Paper Engineering

The Tech Challenge 2021
Grade Levels: 3-8
Duration: 60 min

Students practice defining a problem and developing their own criteria as they recreate an object from paper and test it in this simple design challenge.

Outline

Frame the Challenge	10 min total
Introduce the Challenge	5 min
Define the Problem	5 min
Design Challenge	**50 min total**
Prototype (Build and Test)	30 min
Share Solutions	15 min
Debrief	5 min

Grade Levels: 3-8

Duration: 60 min

Concepts/Skills
Prototyping, engineering design, testing

Objectives
Students will...
- Create a paper prototype of a common object.
- Develop design criteria to test their prototype.

Distance Learning
This lesson is written for virtual synchronous implementation via live video sessions. However, it can be implemented in a variety of settings. Adaptations for asynchronous and in-person implementation are included. For more tips on planning for distance learning, see our Educator Tips for Remote STEM Learning.

Tech Tips
See our educator guides and videos for more design challenge facilitation techniques. For this lesson check out:
- Prototyping
- Sharing Solutions

Materials and Preparation

Students can use whatever they have on hand around their home. Encourage them to be creative, especially with their testing methods and materials.

Materials
Each student will need:
□ 2 Student Handouts: (Paper Engineering and 3D Paper Construction Techniques) □ Paper (Any type and amount of scrap paper: newspapers, old magazines, flyers, old homework, printer paper, post-it notes, etc.) □ Tape (any type) □ Scissors (*optional*) □ Testing materials (Other household materials, which will vary by test. Ex: coins/book for weight)

Tech Challenge Extension
This lesson can also be used to prepare students for the 2021 Tech Challenge Ultimate Upcycle, a signature program of The Tech.

Preparation

1. Plan the process by which you will introduce the challenge to students and collect their work. *For example*, learning management platforms, live video sessions, collaborative documents, photos, videos, etc.
   - *Option*: Have experienced students keep their own journal throughout this activity; choose a format and tool to use for tracking their process.
2. Try the design challenge yourself. Practicing with the materials and tools enables you to anticipate student questions.
   - In particular it may help to practice and build using a few of the 3D paper techniques in the Appendix.

In-Person Adaptation

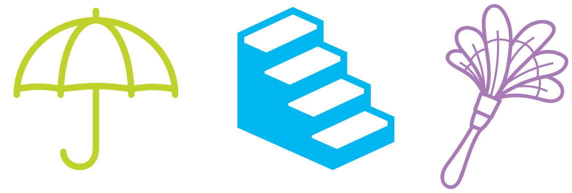
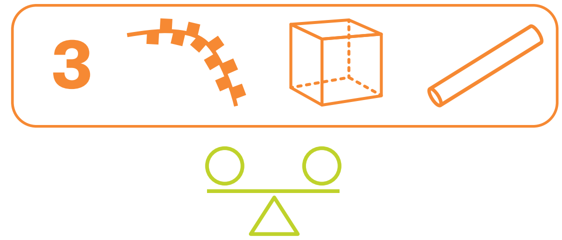
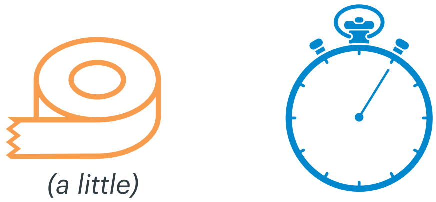
- Prepare materials for students. It may be useful to have a variety of types of paper.
  - Set out materials buffet style for students to choose from during prototyping.
  - Have materials ready for a variety of tests (ex: books, nuts, or coins for weight).
- Decide how students will form teams of 3-4 for this challenge. To scaffold collaboration skills for beginning engineers, assign students roles within their teams: *For example*, timekeeper, materials manager, scribe, etc.

Frame the Challenge

Introduce the Challenge *(5 min)*

1. Hold a live video session with students to introduce the challenge. Tell students they are going to recreate an object from around their home using paper and then test it.
2. Have students consider real-world scenarios where people need to build models or prototypes of objects.
   - *Examples* may include: stop motion animation, architectural models, paper prototypes of games or apps, working prototypes used by engineers.

3. Introduce the Paper Engineering Student Handout and design problem to students. Address any questions students have.

Design Problem	Recreate an item from around your home using paper.	
Criteria	• Use 3 different 3D paper construction techniques. • Choose a way to test your prototype.	
Constraints	• Use as little tape as you can. • There's a time limit!	

Asynchronous Adaptation
Send the Student Handouts to students. Remind students that any paper they have at home will work.

Define the Problem *(5 min)*

1. In this lesson, students will need to refine their design problem and criteria themselves. They will need to decide what object they will build and how they will determine the success of their prototype through testing. Guide them through this process, with some simple steps.
2. First, help them **Brainstorm** the item to prototype: Have students think of some objects they could create using paper. Their object can be from anywhere around their home (inside or outside).
   Options for brainstorming include:
   - Create a class list.
   - Have each student look around their room and write down as many things as they can in a minute.
3. Have students choose an item from the list and share their decision via chat or a polling tool. They can also document their decision in their handout or journal.
4. Next, students will **decide** on a way to test their prototype.

- They will use the examples in the Student Handout (usability, stability, movement, weight, etc.) as a starting point to choose the method that works best for their item and goal.
- The idea of "testing" their prototype may be challenging for students. Model this decision-making by choosing an object no one in the class is building and discussing how to test it.
- Encourage students to think of creative ways to test as well. Paper objects will not behave the same as real ones, but students can still test them:
  - *For example*: If a student is creating a mug, they would want to test how much weight it can hold, but they won't want to get it wet. They can't pour water into it, but they can add other items to test the weight.
  - *For example*: A student creating a paper fork might test it by trying to pick up some strings instead of heavier damp spaghetti.

5. Once again, have students share the test they chose via chat or a polling tool as well as writing it down for themselves.

Asynchronous Adaptation
Have students share their plans (their object and test) via text, a shared document, or discussion board. This will help build some engagement and spark ideas before they begin prototyping.

Sample Tests

Usability	Stability	Movement	Weight
Does your design work the same way as the original?	Does your design stay up on its own?	Does your design move the way it should?	How much weight can your design hold?
Object: Feather Duster Test: Try to remove dust from a shelf or fan.	Object: Chair Test: Put it on a table — test if it stays up without touching.	Object: Umbrella Test: Try to open and close it.	Object: Table Test: How many books does it hold without falling?

Design Challenge

Brainstorm *(Optional)*

- One way to brainstorm is by exploring the materials. If students are lacking inspiration, have them look at some of the 3D paper techniques in the Resources or Appendix.
- As they play with these techniques, have them consider the properties of paper:
  - *Is it easy to bend?*
  - *Do certain shapes seem more stable?*
  - *Are there any techniques or shapes you could use to create part of an object?*

Paper Construction Techniques Resources

- Handout: 3D Paper Construction Techniques
- Video: RIBA Learning: 3D Paper Model Techniques (4:33)
- Video: 3D Paper Folding (7:25)

Prototype (Build and Test) *(30 min)*

1. During prototyping, focus on process over solution.
   - Remind students that prototypes are rough drafts of an idea, so they do not need to have a working solution by the end of the time limit.
2. Ensure all students have materials. If needed, set a timer and give them a minute to collect their materials.
3. Be ready to demonstrate different 3D paper techniques before they build or during the prototyping time. Key techniques will include:
   - Ways to strengthen paper (rolling, prisms, tabs)
   - Ways to attach paper (slots, tabs, loops)
4. Model the process by prototyping and talking through your decisions as you build along with them.
   - If you were previously sharing slides on the screen, stop sharing so students can see you more clearly. Position your camera so students can see you and the materials as you work.
   - Encourage them to turn on their cameras as well so they can see each other on gallery view and get ideas and encouragement as they build.
5. Set a timer and have students begin building.
6. Use open-ended **Prototype Questions** to support students who need help, or guide student reflection on their process.
   - **Partial Build**
     - *Are there paper techniques you could use to create part of an object?*
     - *Which parts of the design can you test to inform the overall prototype?*
   - **Problem Solving**
     - *What components are working in your design?*
     - *Where are the failure point(s)? What caused the failure?*
     - *How can you start to alter that part of the design?*
   - **Pushing Design Further**
     - *What can you try to make this design even better?*
     - *What is a different way to solve the problem?*
7. Encourage students to test as they build.
   - Emphasize that the goal of testing is to find out what works and what can be improved (not a pass/fail test). They shouldn't be changing their test so that their original designs succeed.
   - Students can record their test results on the data collection section of the Student Handout.

Real-world Prototyping Extensions

Video Reflection

- Share one of these video resources with students to show them examples of Paper Prototyping in the real world:
  - How to make a Cardboard Prototype, Quirky
  - Real World: From Idea to Physical Prototype, NASA (mathematics techniques)
- Students may notice:
  - Paper and cardboard prototypes save engineers time and money.
  - Although they are rough models, they often still involve measurements, schematics and careful techniques.
  - In some cases the final version may even be scaled up or down in size from the original.

Advanced Engineers

- Have students research prototyping and look at the ways engineers and scientists use models to test ideas.
- Have them consider how the process of prototyping and testing affects the design problem, criteria and constraints.

8. **Small Group Adaptation:** Place students in teams of 3-4 and have them build the same object. Use break-out rooms or small-group check-ins for students to prototype together and share their progress with each other. In this way they can build one design but have several different physical prototypes of the item.

Tip: Have students finish prototyping asynchronously if they need additional time.

Asynchronous Adaptation
Provide students with a way to check-in with questions or updates if needed during their prototyping. *Options include*: Email or text, class discussion board, shared document, staggered one-on-one calls, or small group check-ins.

Share Solutions *(15 min)*

1. Before students share in the live video session, have them write down their reflection to the **Sharing Questions**. They can jot their ideas down for themselves, or share them using one of the asynchronous methods.
   - *What did you make?*
   - *How did you test your design? What were the results?*
   - *What did you adjust/change as you built?*
   - *What would you change if you had more time?*
2. In addition, have all students share their work with the class during a live video session.
   - The goal is to share their process and thinking so students should share even if they were unable to complete their structure or it was unsuccessful during testing.
3. Techniques for sharing include:
   - **Gallery Walk:** Make sure you are not sharing your screen, and have students go into "Gallery View" so that they can see all of the students in the class. Have everyone turn on their cameras (without virtual backgrounds) and hold up their paper prototypes.
   - **Show and Tell:** Give clear directions for students or teams to take turns sharing their work verbally.
4. Have students give each other positive feedback on their designs. Encourage them to tell the other team one thing they liked or noticed. This can be done with written or verbal comments.

Tip: If there is a limited amount of time for everyone to share, consider spreading sharing out over several sessions, or using asynchronous sharing tools as well.

Asynchronous Adaptation
Give students directions on how to share their work and reflections. Depending on their resources, it can vary from written comments to photos or videos of their prototype and test.
- Options for sharing their reflection and prototype might include:
  - Text messages, photos or videos.
  - Shared Google Slides deck for the class. Students can add their images and comments on the sharing questions.
  - Reflections and images added to Padlet.
  - Videos uploaded to Flipgrid.
  - Responding to questions on a class discussion board.

Iteration Extension *(20 min)*

1. Iteration is an important part of the design process. Provide students time to revisit and revise their devices based on their testing, feedback and observations of other students' designs. (Iterating may be more rapid at this point as students are making minor adjustments.)
2. Teams that have met the initial criteria can try one of the bonus challenges to push their designs further.
   - **More materials:** What other household materials could you use to improve your prototype?
   - **More tests:** Test your design with different criteria. How do you need to change your design to meet more criteria?
   - **Change the size:** Scale it up or down. Try making your design bigger or smaller.
   - **Revise the original:** Use your prototype to improve the original object. What features would you add or change?

Debrief *(5-10 min)*

1. For a final debrief, have students consider the ways in which engineers define criteria, use testing, and create prototypes.
   - Students were responsible for defining their own tests and criteria for success in this challenge. Have them reflect on that process and how they might apply it to other situations.
2. Have students share their ideas in a class discussion, via a poll, or within breakout rooms.
3. Debrief Questions will vary depending on what students have noticed. They may include:

   Criteria and Testing
   - *What did we notice about the different prototypes (similarities and differences)?*
   - *What did we notice about the different testing methods (similarities and differences)?*
   - *How were the tests defined? What did success look like?*

   Process and Paper Techniques
   - *What 3D techniques did you find useful for your design? How did you modify the paper to give it different properties?*
   - *How would the designs be different if we had different materials? For example, how could you apply these techniques to cardboard?*

   Real-world
   - *Where else have you noticed the skills you used in this activity in the real world?*

Asynchronous Adaptation
Have students write a short response on a shared discussion board or shared document. Students could also send a text or email response with their ideas.

Standards Connections

Next Generation Science Standards

Grade	Standard	Description
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	ETS1-3	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.
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 environment that may limit possible solutions.
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.

Vocabulary

For more tips on vocabulary and common engineering terms see our Tech Tip: The Language of Engineering.

- **3D:** Having the 3 dimensions of length, width and height.
- **Feature:** A part or detail that stands out in the design.
- **Reflection:** A thought, idea, or opinion made as a result of thinking about what you have designed or built.
- **Stability:** The resistance offered by a structure to undesirable movement like sliding, collapsing, falling over, etc. The strength to stand or endure, and be firm.
- **Technique:** A method or way of doing a task.
- **Usability:** How easily something can be used, learned or understood.

Resources and References

Prototyping

- Video: How to make a Cardboard Prototype, Quirky
- Video: Real World: From Idea to Physical Prototype, NASA (mathematics techniques)

3D paper techniques

- Video: RIBA Learning: 3D Paper Model Techniques
- Video: 3D Paper Folding

Real-world examples

- Article & Video: Engineers explore origami to create folding spacecraft, NASA, Phys.org, Sept 25, 2017
- Video: How Origami is Inspiring Scientific Creativity, with BYU and Origami Artist Robert Lang, Brigham Young University, provides several real-world examples of scientists and engineers using paper folding techniques to inspire prototyping and design.

Additional resources

- Video: The Ruff Ruffman Show, Ask Ruff First: Ruffman Escapes, Ruff builds a chair out of newspaper
- The Tech Interactive 2021 Ultimate Upcycle Tech Challenge

The Tech Challenge

Paper Engineering

Ready for a little Tech Challenge fun?
Let's see what we can make from paper!

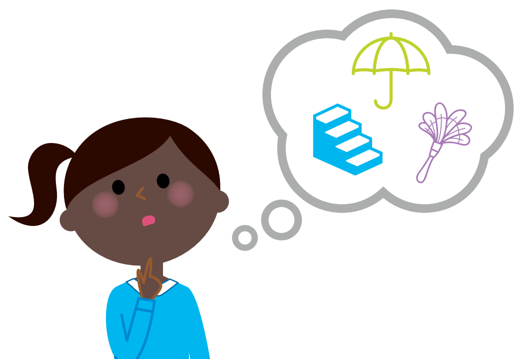
Design Problem: Re-create an object from around your home using only paper. Pick a way to test it and see how it performs!

Materials

- Paper (any type of scrap paper will do!)
- Tape
- *Optional*: Scissors, ruler

Tip: Use as little tape as possible. This will let you change your design faster!

Ready, set, build!



1. **Brainstorm** some objects you could re-create and test using paper. Think of lots of ideas first! Then pick your favorite one.
2. **Decide** how you will test your object. *For example:*

Usability	Stability	Movement	Weight	Other
Does your design work the same way as the original?	Does your design stay up on its own?	Does your design move the way it should?	How much weight can your design hold?	What else can you test?

3. **Create** your prototype using paper and tape.
   - Try to use at least three different 3D paper techniques!
   - *How can you make your paper stronger? How can you connect and attach it (without tape)?*
4. **Test** your paper prototype. How does it do?
   - Make observations on how your design performs.
   - Use these observations to **iterate**, or improve on, your next design!

Tip: Try brainstorming with your hands. Fold, twist, cut and bend the paper and see what happens.

Paper Engineering

Bonus challenges

- **More materials:** What other household materials could you use to improve your prototype?
- **More tests:** Test your design with a different criteria. How do you need to change your design to meet more criteria?
- **Change the size:** Scale it up or down. Try making your design bigger or smaller.
- **Revise the original:** Use your prototype to improve the original object. What features would you add or

Questions to ask yourself

- What 3D techniques did you find useful for your design?
- How would your design be different if you had different materials (ex: cardboard)?

Use the space below to take notes, sketch, and reflect.

The Tech Challenge

Paper Engineering

Name:

Date:

I built...

(Object)

It includes...

(Describe its features. Ex: legs, handle, fringe.)

Test 1:

Does it stay together?

☐ **Yes** ☐ **No**

(Check one.)

Test 2:

I also tested it by... *(Name/describe the test.)*

(Test Results)	*(Iteration Test Results)*

While building I changed...

If I had more time I would change...

The Tech Challenge

Paper Engineering

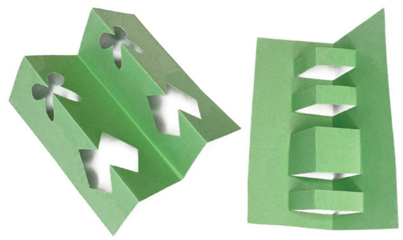
3D Paper Construction Techniques

Loop

Loops can loosely connect pieces to each other.

Cut on fold

Use to quickly create a pop up structure or cut symmetrical holes.



Cone

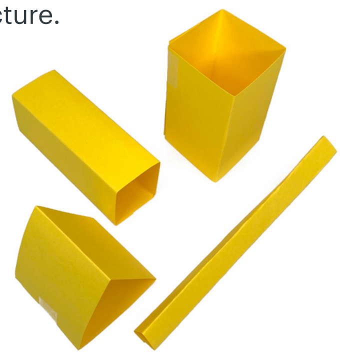
Cones have a strong supporting base and can also hold other objects.

Roll

Large cylinders or narrow dowels can provide strength and structure.

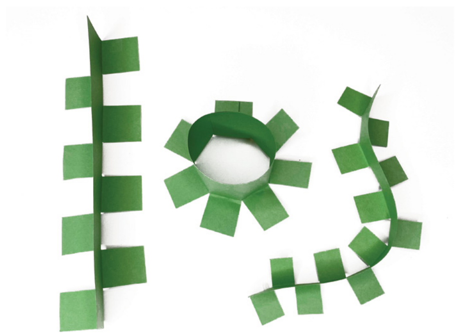
Prisms

Fold into rectangular or triangular prisms to provide shape and structure.



Tabs

Use to attach paper and create curved structures.

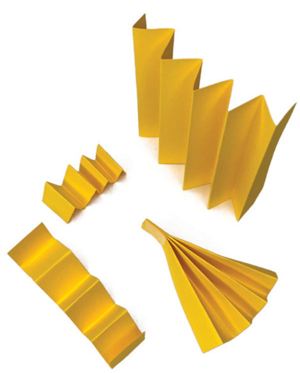


Fringes

Cut or tear edges to create decoration similar to tassles, bristles, or fringes.

Fan

Use paper folding to control how the paper will collapse or expand.



Slots

Use to attach different shapes without tape.