The Engineering Design Process

Building a Complex Machine: the Catapult Lesson Plan

Engineering Connection

Simple and compound machines are the foundation of modern conveniences. Engineers use a combination of levers, wedges, screws, wheels-and-axels, pulleys, and inclined planes to develop simple tools. Compound machines, made from a combination of two or more simple machines, are everywhere. Engineers usually design machines for a specific function and in response to a specific problem. Engineers also have to design within certain constraints including time, money, and human resources.

The Engineering Design Process consists of phases. The process begins when an engineer receives requirements and objectives. From these requirements, engineers **research and develop** (R&D) design specifications to best satisfy the objectives.

From R&D, the design moves the **Build** phase, where engineers construct their designs using their specifications and requirements.

Once built, the design must go through a rigorous **Test** phase that puts the design in real-life simulations. This phase also requires data collection and analysis to measure the design's ability to meet the requirements.

Often, the design returns to the **Build** stage, as prototypes get redesigned and improved. Test and Build remain iterative until the design satisfies the requirements and meets the project's objectives.

Objectives

After this activity, students will be able to:

- Apply the engineering design process to create a compound machine (catapult)
- Describe the relationship between simple and complex machines
- Apply and describe the constraints of time, resources, and materials to the design model
- Use data to reengineer and improve the design prototype

Materials

Each design requires the following:

- 11 popsicle sticks
- 1 tongue depressor
- Hot glue gun and hot glue sticks
- 1 nonflexible drinking straw
- 1 wooden dowel (smaller in diameter than the straw but longer than the popsicle sticks)
- Small rubber bands
- 6-8 grapes or marbles for launching

Procedure

Before the activity:

- Gather needed materials
- Prepare a station of glue guns if there are not enough for all student participants
- Designate floor space to measure the length of the launch—mark every meter (or yard) up to three or four (depending on space available) so students can place their catapult on the designated floor space to measure the length the grape flies
- Build an example catapult

With the students:

Part I: The Engineering Design Process (5 minutes)

1. Introduce the engineering design process concept to include simple and complex machines, structural engineering, design constraints, and the importance of collecting and analyzing design data.
2. Explain the design challenge.
3. Encourage students to work in a team of two, but allow for individual designers.

Part II: R&D and Build (30 minutes)

1. Explain to students that good engineering is characterized by thoughtful designs that are also attractive. Students will receive a Style score, given by the Judge, to add to their launch average. The engineer with the highest score wins the challenge.
2. Handout the basic design instructions.
3. Oversee and assist the design process.
4. Allow students to deviate from the design model and instructions as they choose, but the design must have a lever, a wheel and axel, and the rubber band.

Part III: Test & Redesign (20 minutes)

1. Students will test their prototype design in the designated area established before the activity. The teacher (or another impartial observer) serves as the Style judge.
2. Inspect each catapult for unnecessary amounts of building materials, such as glue, and overall neatness of design—record and initial the Style points on the student's data sheet.
3. Students launch several (as time permits) grapes (or marbles) in the designated area and record the distance each grape travels; students can only record launches that are within one-fifth of the three/four meter measured zone.
4. Students calculate the average launch distance plus the Style point.
5. Students may reengineer to adjust their design, if necessary. The glue can be peeled away if changes are desired.
6. Students may launch one time with the redesigned catapult, recalculate the average, and add (or subtract, as appropriate) the Style points.
7. The student with the highest score wins the challenge.
8. Break any ties with a one-launch run-off.

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Building a Complex Machine: the Catapult

Student Instructions

Part I: Engineering the catapult

1. Gather your materials:
    - 11 popsicle sticks
    - 1 tongue depressor
    - Hot glue gun and hot glue sticks
    - 1 nonflexible drinking straw
    - Bottle cap
    - 1 wooden dowel (smaller in diameter than the straw but longer than the popsicle sticks)
    - Small rubber bands
2. With a partner, begin designing your catapult. Remember, your constraints are that you cannot use more than the allotted materials and you must be ready to launch in 30–35 minutes.
3. Determine the design approach: you can build with rubber bands, hot glue, or a combination of both. Look at the models to help you choose your approach.
4. Begin by securing a bottle cap to one end of the tongue depressor using hot glue. Leave this to dry while you design and build your catapult.
5. Build the two upright sides using the popsicle sticks. Design an **X** with the sticks to best stabilize your structure.

NOTE: There is an optional template available for those needing more assistance during this step. Ask your instructor if needed.

It is important to make these two sides as identical as possible! Be sure to leave a "V" opening at the top of each X to put the wooden dowel (Step 9 below).

6. Create the base of the X using another popsicle stick.
7. Connect the two uprights (see Figure 1).

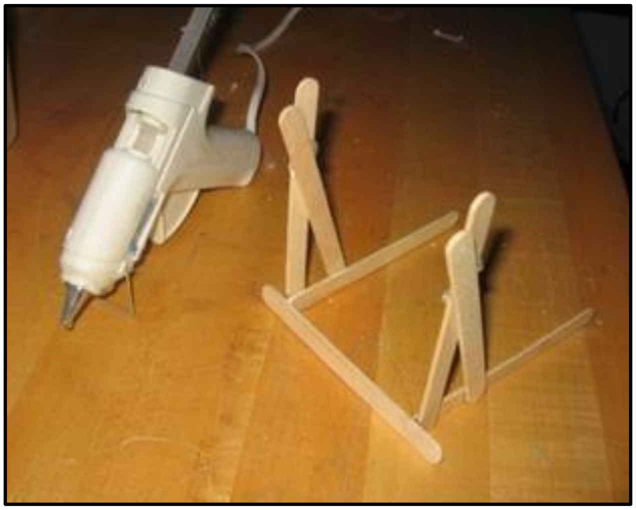

Figure 1: Example Catapult Base

8. Tie a rubber band to one of the sticks that connect the two uprights, leaving a loop extending upwards (see Figure 2).

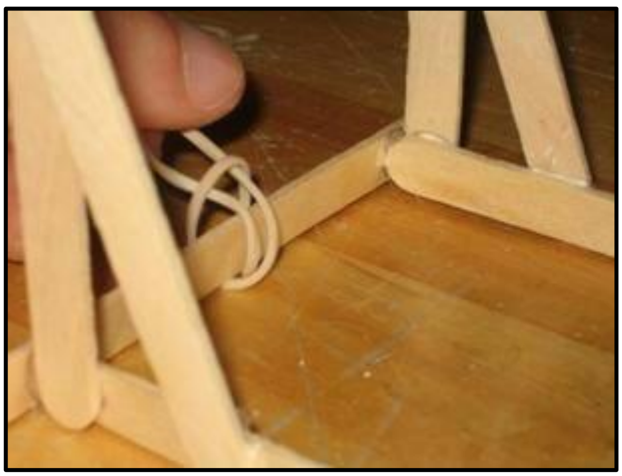

Figure 2: Securing the Rubber Band around the Base of the Catapult

9. Cut a short piece of the straw and slide it over the wooden dowel.
10. Attach the wooden dowel across the top of the side braces created in Step 5.
11. Glue the tongue depressor to the straw.
12. Attach the rubber band to the tongue depressor.

NOTE: You might not want to use glue here yet so you can modify your design, if needed.

At this point, feel free to add horizontal braces to stabilize your structure, because this is where you can get creative in how to meet your requirements (see Figure 3).

Figure 3: Securing the Tongue Depressor to the Wooden Dowel

13. The tongue depressor you just attached in Step 10 functions as the arm of the catapult. **Quality check** your design to make sure it rotates freely around the dowel. You should feel the tension in the rubber band.
    If the dowel rotates freely and you feel the tension in the rubber band, then proceed.
    If not, then carefully examine the design and make the necessary changes.

14. Add two more popsicle sticks to the front of your catapult to stabilize it after launch (see **Figure 4**).

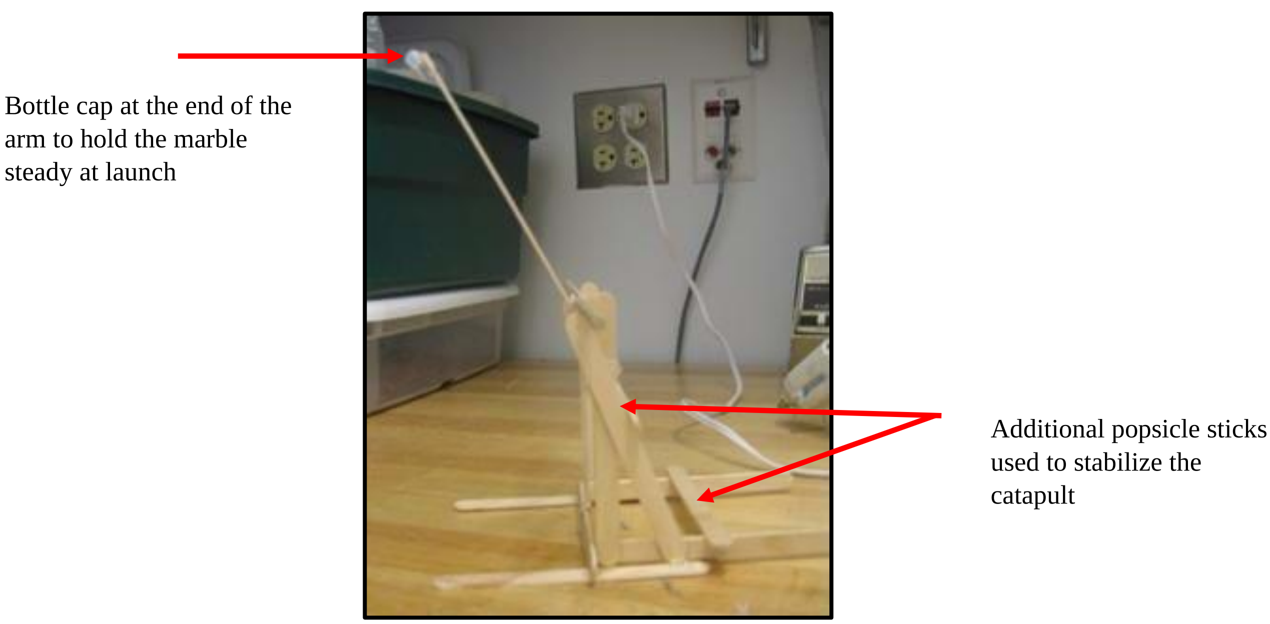

Figure 4: Front and Rear View with Stabilizers

Part II: Testing the Design

An essential aspect of any engineering design is the test phase. This is when engineers get to see their design in action and collect valuable test data to document their design strengths and weaknesses.

1. Take your finished catapult to the launch station for STYLE and DESIGN QUALITY CHECK. The score will be determined as follows:

0=Out of compliance (did not adhere to the constraints)

5= In compliance (adheres to the constraints)

10=In compliance and innovative (the design shows creativity beyond the basic instructions)

2. In the launch area, test launch twice using your catapult.
3. Record the distance AND the accuracy of each launch on your data sheet. The distance is where your marble lands, not to where it rolls!
4. Calculate your overall score as follows: (Launch 1 Distance – Accuracy) + (Launch 2 Distance – Accuracy) + QUALITY score.
5. Redesign and launch again, time permitted. If you decide to launch again, you get ONE launch ONLY. This can replace your lowest score. Recalculate.

The catapult with the highest overall score wins the engineering contract (and prize ☺)