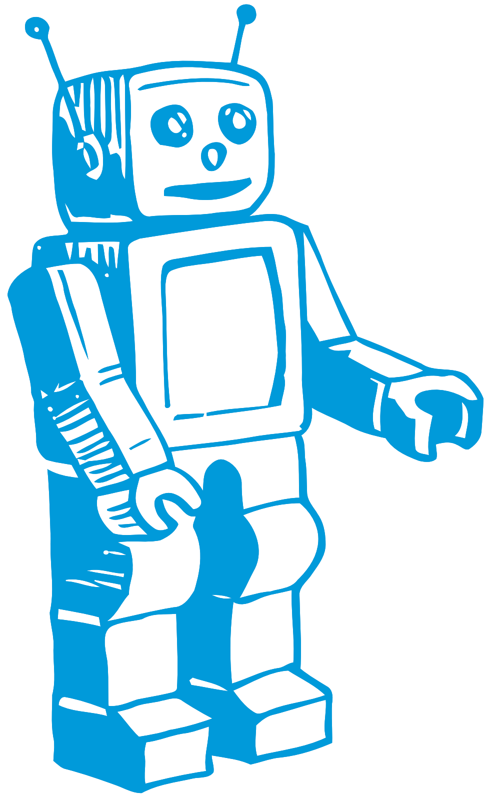

UNIT 2 ENGINEERING DESIGN

BOYS & GIRLS CLUBS OF AMERICA

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The Engineering Design DIY Unit provides members with exposure to the practical application of engineering in the world around them. Members will be introduced to the engineering design process and the iterative design process to help them create experiments that meet the outlined activity objectives. From designing water filters to building stable bridges to hold specified amounts or weights and rockets that are powered by pressure, participants will formulate hypotheses and collect data about the experiments, then verify and interpret their results.

Additionally, members are encouraged throughout the modules to record their data and observations in their scientific notebooks and observe safety practices in their laboratory experiments. Each activity and module is aligned to the NGGS to help members and Club facilitators determine how the activities prepare them for success. Moreover, the creativity and engineering aspects that are required for the modules will engage and connect with their understanding of how science plays a major role in their lives. The approximate cost range for the materials can be found in the Appendix B: Materials List with Estimated Costs.

UNIT 2 – ENGINEERING DESIGN		
Activity	**Goals**	**Recommended Time Allotment**
Water Filtration	Create a water filtration device using common household materials. Use common household ingredients to simulate wastewater composition.	90-120 min.
Bridge Building 101	Design and build a bridge from Popsicle sticks using engineering specifications that can hold varying weights	90-180 min.
Full of Potential: Water Bottle Rockets	Design and launch homemade rockets using a pressure chamber to generate propulsion	90-120 min.

Teaching Strategies for an Engineering Design Challenge

The following guidelines are intended to help you make these activities as productive as possible.

- Discuss the designs before and after testing. If possible, make observations or ask questions during the test. Discussing the designs before testing forces members to think about and communicate why they have designed as they have. Discussing the designs after testing while test results are fresh in their minds helps them reflect on and communicate what worked and what didn't so they can improve their design next time.
- Watch what members do carefully, and listen closely to what they say. Observation will help you understand if members are designing, prototyping and modifying their design with an understanding of the engineering concepts.
- Remind them of what they have already done. Compare their designs to previous ones to help them learn from the design-test-redesign approach.
- Steer members toward a more scientific approach. If they have changed multiple aspects of a design and observed changes in results, ask them which change caused the difference in performance. If they are not sure what caused the change, suggest they change only one thing at a time. This will teach them the value of controlling variables.
- Model brainstorming, careful observation and detailed description using appropriate vocabulary.
- Ask "guiding" or "focusing" questions.
- Require members to be precise about what they are describing by using specific language.
- Compare designs to those of other groups. Endorse borrowing. After all, engineers borrow a good idea whenever they can. However, be sure to give credit in documentation to the team that came up with the good idea.
- Emphasize improvement over competition. The goal of the challenge is for each team to improve its design. However, there should be some recognition of designs that perform extremely well. There should also be recognition for teams whose designs improve the most, for teams that originate design innovations that are used by others, for elegance of design and for quality of construction.
- Encourage questions. Get members to articulate what they are doing in the form of "I want to see what will happen if…"
- Connect what members are doing to what engineers do. They will understand the significance of the design challenge if they see that their process is the same process of adult engineers.
- Help members understand that designs that fail are part of the normal design process. Much can be learned from a failed design. Discuss how engineers and scientists learn from their failures.

Helping Members Understand the Design Process

Engineering involves systematically working to solve problems. To do this, engineers employ an iterative process of design-test-redesign until they reach a satisfactory solution. To help members visualize the cyclic nature of the design process, we have provided a chart that you can use in a discussion.

Once members have sufficient experience designing, building and testing models, it is valuable for them to formally describe the design process. Members require a significant amount of reinforcement to learn they should not just study their own results, but also the results of other teams. They need to realize they can learn from the successes and failures of others, too.

Use a specific design to review the engineering design process step-by-step. It's useful to hold up the model and point out specific features that resulted from studying the test data, unsuccessful builds or additional research. For example, using a particular model ask, "How did this feature come about? Where did you get the idea? Was it a result of a previous test, either by you or by another team?"

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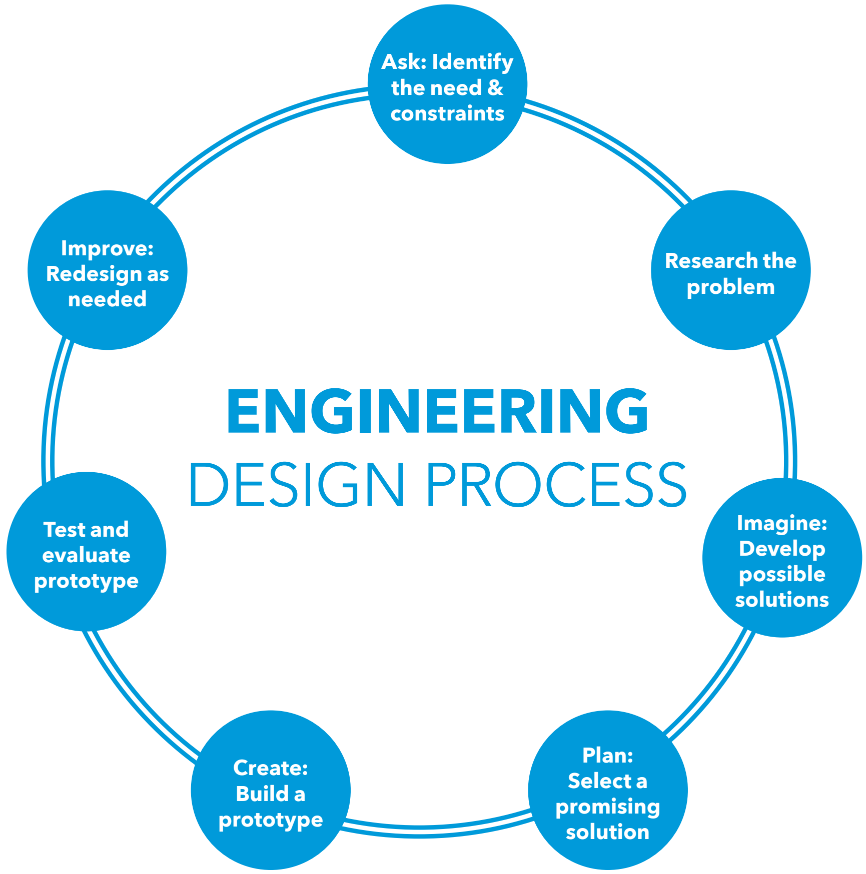


WATER FILTRATION

(90-120 MINUTES)

Introduction: Before beginning the activity, engage members in a 10-15 minute discussion about the importance of clean water. You could consider current events related to the pollution of freshwater sources in lakes, rivers and streams to help them understand why water filtration systems and devices are so important to their survival. You could also extend your discussion and brainstorming session to talk about the lack of available clean drinking water in poverty-stricken countries around the world.

Objective: To create a water filtration device using readily available materials.

NGSS Alignment: 3-5-ETS1-1: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on material, time or cost.

MS-LS2-5: Evaluate competing design solutions for maintaining biodiversity and ecosystem services.

FACILITATOR'S TIP BLOCK

If equipment is available, instruct groups to film or photograph their work. This can be used to create an electronic diary and presentation of their filtration device and results at DIY STEM Family Night.

MATERIALS

- [ ] **pH strips** (3-4 per group)
- [ ] **Plastic cups**
- [ ] **Newspaper**
- [ ] **Sharpie marker**

For each filtration device:

- [ ] **Plastic water bottle** (2)
- [ ] **Rubber band** (2)
- [ ] **10x10 cm section cheesecloth**
- [ ] **10x10 cm section plastic wrap**
- [ ] **10x10 cm section window screen**
- [ ] **Utility knife**
- [ ] **Masking tape**

For filter media
(each member team):

- [ ] **Cotton ball**
- [ ] **Coffee filter**
- [ ] **Activated carbon**
- [ ] **Gravel** (200 g)
- [ ] **Sand** (200 g)
- [ ] **Uncooked macaroni** (100 g)
- [ ] **Hair** (handful) *
- [ ] **Dust** (handful) *
- [ ] **0.5-liter bottle**

*Optional

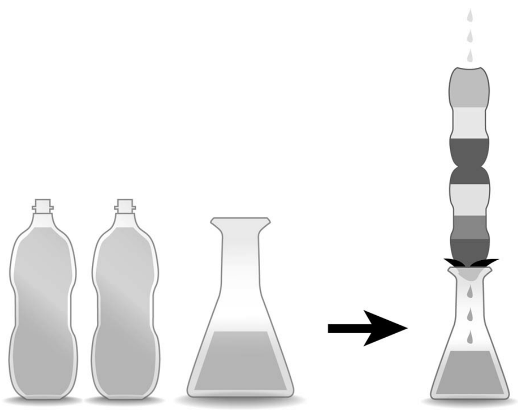
WATER FILTRATION A: MAKING THE FILTRATION DEVICE

(30-45 MINUTES)

FACILITATOR'S TIP BLOCK

If equipment is available, instruct groups to film or photograph their work. This can be used to create an electronic diary and presentation of their filtration device and results at DIY STEM Family Night.

Facilitators: Divide members into groups of two or three and give them two 0.5-liter bottles. Give them 10-15 minutes to ideate on approaches to construct their device. After 15 minutes, guide them through the following process for construction:



1. Remove the labels from two 0.5-liter (16.9 oz.) water bottles. Discard the screw caps.
2. Cut 2-3 cm (1 in.) from the bottom of each bottle. For most bottles, there will be a groove near this point. Use this groove as a guide, even if it is a little more or a little less than 2-3 cm from the bottom of the bottle. Discard the portion cut from the bottles. It is possible to reuse the bottles for repeat measures or activities, but it is time-consuming to clean them out.
3. Use masking tape to cover the rough edges from the cutting process.
4. Turn the bottles so that the mouth of the bottle faces down. Stack the bottles on top of each other by placing the mouth of one bottle in the cut portion of the second bottle.

WATER FILTRATION B: MAKING THE SIMULATED WASTEWATER (15 MINUTES)

Introduction: It will take approximately 15 minutes to make the simulated wastewater. This should be done the morning of the filtration experiment. Each team will need 200 mL of the wastewater. Thus, a 2-liter supply will allow 10 teams to conduct the filtration experiment once each.

Objective: To simulate wastewater using readily available materials.

NGSS Alignment: 3-5-ETS1-1: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time or cost.

3-5-ETS1-2: Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

3-5-ETS1-3: Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.

Facilitator Steps:

1. Measure the dry materials and place them one at a time into a large container that can hold at least 2 liters of water.
2. Measure the vinegar and add it to the dry materials.
3. Put two liters of water in the container.
4. Add 1-2 drops of food coloring.
5. Stir to mix.

Instruct Members To:

1. Members should create measured layers of filter media in each bottle. Since some materials are optional, allow groups to use different media. At the end of the activity, have the groups compare their selected media and the differences in color and pH of their simulated wastewater after filtration.
2. Members will pour simulated wastewater through their constructed filters and observe the filtration process and note changes in color as it travels through the filter.

KEY VOCABULARY

Filtration – The act or process of removing something unwanted from a liquid, gas, etc., by using a filter

Conductivity – The ability to move heat or electricity from one place to another

Dissolve – To cause to pass into a solution

Submerge – To make something go under the surface of water or some other liquid

An acid – Any of a class of substances that yields hydrogen ions (H+) when dissolved in water. The greater the concentration of hydrogen ions produced, the more acidic the substance is. Acids are characterized by a sour taste and the ability to react with bases and certain metals to form salts.

A base – Any of a class of substances that yields hydroxide ions (OH-) when dissolved in water. The greater the concentration of hydroxide ions produced, the more basic the substance is. Bases are characterized by a bitter taste, a slippery feel, and the ability to react with acids to form salts.

Facilitators: Measuring pH

The pH scale lets you determine the relative acidity of a substance. The pH scale ranges from 1 to 14 where 7 is neutral, greater than 7 is basic, and less than 7 is acidic.

The water recovered and purified by the WRS on the ISS has a pH of 4.5 to 7. This lower pH is a result of the addition of iodine to the filtered water.

Members will be measuring the pH of the unfiltered wastewater and the filtered wastewater. Have members pour a few drops of the sample onto the pH paper rather than contaminating the sample by dipping the pH strip into it. The students will use the color guide provided with the strips to determine the pH of their samples.

Extension Activity Questions:

1. What happened to the water as it passed through the different layers of the filter?
2. What changes occurred to the properties of the gray water as it was filtered (pH, appearance, odor)?
3. Compare your filtered water to the clean water. Did your gray water become "clean"? What properties told you it was or was not clean? Does this data support your hypothesis? Why or why not?
4. If you could build a water filteration system by using any of the materials available in this activity, which three materials would you use and in what order would you layer them? Why?

Extension and Enrichment Activities:

1. Collect and filter other samples of water, (e.g., rain water, hand wash water, stream, pond water, etc.).
2. Try using other filter media such as Styrofoam™ pieces, potting soil, marbles and popcorn. Ask the students to research how the water in your town is filtered/treated. Maybe take a field trip to the water treatment plant, or see if someone from the water treatment plant can speak to your class.
3. Investigate other water treatment methods, such as desalination. Conduct experiments using these methods.
4. Have members compete in a run-off to determine the best design from the data collected.
5. Have members create a poster about their design and test results for DIY STEM Family Night. Select two to three members to make a poster for the class-designed filtration device.

BRIDGE BUILDING 101

(90-180 MINUTES)

Introduction: This activity will introduce members to the six basic types of bridges. Members will combine aspects of civil engineering design, planning and construction as they compete to construct a bridge that withstands pre-determined height and weight specifications. This project should branch out over two days.

Objective: To use the engineering design process to build a bridge using Popsicle or craft sticks.

MATERIALS

- ☐ 200 Popsicle or craft sticks (per team/group)
- ☐ Craft glue
- ☐ Glue gun*
- ☐ 1 lbs. and 5 lbs. weights
- ☐ Activity Resource Sheet
- ☐ Activity Worksheet

*Optional

NGSS Alignment: **MS-ETS1-1:** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environments that may limit possible solutions.

MS-ETS1-2: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

MS-ETS1-4: Develop a model to generate data for iterative testing and modification of a proposed object, tool or process such that an optimal design can be achieved.

Facilitators, Day 1:
(30-60 minutes)

1. Focus on the introduction to the engineering design process and the iterative design processes.
2. Introduce members to each phase of both of the design processes so they will understand how their experiment with bridge building should move through each phase.
3. Ask them to brainstorm the need for their experimental bridge.

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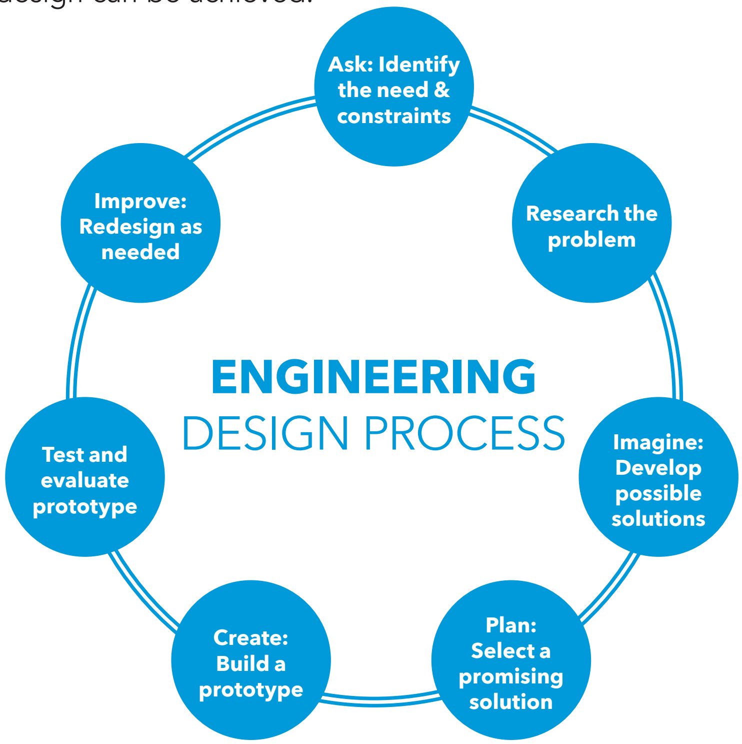
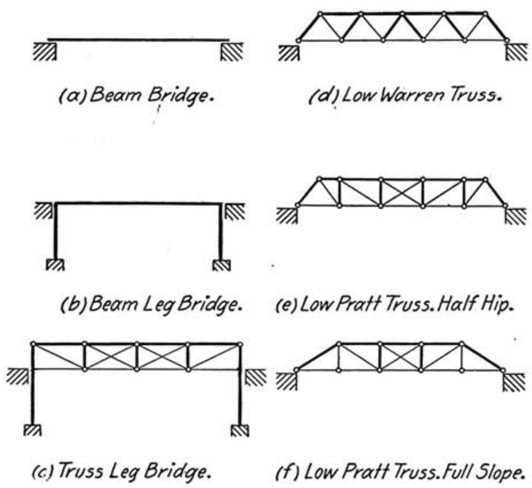


Instruct Members To:

1. Begin with the Activity Resource Sheet that describes the six main types of bridges.
2. Have members identify where they may have seen the different types of bridges.
3. Once members have brainstormed where they have seen some of the major types of bridges, divide members into groups of three or four and distribute the recommended materials.
4. Allow members to become familiar with their materials and begin to develop an initial plan for how they want to design their bridge. They will begin the building process in the next session.



Facilitators, Day 2:
(60 minutes)

1. Explain to members that they must construct their own bridge using up to 200 Popsicle or craft sticks. Bridges must be able to hold a 1 lb. weight (younger members) and a 5 lbs. weight (older members).
2. If you do not have access to weights, members can use commonly found materials around the Club at varying weights such as book bags, textbooks and other materials.
3. The bridge must span at least 14 inches. Explain that when the bridge is constructed, it will be placed at least 1 foot above the floor (in between two chairs, for example) and tested with a weight for structural integrity.
4. Bridges will also be judged on aesthetics and the number of sticks used (the fewer sticks the better).

Instruct Members To:

1. Get into groups to develop a plan for their bridge. They will draw their plan and present it to the entire group.
2. Members will begin to construct their bridge based on their plans. Encourage members to evaluate their design and, if necessary, allow them to start over.

FACILITATOR'S TIP BLOCK

Continue to emphasize the scientific method with an emphasis on the experiment and analysis steps used to test their experiments and hypothesis. Require members to use their scientific notebook to record their information.

Facilitators, Day 3:
(30-60 minutes)

Instructions For Competition:

1. Each team will test their bridge's weight capacity by placing it at least 1 foot above the floor using blocks or chairs. Each bridge must bear the assigned weight.
2. Have members from other teams rank the team's bridge in three areas:
    a. Aesthetics: How does the bridge look? Rated on a scale of 1 to 5 (1: not appealing, to 5: very appealing).
    b. Efficiency of Materials: How many sticks did the team use? Rated on a scale of 1 to 5 (1: used quite a few sticks, to 5: limited number of sticks used).
    c. Weight Capacity: Did the bridge withstand lots of weight? Rated on a scale of 1 to 5 (1: did not last long, broke under pressure, to 5: took quite a bit weight).
    d. Groups will complete an evaluation.

FACILITATOR'S TIP BLOCK

Members could test the stability and strength of their bridges as a part of DIY STEM Family Night.

Participants would benefit from a tangible example of a bridge that you have created using the same requirements so that they have an idea about what they are expected to build. You may even decide to build alongside them as they create their bridges to make the process more enjoyable and collaborative.

Examples of Popsicles Bridges:

Extension Activity Questions:

1. If your bridge did not hold the 1 lbs. or 5 lbs. weight, what flaws did you notice in your design?
2. What are some of the changes that you made to your original bridge design to strengthen it?

FULL OF POTENTIAL: WATER BOTTLE ROCKETS (90-120 MINUTES)

Introduction: The purpose of this activity is to allow members to explore how design plays an integral part in the successful launch of their rocket.

Objective: Design and launch a rocket reflecting the members' innovative design and use of a pressure chamber to generate propulsion.

NGSS Alignment: **MS-ETS1-1:** Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution by taking into account relevant scientific principles and potential impacts on people and the natural environments that may limit possible solutions.

MS-ETS1-2: Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-3: Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

KEY VOCABULARY

Pressure chamber – A chamber designed to hold material under pressure

Scale – An instrument or machine for weighing

Nose cone – The pointed front end of an aircraft, rocket, missile, etc.

MATERIALS

- [ ] **Eye Protection** (During launch)

Body:

- [ ] 1-liter or 2-liter soda bottle

Fins:

- [ ] Index cards
- [ ] Duct tape or clear packing tape
- [ ] Cardstock board
- [ ] Poster board or tag board

Nose cone:

- [ ] Poster board or tag board
- [ ] Clay
- [ ] Parachutes*
- [ ] Kite string or yarn
- [ ] Baby powder
- [ ] Grocery bags or tall kitchen bag
- [ ] Scotch tape

Launcher:

- [ ] See instructions for constructing your own or purchase online

*Optional

Facilitators: Use the following questions to engage participants in the activity and build background knowledge before beginning the experiment.

1. Why do bottle rockets fly?
2. Why do we have to use water, or do we?
3. Will it fly without water?
4. If a little water works well, will a lot of water work better?
5. Will it fly best when it is totally full?
6. What volume of water works best?

Use a plain water bottle with different levels of water to demonstrate the answers to these questions. Reintroduce the scientific method before beginning the experiment. After answering the engagement questions, members should develop their own hypothesis about what they think will happen in the experiment.

FACILITATOR'S TIP BLOCK

This is a great place to require members to use their lab notebook to record their responses to the discussion questions and write their hypothesis.

Review the main parts of a rocket – the body, nose cone and fins with members. Have a rocket available so that you can point these parts out as you introduce them.

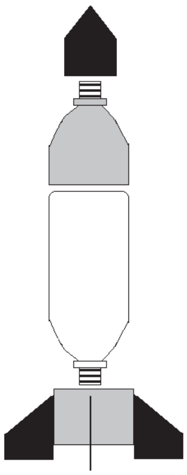
Instruct Members To:

1. The main part of your rocket is the body or pressure chamber. Provide members with all the materials listed in the materials list. Instruct members to sketch a rocket using only the materials provided in their scientific notebook. Allow them to tinker, explore and create for 20 minutes.
2. Ask members what items are most useful for the main body.
3. After reviewing all options possible for the main body of the rocket, ask each group to select the material they will use for the body. After your review and approval, instruct members to draw their rocket to scale using the provided graphing paper.
4. After you have reviewed the scale drawings, tell members to add fins to their rockets.
5. Tell members to be creative and cut out any shape for their fins except "forward swept" fins. After they decide on their shape, ask them to cut three or four identical fins and place their fins at the base of the rocket.
6. Remind them the importance of making the fins the same size and placing them evenly around their rocket to ensure rocket stability.

7. Tell them to attach their nose cone, which is pretty simple. Members will cut a piece of paper into a circle, then cut out one-fourth of the circle (it should look like Pacman when complete) and fold the paper over itself, forming a point.

8. Tell members to attach their nose cone securely to their rockets.

9. Have members share/present their rockets to the group.



Extension Activity Questions:

1. What other design changes would you make if you were to replicate this experiment?

2. How important are the materials that you selected for the effectiveness of your rocket?