member of your team knows everything and is comfortable.

Engineering Presentation

Technical presentations have two purposes to inform and persuade an audience. Always make eye contact with your audience and speak clearly and not too fast. This is a formal delivery of your design document; make sure you know your information inside and out!

Presentation Rules:

Every member of the team must have on the official MESA USA National Engineering Design Competition t-shirts
Design poster, models, or any other visual aids should be used
Each member of each team should speak for maximum of ten minutes
Introduction, STEM explanations, Design Process and Approach, Conclusion, and Analysis
Every key concept should be known by all team members

IMPORTANT- The data and information used for each of these is the same:

Much of the information your team needs already exists in the MESA Engineering Design Notebook. You are not making up anything new when making a technical presentation or writing a technical paper or academic poster.

HINT - Some Guidelines:

Charts: preferred over tables, must be completely labeled with titles, units, and parameter names
Math: show every formula used
Drawings, Sketches, and Pictures: each one should include a title

W

elcome to the MESA USA National Prosthetics Challenge Curriculum! This document was written to accompany the 2016-2017 MESA USA National Prosthetics Challenge Advisor Lesson Plans. This curriculum will help students better understand the concepts and background behind the challenge. Most importantly, we hope it helps them step through the Engineering Design Process in a clear and understandable manner.

The curriculum consists of three parts: The Cirriculum Outline, Advisor Instructional Reference, and Student Workbook. This document summerizes this the cirriculum from a Common Core/ NGSS alligned standpoint. The Advisors Instructional Reference provide supply lists, instructions and resources for each of the 11 Lessons. Each one is expected to take 4-5 hours on average, and is written for the after school setting. That does not mean that your students will have working prototypes ready for the competition in 11 weeks. Students will need additional time for building and testing. The second part of the curriculum is the Student Workbook. These are pages with instructions for the students. In many cases, they are intended to be used as work sheets with places for students to write down observations. However, you may modify what you have been given to fit your particular needs and preferences. We strongly encourage you to have students keep an Engineering Design Notebook but what that looks like is up to you.

MESA Prosthetic Arm – Curriculum Outline

Week	Subject	Goals	Core Standards	NGSS	Objectives
Week 1	**Introduction to the Engineering Design Process**	Upon completion of this lesson the student will have experienced the engineering design process. • Students will be introduced to the Engineering Design Process by building paper towers • Students will be able to identify some of the challenges that designers face in developing solutions to problems.	**3.4.12.A3**	HS-ETS1-2	Students will be able to compare the steps they took in creating their Paper Towers with the Engineering Design Process.
					Students will compete to build the tallest tower using standard sheets of paper. Variables (time, resources, etc) can be changed to effect outcomes.
			3.4.10.C1	HS-ETS1-3	Students will be able to begin the engineering design process for the MESA Challenge.
			3.4.10.E4		Student will be able to discuss the challenges that engineers face when creating a new product.

		• Students will become familiar with using their engineering notebooks.	3.4.12.E6:		
	Procedures	Session 1: Intro to the EDP	EDP handout, note taking		
		Session 2: Engineering Challenge (Paper Tower)	General supplies, Competition based design mini contest		
	Materials	Engineering Design Process Lesson Plan Student Handout			
		Paper Tower challenge materials (i.e. paper, tape, a meter stick)			
		An internet connection, projector and screen or a DVD player/TV			

MESA Prosthetic Arm – Curriculum Outline

College of Engineering TEMPLE UNIVERSITY®

Week	Subject	Goals	Core Standards	NGSS	Objectives
Week 2	Introduction to Prosthetic Arms	Students will develop an interest in Designing, and also be better prepared to analyze the MESA USA National Competition specifications. ● Scan a client profile and develop a design plan focused on the client's needs. ● Summarize relevant information about Lara, a hypothetical seventeen year old. ● Brainstorm a list of local experts and resources that might support this design. ● Define, in their own words, the scope of the engineering problem in this year's.	3.4.10.C3:	HS-ETS1-2	Students will be able to reach out to local experts for support in ways that reflect appropriate.
			3.4.10.D2:	HS-ETS1-3	Students will be able to scan S.T.E.M. texts with attention to precise details and potential questions.
			3.4.10.C1:		Students will be able to scan a client profile and develop a design plan focused on the client's needs.
			3.4.10.A2:		

	Procedures:	Approaching the Engineering Process (Discussion)	Building from Students' Funds of Knowledge, Community: Local Research, Introduce New Vocabulary (prosthetist), Develop Class Definition for Prosthetist for their Glossary.
		Seeking Out Local Experts (Discussion)	Seeking Out Local Prosthetists: Brainstorm, Seeking Out Amputees as Experts: Discussion, Class Vote.
		Client-Centered Design	As a class or individually, have students read the Client Profile (2.1). Discuss as a class, or pair-share and report back their observations/questions.
		Effective Problem Statements, Review	Ask teams/students to carefully read the specifications as indicated in their handout. If needed, guide them through the specifications and model the kinds of questions to consider as designers.
	Materials	MESA Engineering Design Notebooks, Noted Handouts	

Week 3	Subject	Goals	Core Standards	NGSS	Objectives
	Brainstorming a Prosthetic Arm	Part of the MESA USA engineering design process (EDP) involves brainstorming and research. Taking time to research existing solutions to your engineering problem will help seed creative ideas. This design activity is a brief exploration into existing prosthetics and to help generate ideas for each team's designs. ● Students will practice brainstorming, research, sketching and group problem ● Solving while increasing their understanding of the prosthetic design**.**	**3.4.10.C1:**	**HS-ETS1-2**	Students will be able to apply their reflections from this simulation activity to their design approach.
			3.4.12.C2:	**HS-ETS1-3**	Students will be able to articulate to their peers, with specificity, how they revised their design approach based on this simulation.
			3.4.10.E7:	**HS-PS2-3**	Students will be able to explain how prosthetics enable complex, everyday activities.
	Procedures:	The Brainstorming Process			In these activities, students will brainstorm on about their design, learn about biomimetics, research cutting-edge prosthetics design, learn about one college students design process, and

		come together as a team to reflect on what they have learned.
	Brainstorming About Design	(Student Pages section entitled "Brainstorming About Design" and Activity 3.1)
	Biomimetics	(Student Pages section entitled "Biomimetics")
Materials:	Engineering design notebooks.	
	Assorted tools and related objects for simulation (e.g. tongs, plastic silverware, screwdriver, hammer, tweezers, bag of chips, etc.)	
	Laptop/computer and projector to show videos, prosthetics pictures or related powerpoints.	

MESA Prosthetic Arm – Curriculum Outline

Week	Subject	Goals	Core Standards	NGSS	Objectives
Week 4	**Design and Build a Prototype**	Introduce the teams to the process of choosing the best design from the results of the brainstorming lesson.	**1.5.11.C:**		Students will construct a mechanical finger, foam finger, to analyze simple construction and anatomical design.
		Each team will build a mechanical finger as an exploration of how the finger works. Basic physics principles will be identified and used to explain the finger.	**3.4.10.E4:**	**HS-PS2-3**	Students will be able to identify the basic physics that govern the operation of the mechanical finger.
		Teams will choose the best option from the results of the brainstorming lesson.	**1.8.11.A:**	**HS-ETS1-3**	Students will apply logic processes to evaluate the effectiveness and merit of a design.
		Students will construct at least one prototype per team	**1.6.10.A:**	**HS-PS2-3**	Students will be able to come to a consensus on which design is best suited for the challenge and which they will construct at least one prototype
	Procedures:	Students develop proof of concept prototype	Activity 4.1 see below		

		Building a Mechanical Finger, Diagraming student prosthetics	Does a prosthetic arm need to have the exact number of DOFs as a real arm? How many DOF do students think are necessary for the three MESA challenges?
		Building a Prototype – Activity 4.1	Students will utilize sketches from previous lessons in order to construct a non-automated prototype.
	Materials:	Prototype supplies: Cardstock, Wooden or metal dowels, Masking tape, Popsicle sticks, Rulers, Hot glue, Cotton balls, String, Paper clips, Empty water bottles, Empty soda bottle	
		Foam Finger supplies: Foam board, masking tape, straws, string, scissors	
		Student Sketches from previous lesson	

Week 5	Subject	Goals	Core Standards	NGSS	Objectives
	Testing the Design	Students will apply Engineering validation testing to their prototypes • Demonstration • Inspection • Analysis • Testing	**CC.3.6.11-12.B:**	**HS-ETS1-2**	Students will be able to identify independent and dependent variables
			CC.3.6.11-12.E:	**HS-ETS1-3**	Students will be able to determine how many different tests are needed to describe all variable's impact.
		Students will evaluate prototypes and develop a final design to peruse in following lessons	**CC.3.6.11-12.C:**		Students will be able to design data table Use data from table to create and label X/Y graph Statistical analysis
			CC.3.6.11-12.H:		
	Procedures:	Activity 5.1: Plan Engineering Verification Testing		Students will step up their EDN for Activity 5.2	
		Activity 5.2: Demonstration/Inspection/ Analysis/Similarity Verification		Compare student prototypes against EVT standards from Activity 5.1 and competition rulebook	
		Activity 5.3: Testing		All students time to test, data collect, and analyze their prototypes against competition challenges. Students should make data tables and charts of their trials in this activity.	
		Activity 5.4: Mock Competition		Allow teams time to compete in a competition setting so students can analyze how the human variable affects the device performance, lead students to understand that teams	

			will need to interchange operators and how the device should be standardized for anyone using it
	Materials:	MESA engineering design notebook	
		Student prosthetic arms	
		Competition Supplies per which challenge or task students will mock	

Week 6	Subject	Goals	Core Standards	NGSS	Objectives
	Evaluate and Revise the Prototype	Expose the teams to comparative analysis, both independently and in a group.	**1.8.9.A:**	**HS-ETS1-2**	Students will be able to analyze their initial design the design constraints and performance criteria and choose the best option.
			CC.3.6.11-12 .C: CC.3.6.11-12 .H:		Students will apply logic and statistical processes to evaluate the effectiveness and merit of a design.
		Students will revise previous prototype to design a final design.	**1.8.11.A:**	**HS-ETS1-3**	Students will be able to come to a consensus on which design is best suited for the challenge and which they will begin construction on next lesson.
	Procedures:	*Activity 6.1: Individual Analysis of the Verification and Testing Process*		Students should work isolated to draw conclusions from the previous lesson EVT	
		Activity 6.2: Group Evaluation of the Testing Process		Students should come together as a group to compare and contrast their conclusions	
		Activity 6.3: Redesign and Reiterate the Engineering Design Process		Using the results of the previous two activities students should complete individual new	
	Materials:	MESA USA Engineering Design Notebook			
		Results of EVT from Week 5			

MESA Prosthetic Arm – Curriculum Outline

Week	Subject	Goals	Core Standards	NGSS	Objectives
Week 7	**Introduction to Arduino**	Students will be introduced to the Arduino electronics programing platform.			Students will be able to differentiate between Arduino Hardware and Software components by name and functionality
		Students will wire a simple circuit using Arduino compatible hardware or Arduino simulator software	3.2.10.B2 3.2.10.B4	**3.2.P.B5**	Students will be able to use simulator software or actual hardware to wire an simple circuit including at least one button, power supply, led, support wiring, and necessary resistors
		Students will provide code to the Arduino hardware in order to command an LED to illuminate or blink as commanded	3.2.10.B2 3.2.10.B4	**3.2.P.B5**	Students will be able to code basic functions in Arduino.
	Procedures:	Activity 7.1: Turning on an LED		Students will wire a circuit and provide base code to turn on an LED when a button is pressed	
		Activity 7.2: Blinking an LED		Students will modify their circuit or code from Activity 7.1 to make the LED blink on command, or when timed	
	Materials:	USA MESA Engineering Design Notebook			
		MESA provided Sparkfun kit			
		Computer access to: https://circuits.io/			

MESA Prosthetic Arm – Curriculum Outline

Wee	Subject	Goals	Core Standards	NGSS	Objectives

k 8	**Arduino and Servo Motors**	This module is an extenuation of Week 7. Students will refresh and apply their knowledge from their experience with Arduino in order to program and actuate a servo motor.	**3.2.10.B2 3.2.10.B4**	**3.2.P.B5**	Students will be able to apply their previously obtained understanding of Arduino Circuits to include at least one servo motor.
					Students will be able to provide code in order to command at least one servo motor.
		Students will apply their combined knowledge of Arduino circuits and servos to add as many servo motors to the prosthetic as necessary by their design (at least one)	**3.2.10.B2 3.2.10.B4**	**3.2.P.B5**	Students will be able to apply automation to their prosthetic arm by wiring and coding at least one servo motor and control.
	Procedures:	Activity 8.1 – Servos		Students will wire a completed circuit with a servo motor.	
				Students will program an Arduino to actuate a servo on command	
	Materials:	USA MESA Engineering Design Notebook			
		MESA provided Sparkfun kit			
		Computer access to: https://circuits.io/			

Week	Subject	Goals	Core Standards	NGSS	Objectives
9	**The Science Behind the Design- Force, Levers, and Torque**	Expose the teams to the technical concepts and terms used to understand and define motion as applicable to the arm This lesson is broken down into three parts:	**3.4.12.A2:**	**HS-ETS1-2**	Students will be able to define degrees of freedom of an object (how it moves).

	Students will be introduced to force and how it is applicable to simple machines (levers)	**3.2.10.B1** **3.4.10.D2:**	**HS-PS2-1.**	Students will be able to define and apply the concept of force to objects
	Students will make various levers and move the pivot point to demonstrate the law of levers	**3.2.12.B6** **3.2.P.B2** **3.4.10.D2:**	**HS-PS2-1.**	Students will be able to demonstrate the law of levers by creating a conceptual and physical model.
	Students will complete the door activity to demonstrate torque	**3.2.P.B1** **3.2.P.B2**	**HS-PS2-3.**	Students will be able to resolve vectors to demonstrate the concept of torque and how it can apply to their prosthetic arm
Procedures:	Review of Newton's Laws, specifically the third law of motion in the context of force		Moving boxes across different surface types to highlight the effect of forces on an object	
	Review the three different types of levers with the class.		Class I, II, III advantages and disadvantages in addition to proper application purpose	
	Review Law of Levers		Sesame Street Super Grover 2.0 Mini Episode	
	Review of Mechanical Advantage		Demo MA with materials listed allow students to arrive at MA formula by context	
	Review of Torque		Illustrate Torque and its application to the prosthetic arm, link back to servo motors and their basic functionality	
Materials:	MESA USA Engineering Design Notebook			
	Lever Activity – popsicle sticks or rulers, rubber bands, rubber cork or round object about 4 cm x 3 cm x 3cm			
	Torque Activity – a classroom door			

Week 10	Subject	Goals	Core Standards	NGSS	Objectives
	Technical Drawing	The teacher will introduce the topic of technical drawings; the key types of notations used for Multiview Drawings and provide examples. NOTE: The MESA rules allow for the use of computers to make the drawing. This lesson only covers TinkerCAD for 3d printing purposes	**7.G.1.**	**HS-ETS1-2**	Students will be able to use drawings to communicate design ideas.
			7.G.2.	**HS-ETS1-3**	Students will be able to Identify and use drawing notations: construction lines, object lines, and hidden lines.

	• Students will communicate design data through drawings. Students will use the method of Orthographic Projection to represent their design according to MESA rules.	**7.G.3.** **G-GMD.4.**		Students will be able to Identify front, side and top (plan) views for an object.
Procedures:	Introduce the activity-		• Print and distribute graph paper titles "INTRO to Orthographic Projection" • Use the following steps to complete the Orthographic projection drawing with the class.	
	Review the MESA Rules for Scaled Drawing		See Resource Materials section for example scaled drawing format	
	Review Geometric Contracts as necessary		Students will more than likely need a strong review of the geometric constructs that are used in orthographic projection. Review as appropriate.	
Materials:	Graph paper			
	Pencils			
	Rulers			
	MESA engineering design notebook			

Week 11	Subject	Goals	Core Standards	NGSS	Objectives
	Presentations	The students will have a chance to think about a component of their MESA engineering design and make a short presentation for others in their group. This experience will lead to a review of subjected presentation guidelines for the teams to follow in preparation for the MESA Day presentation.	**3.4.12.A2:**	**HS-ETS1-2**	Students will be able to make a presentation outline (notecards).
			3.4.12.D2: **3.4.10.E4:** **3.4.12.E5:**	**HS-ETS1-3**	Students will be able to understand the guidelines for making presentation aides (Power Point or Poster)

Procedures:	Introduction to Activity – Lighting Presentations	Bring the class to attention. Explain that when you say "start" there is to be no talking or questions for 60 seconds. Have each person in the new groups answer the following: "What was a technically challenging part of your design?" After 60 seconds, say STOP and Pencils down now. Now, with the students staying in the new groups, have each person present what they wrote to their new group. This is not a formal presentation; the students can remain seated, etc. Allow 90 seconds for each person to present their answer to the question "What was a technically challenging part of your design?"
	Class discussion	How many words were written on your card? How many words (or info) were spoken? Could you have used a drawing to help in your presentation?
	Student's synthesize for MESA competition presentation	Students apply discussion topics to their MESA competition presentation they are making.
Materials:	Pencils	
	3x5 Notecards	
	PowerPoint or Trifold Presentation Board	