Catapult Design:
Flight of the Marshmallows
Student Advanced Version

Queen Kathy of Candyland needs your help! Her kingdom is being plagued by a devious dragon named Dave, who won't leave the people alone. Candyland has a very old catapult device for launching marshmallows at invaders, but it is heavy and doesn't work very well.

In this lab you will design a better catapult device for Queen Kathy's kingdom using only copy paper, two rubber bands, tape, and a single ruler. Designs will be evaluated on both distance traveled by the marshmallow and catapult weight. This lab draws from concepts in the engineering design process as well as elements of projectile motion.

Key concepts:

- Balancing multiple objectives with one another, a critical part of the *Engineering Design Process*. Done by exploring the balance between maximizing projectile distance and minimizing catapult weight. This is known as *design compromise*.
- Exploring the basics of *projectile* motion including the conversion of *potential energy* to *kinetic energy* and the effects of projectile mass on flight path.

Part I: Ask

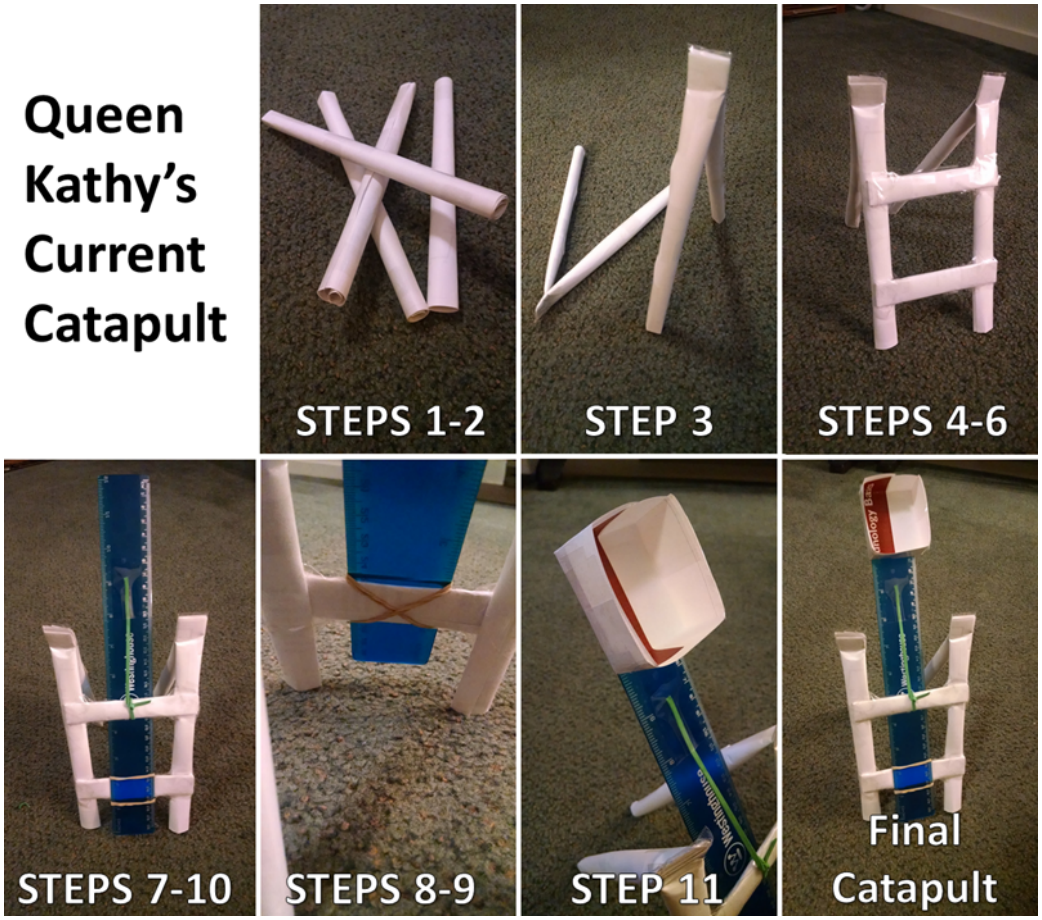
The first step in the Engineering Design Method involves identifying a problem to solve. Sometimes engineers are given a problem to solve and other times they find a problem on their own. Today Queen Kathy of Candyland has a problem for us to solve.

For as long as Queen Kathy could remember, everything had been peaceful in the kingdom of Candyland. Who wouldn't be happy in a land full of gingerbread houses, gumdrop mountains, lollipop flowers, and chocolate rivers? She had an army of gingerbread men, but they never needed to do much more than help an old lady cross the street, retrieve a kitten that was stuck in a tree, or guide a lost child home. Then one day, King Kevin of Carrot Country became angry that everyone preferred Candyland to his kingdom full of deliciously healthy foods. His subjects were running away to Queen Kathy and her candy creations, and his anger continued to brew. As a result, King Kevin sent his friend Dave the Devious Dragon to torment Queen Kathy and all of Candyland. Dave the Dragon was ruining Candyland, and Queen Kathy knew she had to put a stop to it. She assembled her army and devised a plan to attack Dave the Dragon using their marshmallow catapults. As the gingerbread army dusted off their catapults and tried to take out the dragon with their marshmallow ammo, they realized they had a very big problem - because Candyland was such a happy place, their catapults were 20 years old and seriously outdated. Dave the Dragon was getting worse and people were flocking back to King Kevin's Carrot Country. Queen Kathy knew she needed help, and she needed it fast. This is where you come in - Queen Kathy is hiring you to design a better catapult that her army can use to stop Dave the Dragon and prevent King Kevin from luring people away to Carrot Country. To start your job, Queen Kathy will be showing you how the current catapults were built.

Building Queen Kathy's Current Catapults:

Step-by-step images follow the instructions

1. Roll up four sheets of paper widthwise
2. Tape the sheets, so they stay rolled
3. Flatten the top centimeter of each roll, and tape two of the tubes together to make an 'V' shape
4. Cut a sheet of paper in half widthwise, and make two more rolls of paper (these should be shorter than your other rolls)
5. Flatten the two new rolls of paper
6. Tape these new rolls of paper between the 'V' shapes you built like two rungs on a ladder
7. Slide the ruler behind the top bar and in front of the bottom bar
8. Wrap a rubber band twice around the bottom of the ruler, and slide it above the bottom bar
9. Wrap the rubber band around the bottom of the ruler twice more, catching the bottom bar in the rubber band
10. Tie a rubber band to the top bar and tape it towards the middle/top of the ruler
11. Build a small box out of paper and tape it to the top of the ruler
12. Place a marshmallow in the small paper box
13. While one person holds the catapult frame, another person pulls back on the ruler and launches the marshmallow



Queen Kathy told you the current catapults were terrible. I'm sure you agree with her now that you've used one yourself.

Part II: Imagine

Now that you have built Queen Kathy's current catapult and have seen have terrible it is, you can begin to re-design a better catapult to help Candyland with their Dave the Dragon problem.

1. As a group, discuss the good and bad features of Queen Kathy's current catapult.
2. Make a list of these good and bad features.
3. Why were these features implemented in the way they were?

Table 1: Good and Bad Features of Queen Kathy's Current Catapult

Feature	Good or Bad?	Why was it done this way?

As a reminder, A '**must have**' is a function or feature that your product must fulfill in order to be useful. A '**nice to have**' is a function or feature that would provide value to the user but isn't necessary for proper function of the product.

While you were away with Queen Kathy learning how the current catapults work, the rest of the gingerbread army talked about what they wanted in the new catapults. Here is the list they came up with:

- light weight so they can move them around easily and quickly
- pouches to store the marshmallow ammo, so they don't have to carry it in their packs
- bright and colorful designs, so they will be happier on the battlefield
- ability to launch various different distances to attack the dragon as he moves around; longer is best, so the dragon can be taken out from far away
- ability to use either large or small marshmallow ammo in every catapult
- automated reloading, so they don't have to do any work
- single person operation, so the army can be more efficient

4. Based on your discussion and the ideas from the gingerbread army, make a list of 'must haves' and 'nice to haves' for a new catapult.

Table 2: 'Must Haves' and 'Nice to Haves'

'Must Haves'	**'Nice to Haves'**

Part III: Plan

Now you're ready to start designing a new and improved catapult for Queen Kathy. Before engineers start building their designs, they draw them on paper. We are going to start by planning our designs on paper as well.

1. Grab your Post-It notes and begin drawing solutions to the bad features or completely new features on your own. Make sure to put each solution or new feature on its own Post-It note.

REMEMBER: You will have access to unlimited copy paper, one ruler, 2 rubber bands, and unlimited tape when you make your design, so plan accordingly.

2. Share your ideas for solutions or new features with your group.
3. As a group, categorize all of the features and solutions by their purpose or the problem they address.
4. As a group, come up with three full designs for a new and improved catapult.
5. Draw your design on a full sheet for paper using front and back views or close ups of certain areas if necessary.

In order to decide which designs to prototype, engineers often use a **Concept Scoring Matrix** to 'grade' their designs. This looks primarily at functionality and 'must haves' but also considers the cost and other essential factors. You will make a Concept Scoring Matrix to decide which design your group wants to prototype.

6. Use the following Concept Scoring Matrix to choose the design you will prototype. If a design does a great job of meeting a criteria, give it a 2. If it does an okay job of meeting a criteria, give it a 1. If the design does not meet the criteria, give it a 0. The design with the highest total score is the one you will prototype.

Table 3: Concept Scoring Matrix

Criteria	Design 1 Score	Design 2 Score	Design 3 Score
Reasonable Cost of Design			
Feasibility to Build			
Minimizes Environmental Impact			
Must Have #1:			
Must Have #2:			
Must Have #3:			
Must Have #4:			
Must Have #5:			
Total Score (add up all the boxes above)			

Part IV: Create

Once engineers have a design they feel good about on paper, they grab materials and start building a prototype. A **prototype** is a sample of their design that can be used for testing or to identify unanticipated problems. Now you are going to build and test your own prototype of your improved catapult.

1. Once you have completed your Concept Scoring Matrix from Part III, ask your teacher for prototyping materials.
2. Use the copy paper, tape, ruler, and 2 rubber bands to make a prototype of your new and improved catapult. Your prototype should be based on your highest scoring design, but you should feel free to make changes and adjustments as you build.
3. As you are building your catapult, make note of how many sheets of paper you use. This will be converted to weight later.

# of sheets of paper used = _____*sheets*

3. Be sure to test your catapult with both large and small marshmallows after you build it.

Part V: Improve

Once engineers have built a prototype, they test it and present the results to many different people: fellow engineers, administration, businessmen, friends, and family. Today you will be presenting your designs to your customer, Queen Kathy. She will be scoring your designs with the following equation. This equation incorporates many of the 'must haves' you identified earlier.

$$score = \frac{(marshmallow\ size) * (distance\ the\ marshmallow\ flew\ in\ cm)}{weight\ of\ the\ catapult}$$

$$marshmallow\ size: 10\ for\ large\ marshmallow, 1\ for\ small\ marshmallow$$

$$If\ you\ do\ not\ have\ access\ to\ a\ scale,$$
$$weight\ of\ the\ catapult = (\#\ sheets\ of\ paper) * \left(4.5\frac{grams}{sheet}\right) + 5\ grams$$

1. Have someone in your group launch both a large and small marshmallow for Queen Kathy. Record and calculate the following information and calculate your catapult's score.

# of sheets of paper used = _____*sheets*

weight of the catapult = _____ *g*

distance the small marshmallow flew = _____ *cm*

small marshmallow score = _____

distance the large marshmallow flew = _____ *cm*

large marshmallow score = _____

2. As you present your design to the class and Queen Kathy, make note of how you addressed the 'must haves' and which 'nice to haves' you included. Don't forget to mention cost and feasibility to make.
3. Listen to other groups present their design and make notes about things you like about their designs.
4. After you are finished with the discussion, answer the following questions about your design.

Engineering Design Follow-up Questions:

Q1. What worked well in your design?

Q2. What were some flaws in your design?

Q3. What were some cool features from other groups?

Q4. How would your improve your design, so it would be even better next time?

Q5. How does cost factor into your design?

Q6. Can you think of ways to make your design more cost effective?

Q7. Draw a new design in the space below that incorporates things you liked from other teams and fixes any flaws you identified in your design. Score this design using the Concept Scoring Matrix and see how it compares to your previous design.

Concept Questions:

Q1. All of the kinetic energy of the marshmallow projectile has to come from the stored elastic potential energy in the rubber band (the two energies must be equal). If we know our rubber band has a spring constant of 1000 g/s^2, how far would we need to stretch the rubber band to launch a small marshmallow out of our catapult at a speed of 100 cm/s? You can assume a small marshmallow weighs 1 g.

Remember,

kinetic energy is $KE = \frac{1}{2}mv^2$

elastic potential energy is $PE = \frac{1}{2}mv^2$

Q2. How far would we need to stretch the rubber band to launch a large marshmallow? You can assume a large marshmallow weighs 10 g.

Q3. Do you expect the large or small marshmallow to fly faster and farther if you stretch the rubber band the same amount for each? Why?

Q4. Would a marshmallow launched at a 70° angle or a 30° angle be expected to fly further? Why?