# Activity One: Assess the Structural Integrity of a Space Module

## Educator Notes

### Challenge

Students will work as a team to design and build the skeletal structure or framework for a spaghetti space module that can support as much weight as possible.

### Suggested Time

60 minutes

### Learning Objectives

Students will
- Apply the steps of the engineering design process to successfully complete a team challenge.
- Design, build, and test their own space habitat module.
- Collect data after each weight test for comparison with other groups.
- Improve their model based upon the results of the experiment.
- Understand the relationship between mass and weight.

### Curriculum Connection

| Science and Engineering (NGSS) | |
|---|---|
| *Disciplinary Core Ideas*<br>• MS-ETS1-1 Engineering Design: 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.<br>– ETS1.A: The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that are likely to limit possible solutions.<br>• MS-ETS1-3 Engineering and Design: 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.<br>– ETS1.B: There are systematic processes for evaluating solutions with respect to how well they meet the criteria and constraints of a problem. Sometimes parts of different solutions can be combined to create a solution that is better than any of its predecessors.<br>– ETS1.C: Although one design may not perform the best across all tests, identifying the characteristics of the design that performed the best in each test can provide useful information for the redesign process—that is, some of those characteristics may be incorporated into the new design.<br>*Crosscutting Concepts*<br>• Cause and Effect: Events have causes, sometimes simple, sometimes multifaceted. Deciphering causal relationships, and the mechanisms by which they are mediated, is a major activity of science and engineering. | *Crosscutting Concepts (continued)*<br>• System and System Models: A system is an organized group of related objects or components; models can be used for understanding and predicting the behavior of systems.<br>• Interdependence of Science, Engineering, and Technology: Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems.<br>*Science and Engineering Practices*<br>• Asking Questions and Defining Problems: A practice of science is to ask and refine questions that lead to descriptions and explanations of how the natural and designed world works and which can be empirically tested.<br>• Develop and Use Models: A practice of both science and engineering is to use and construct models as helpful tools for representing ideas and explanations. These tools include diagrams, drawings, physical replicas, mathematical representations, analogies, and computer simulations.<br>• Planning and Carrying Out Investigations: Scientists and engineers plan and carry out investigations in the field or laboratory, working collaboratively as well as individually. Their investigations are systematic and require clarifying what counts as data and identifying variables or parameters.<br>• Construct Explanations and Design Solutions: The products of science are explanations and the products of engineering are solutions. |

| Technology (ISTE) | |
|---|---|
| *Standards for Students*<br>• Innovative Designer: Students use a variety of technologies within a design process to identify and solve problems by creating new, useful, or imaginative solutions.<br>– 4a: Students know and use a deliberate design process for generating ideas, testing theories, creating innovative artifacts or solving authentic problems.<br>– 4c: Students develop, test, and refine prototypes as part of a cyclical design process.<br>• Computational Thinker: Students develop and employ strategies for understanding and solving problems in ways that leverage the power of technological methods to develop and test solutions. | *Standards for Students (continued)*<br>– 5c: Students break problems into component parts, extract key information, and develop descriptive models to understand complex systems or facilitate problem-solving.<br>• Global Collaborator: Students use digital tools to broaden their perspectives and enrich their learning by collaborating with others and working effectively in teams locally and globally.<br>– 7c: Students contribute constructively to project teams, assuming various roles and responsibilities to work effectively toward a common goal. |

| Mathematics (CCSS) | |
|---|---|
| *Content Standards by Domain*<br>• CCSS.MATH.CONTENT.6.NS.B.3: Fluently add, subtract, multiply, and divide multi-digit decimals using the standard algorithm for each operation.<br>• CCSS.MATH.CONTENT.6.SP.B.5: Summarize numerical data sets in relation to their context, such as by:<br>– CCSS.MATH.CONTENT.6.SP.B.5.A: Reporting the number of observations.<br>– CCSS.MATH.CONTENT.6.SP.B.5.B: Describing the nature of the attribute under investigation, including how it was measured and its units of measurement. | *Mathematical Practices:*<br>• CCSS.MATH.PRACTICE.MP1: Make sense of problems and persevere in solving them.<br>• CCSS.MATH.CONTENT.MP3: Construct viable arguments and critique the reasoning of others.<br>• CCSS.MATH.PRACTICE.MP5: Use appropriate tools strategically.<br>• CCSS.MATH.PRACTICE.MP6: Attend to precision. |

## Preparation Time

### 15 minutes

- Read the Introduction and Background, Educator Notes, and Student Handout to become familiar with the activity.
- Gather and prepare all supplies listed on the materials list.
- If using a glue gun, even with cool-melt glue, set up a glue gun station for safety and supervision.
- Print copies of the Student Handout for each team.
- If presenting videos or web-based resources, test the links and the classroom technology ahead of time.
- Determine the internal volume constraint for the space module in advance of the lesson. Any lightweight cylinder, ranging in size from a toilet paper tube to a 12-oz aluminum can, will work.

## Materials

- ☐ Toilet paper tubes, aluminum cans, or similar lightweight cylinders (1 per team for use as a volume constraint)
- ☐ 30 pieces of uncooked spaghetti for each team
- ☐ Clear tape or low-temperature glue gun with cool-melt glue (Note: teams will have limited quantities per challenge constraints)
- ☐ Index cards
- ☐ Mass (lead weights, coins, large washers, or similar)
- ☐ Scissors
- ☐ Metric scale
- ☐ Rulers
- ☐ Paper and pencils for brainstorming
- ☐ Copies of Student Handout and blank paper

## Introduce the Challenge

- Provide context for this activity using the Introduction and Background information in this guide. Discuss the different types of modules in a space habitat.
- Engage students with the following discussion questions:
  - Why is a space habitat made up of individual modules?
  - Why is it important for modules to be hollow with as much open space inside as possible?
  - If a space habitat orbits in a microgravity environment, why does it need to be lightweight?
  - What are some safety concerns or consequences of a module that is not structurally strong?
  - What types of forces do modules experience on Earth, during launch, during assembly, and while in use?
- Explain the role of engineers in designing technology to solve problems. Share the NASA for Kids video Intro to Engineering and introduce the engineering design process.
- Divide the class into teams of three to five students and pass out the Student Handout to each team. Use the handout to explain the details of the challenge, including the design constraints and your expectations for teamwork and classroom management.

### Share With Students

### Brain Booster

NASA is looking at options for astronauts to shuttle between the Gateway and the Moon on reusable landers. Just as planes use an airport here, spacecraft bound for the lunar surface or for Mars can use the Gateway to refuel, replace parts, and resupply things like food and oxygen without going home first.

Learn more: https://appel.nasa.gov/2019/06/06/nasa-selects-partners-for-lunar-lander-development/

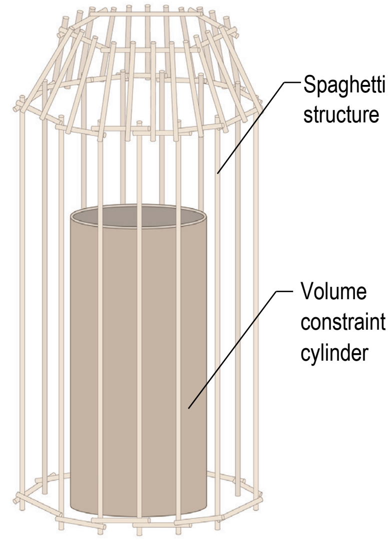
### On Location

The Marshall Space Flight Center in Huntsville, Alabama, will manage NASA's plans to build a lunar landing system that will carry the next man and the first woman to the surface of the Moon by 2024. Check out Touchdown, an engineering design challenge for students to investigate gravity, motion, and forces to design and build a shock-absorbing system for a lunar lander.

Touchdown Activity: https://www.nasa.gov/stem-ed-resources/otm-touchdown.html

**Design Constraints**

1. The volume constraint cylinder must fit completely and securely within the spaghetti structure each team builds. It cannot be attached to the structure with tape or any other means; it must remain loose within the structure without falling out.
2. Teams are only allowed to use the supplies provided. If they make a mistake or change their design, they **cannot** trade in used tape, glue sticks, or broken spaghetti pieces for more, nor can they trade materials with another team. Instead, they must recycle used materials into their design.
3. The module frame will be tested standing upright on its end (oriented like a soda can), and there should be a gap between the top of the volume constraint cylinder and the spaghetti structure.




## Facilitate the Challenge

**Ask, Imagine, and Plan**

- Answer any questions teams have about the challenge or design constraints.
- Consider requiring teams to submit their design for review before allowing them to collect building materials.

**Create**

- In the first phase of the challenge, teams may only use 25 pieces of uncooked spaghetti and 50 cm of tape or one small glue stick to design and build the skeletal structure or framework of a space habitat module.
- In order for the interior of their module to remain open for "usable" space, the framework must be built around the cylindrical volume size constraint. The cylinder (toilet paper tube or aluminum can) must be loose within the framework and not attached in any way.

**Test and Improve**

1. Each team will test the strength of their design by placing it upright on its end (oriented like a soda can) and gradually adding weights until the structure "fails." The structure has "failed" when it meets any of the following three criteria:
   - Any piece of spaghetti has broken/snapped.
   - Any end of a piece of spaghetti has become detached from the tape or glue.
   - Any piece of spaghetti has bent to the point that it touches the top of the volume constraint cylinder.
2. After the first weight failure test, students will measure and record the mass that was necessary to cause their module structure to fail. In the second phase of the challenge, teams will receive five additional pieces of spaghetti and an additional 10 cm of tape (no additional glue) to repair and improve their design.
3. After their improved design is complete, students will again test their module structures to failure. Their goal is to increase the mass that their structure can support by 50 percent.

**Share**

Allow teams time to share their designs with the class. Engage students with the following discussion questions:

- What was the greatest challenge for your team today? How did you address this challenge?
- Which was most difficult: Keeping the spaghetti from bending, breaking, or becoming detached?
- What was the purpose of the design constraints? Why were you limited in how much the spaghetti could bend?
- Would this challenge be more difficult with a larger or smaller cylinder used as a size constraint? Why?

Northrop Grumman Innovation Systems has proposed a Gateway module design based on its Cygnus cargo spacecraft, pictured here. (NASA)

### Extensions

- Add a cost constraint to the challenge and create a budget for your students to "purchase" materials. Assign cost to each piece of spaghetti and centimeter of tape. Challenge students to create the most efficient design (smallest ratio of cost to mass supported).
- Repeat the challenge using different materials for the structure.

### References

Modified from the following activities:
Spaghetti Anyone? Building With Pasta. https://www.jpl.nasa.gov/edu/teach/activity/spaghetti-anyone/
NASA Engineering Design Challenges: Spacecraft Structures. https://www.nasa.gov/pdf/361814main_EP_2009_06_115_MSFC.pdf

### Additional Resource

- Digital Badging: Online NASA STEM Learning. https://www.txstate-epdc.net/digital-badging/

# Activity One: Assess the Structural Integrity of a Space Module

## Student Handout

### Your Challenge

Design and build the skeletal structure or framework for a spaghetti space module that can support as much weight as possible.

### Design Constraints

1. The volume constraint cylinder provided by your teacher must fit completely and securely inside the spaghetti structure you build. It cannot be attached to the spaghetti structure with tape or any other means. It must stay loose inside your structure, and it cannot fall out.
2. You are only allowed to use the supplies provided by your teacher. If you make a mistake or change your design, you **cannot** trade in used tape, glue sticks, or broken spaghetti pieces for more, and you **cannot** trade materials with another team. Instead, you must recycle used materials into your design.
3. Your module frame will be tested standing upright on its end (oriented like a soda can). When you place the module on its end, there should be a gap between the top of the volume constraint cylinder and your spaghetti structure.

### Ask, Imagine, and Plan

- Discuss different design and assembly methods for your module.
- What are the strengths and weaknesses of the materials provided in the challenge?
- How can you best use the limited number of supplies?
- What are some design elements that you can include in your design to maximize strength?
- Sketch your module design on the paper provided by your teacher. Remember to include the volume constraint cylinder.

### Create

Your team will build a skeletal structure or framework for a space module using only the materials provided. It must be constructed around the provided volume constraint cylinder, which represents the interior "usable" space of the module.

### Test and Improve

1. After building your module, you will test its strength using a weight failure test. Write down any observations about how your structure performs during the test.
2. **Weight failure test:** Place your module upright on one end (oriented like a soda can) and place a single index card on top. Slowly add mass on top of the card until your structure fails in one of the following ways:
   - Any piece of spaghetti has broken/snapped
   - Any piece of spaghetti has become detached from the tape or glue
   - Any piece of spaghetti has bent to the point that it touches the top of the volume constraint cylinder
3. After your structure has reached its failure point, measure the mass you added and record the mass in grams on your brainstorming paper.

### Fun Fact

Practice makes perfect! The Gateway will be a home base for astronaut expeditions on the Moon and future human missions to Mars. Even before the first trip to Mars, astronauts will use the Gateway to train for life far away from Earth.

Learn more: https://www.youtube.com/watch?v=YOG3tAkPpPE

### Career Corner

Geology is the study of rocks, and geologists are the people who study them. There are different types of geologists. Planetary geologists at NASA study planets and their moons, asteroids, comets, and meteorites. NASA wants to use the Gateway as a science platform to look back at the Earth, observe the Sun, and get unobstructed views of the vast universe. By studying the geology of the Earth, the Moon, and Mars, we can learn important things about how planets and planetary systems form!

Learn more: https://solarsystem.nasa.gov/people/500/phil-christensen/

4. Now it is time to repair and improve your design. The goal for your redesign is to hold 50 percent more mass than your previous weight failure test. Calculate your goal by multiplying the mass from the first test by 1.5 and record on your paper.
5. You must reuse the existing structure, but you will receive five additional pieces of spaghetti and another 10 cm of tape (no additional glue). Recall what caused your design to eventually fail. Discuss what improvements you can make based on your experience and your new materials.
6. Sketch your module redesign on your paper. Be sure to indicate where you made design improvements and why.
7. Make the indicated changes to your existing structure.
8. Repeat the weight failure test with your redesigned module structure, slowly adding mass until it fails. On your paper, record the mass in grams for the second weight failure test.

### Share

- What improvements did you make to the structure of your module based on your first test?
- Did you meet your goal of supporting 50 percent more weight in the second test? Describe the results.
- As you compare the various team designs, what characteristics did the most successful structures have in common?
- If you could repeat the experiment, what changes would you make to your structure?