ARE YOU DRESSED FOR A SPACEWALK?

Harnessing Student Interest in Space Exploration to Engage Them in Energy and Engineering

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CONTENT AREA

Physical science

GRADE LEVEL

6–8

BIG IDEA/UNIT

Thermal energy moves from high to low at a rate dependent on the property of the material in between.

ESSENTIAL PRE-EXISTING KNOWLEDGE

Heat, temperature

TIME REQUIRED

Four days

COST

< $100

FIGURE 1: Materials

- model astronauts made from a 1 oz. cup filled with water, with plastic wrap rubber-banded over the top to keep the water in (per group)
- two or three infrared temperature guns
- cotton or felt
- bubble wrap
- white paper
- aluminum foil
- scissors
- masking tape

Other materials, such as blank paper and plastic wrap, can also be included; four or five different space suit materials are optimal, as this provides enough options for students to choose from without becoming overwhelmed with choices. The masking tape is used to "stitch" the suit onto the astronaut.

Cups were used to represent astronauts

Covering the cups with plastic wrap

Drawing connections between what excites students and what they do in the classroom can inspire them to pursue those interests later in life. Teachers and researchers have long posited that space exploration is inspirational to students (Bennett 2015). Taking advantage of this interest is a great way to show students that many academic fields are integral to space travel, thus raising their awareness of lesser-known science, technology, engineering, and math (STEM) careers. In the engineering activity described in this article, students are challenged to design a space suit.

A space suit is a complex system that maintains temperature, air pressure, and safe levels of carbon dioxide and oxygen, among other things, for the astronaut who wears it. All parts must work together for the astronaut to be safe, but each subsystem is separately designed. The activity described in this article focuses on maintaining a safe temperature, because an astronaut in an otherwise fully functioning space suit would warm or cool to unsafe levels in a matter of minutes while in space. If an astronaut is working outside of a spacecraft while orbiting Earth, temperatures can range from 250°F (if in direct sunlight) to -250°F (when working in the shade of our planet). The extreme heat is the result of the astronaut being exposed to seven times the amount of radiation experienced on Earth (Kiehl and Trenberth 1997). Conversely, the extreme cold is due to the lack of atoms and molecules in the vacuum of space, and molecular movement is related to temperature.

Getting started

The space suit engineering activity begins with providing students with the Student Worksheet (see Online Supplemental Materials) and describing the challenge to them. Students are challenged to maintain successfully the body temperature of an astronaut in space. The student worksheet outlines the motivation behind the project and highlights the criteria: the spacesuit must allow the astronaut to survive for 10 minutes in a testing area with minimal temperature change, and it must be economical. These two criteria force students to make a tradeoff between better temperature control and price. Many student engineering projects specify an amount of money that students can spend on materials. We do not provide price ceiling to reflect an authentic example of an engineering project. Students are constrained in the time allocated to designing and work-

FIGURE 2: Testing area setup

The cold environment can be a freezer or a cooler filled with ice. With the chest cooler, loading and unloading must be scheduled, otherwise the temperature increases and testing is not effective. The hot environment is a hot box assembled using an aluminum container and heated with heat lamps or incandescent light bulbs. Materials for constructing it are shown below.

FIGURE 3: Suiting up the model astronaut

Materials testing using a control, or "naked astronaut," and one suited in white paper, followed by measuring the temperature using an infrared temperature gun.

ing on their space suits and the materials they are allowed to use. Students are given these constraints and can be challenged to list others as they occur. Addressing these aspects not only helps students see the big picture, but also engages them in using the terms criteria, constraints, and tradeoffs—vocabulary that they then use more often as they recognize the words as important engineering concepts. In preparation for this project, the teacher should collect materials and set up the testing area for students' designs (Figures 1 and 2). Because astronauts experience such different extremes, testing must take place under two different conditions, hot and cold, as shown and described in Figure 2.

Once students understand the activity's "big picture," they can form design teams of three or four. Groups can develop team names to enhance camaraderie. Next, discuss the idea of using models in engineering. NASA, for example, would not send an astronaut into space with a prototype space suit that had never been tested. Not only is it safer to use a model than a human for testing, it is also much less expensive to test the suit in an Earth-based testing area than to actually send it up to the International Space Station. Therefore, because human beings are mostly water, classroom testing uses a one-ounce container filled with water as a model astronaut (Figure 1). We also experimented with eight-ounce water bottles. These small water bottles work well and are leak-proof, but because of the larger volume (compared to the one-ounce cups), the amount of time needed in the testing areas at least doubles. The test areas, the hot box and freezer, simulate the cold and hot environments a living astronaut must survive.

Collecting data and prototyping

Safety note: Students should wear goggles when conducting all activities. Care should be taken near the heat source to prevent burns. Students should be warned not to point the temperature gun at anything other than the model astronaut.

In engineering, design choices must be data driven. Therefore, in the first phase of the activity, students test their model astronauts wrapped in exactly one layer of each of the materials that they can use for prototyping the space suits. This can be done by having each group test one material and then combining the data from all groups. Groups should have enough of one material to create one layer for the model astronaut. Each layer is tested under both testing conditions, hot and cold. An astronaut should be outfitted in one layer of material using minimal tape. These astronauts are placed in the testing area along with one control, or “naked astronaut,” as shown in Figure 3. Students record an initial temperature and, after 10 minutes, the final temperature. It is best to perform more than one trial for each material and, if the activity is implemented in more than one classroom, multiple trials can be combined. Once the data are collected, the class should discuss the results while the instructor formatively assesses students’ mathematical and computational thinking skills. Assessment of student conceptions of accuracy and precision are particularly important because some students may regard two temperatures, such as 24.1°C (75.4°F) and 24.2°C (75.6°F), as being very different temperature readings.

During materials testing, students also learn that thermal energy leaks from areas that are left exposed. They can improve their test data reliability by ensuring that there are no thermal energy leaks. When comparing different materials, be mindful that, although some materials should, according to science, perform better than others, they may not perform that way in this activity. For example, felt should perform better than cotton because, although the base material is the same, the felt contains trapped air that acts as an insulator. At this point, it is helpful to discuss with the class how radiation can be reflected, absorbed, or transmitted through different materials and how that would affect the material’s ability to transfer heat. This is important because space is a radiation-dominated environment. Aluminum foil should perform well in a radiation-dominated environment because it is good at reflecting energy and not absorbing and transmitting radiation; however, conduction is different from radiation and can produce different results. Plastic wrap and bubble wrap will not perform well because they transmit energy. However, bubble wrap can be inferred to be a good insulator for conductive energy transfer, as long as the surface is covered with another material, because it is a layer of air. The testing data students assemble may not reflect the expected outcomes. If the results seem convincing and free of any gross errors, then

FIGURE 4: Engineer’s notebook template

Which materials will you use in this design? Why did your group select these materials?

Materials	**Size (cm^2)**	**Cost**		
		$		
		$		
		$		
		Results		
		Beginning temperature	End temperature	Change in temperature
Control astronaut	Hot			
	Cold			
Trial #1	Hot			
	Cold			

What were the results of your testing? Any surprises? What will you choose for the next design?

FIGURE 5: A student-designed prototype using an eight-ounce water bottle

Note: Earlier iterations of this activity made use of eight-ounce water bottles, but at least 20 minutes are required in the hot or cold box to see a significant temperature change.

students should base their material selections for their first prototype space suit on the data they have and not what they think should work better. Otherwise, if there is a concern, students should retest.

Common constraints in real-world engineering projects are time and money. The teacher can use the materials testing data to set the prices of the materials. Those that performed well should be more expensive; ones that did not perform well should be more economical. This encourages greater creativity in student designs. Alternatively, real-world information can be used to set prices for the materials. However, because aluminum foil is inexpensive and performs well during testing, this approach leads to

FIGURE 6: Formative and summative student questions

Formative questions to ask students during the unit:

- What is the system in this activity?
- How can we track energy flow in this activity?
- Why is energy flowing through our system? When would energy stop flowing? In which direction is heat flowing in our system? What is your reasoning?
- What types of heat transfer are occurring in our system?
- What are your criteria and constraints? What are some possible solutions? How do your solutions deal with these criteria and constraints? Which possible solutions will meet the criteria and constraints best? What evidence supports your argument for your design solution?

Summative questions to ask students at the end of the unit:

- What were the criteria for this activity?
- What were the constraints in this activity?
- What factors were you optimizing?
- Give one example of a trade-off you made.
- Which design would you choose to prototype? Explain your reasoning and provide evidence.

designs using, primarily or exclusively, aluminum foil. To mimic reality, teams must calculate the cost of the materials used in the R&D (research and development) phase separately from materials used in the final prototype. Thus, instead of "setting up a store" for students to purchase materials, have enough on hand for teams to design freely while they keep track of the amount of materials they use and then calculate R&D costs (Figure 4). This allows for the incorporation of math skills, as students must determine the square centimeters of each material and the length of tape used to calculate a materials cost. The final prototype cost must therefore include an R&D and a production cost.

Teams decide on materials to use and the number of layers needed for the prototype. Most teams prefer two layers; encouraging them to consider more than two might be helpful. Additionally, teams can be encouraged to recognize the value of air as an insulator and incorporate a layer of air into their design. Teams should value intentional, data-driven design and reflection as well as documentation (Figure 4). Groups choose their most successful prototype and create a presentation that outlines their strategy in addressing the requirements outlined at the beginning of the activity (Figure 5). More specifically, they should share the data and reasoning that drove their prototyping.

There are no cost limits. Students can use as much material they want; however, they should know that cost will be evaluated. Assessing the project can be done using a rubric that measures how well the space suit keeps the astronaut's temperature stable, the cost of the space suit, teamwork, and the documentation and reasoning (see Online Supplemental Materials). Documentation should be valued because in this activity, as in the real world, documentation provides convincing evidence in support of their design.

Underneath the space suit

This challenge provides an opportunity to address energy concepts and engineering practices. The disciplinary content is mainly focused on differentiating among heat, temperature, and thermal energy, which represents a common challenge in student understanding. Common misconceptions to be aware of include:

- regarding heat or thermal energy as a kind of substance,
- understandings of thermal equilibrium, and
- a confusion between the temperature and the "feel" of an object (Carlton 2000; Taber 2000).

Using terminology correctly, reinforcing correct usage, and asking explicit questions of students will integrate the content into the activity. Example formative and summative questions to facilitate explicit discussions in science and engineering content are found in Figure 6. Note that less emphasis is put on the engineering design cycle and more is put on concepts such as criteria, constraints, optimization, and trade-offs, because in my experience, these are important indicators that students understand the engineering design process.

Be sure to recognize that heat transfer is a complex event. In this activity, and commonly, all three

Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

- The chart below makes one set of connections between the instruction outlined in this article and the *NGSS*. Other valid connections are likely; however, space restrictions prevent us from listing all possibilities.
- The materials, lessons, and activities outlined in the article are just one step toward reaching the performance expectations listed below.

Standards

MS-PS3-3: Energy
www.nextgenscience.org/pe/ms-ps3-3-energy

Performance Expectations

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.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Analyzing and Interpreting Data Designing Solutions Engaging in Argument from Evidence	Students analyze test data from different materials and a control, which are exposed to 20 minutes in the hot box and 20 minutes in the freezer, to decide which materials work best. Students also compare the costs of the materials. Students develop and test different space suit designs using provided materials to optimize heat transfer and cost. Students share their optimized solution and provide evidence to support their selection.
Disciplinary Core Ideas	
PS3.B: Conservation of Energy and Energy Transfer • Energy is spontaneously transferred out of hotter regions or objects and into colder ones. ETS1.B: Developing Possible Solutions • A solution needs to be tested, and then modified on the basis of the test results in order to improve it. There are systematic processes for evaluating solutions with respect to how well they meet criteria and constraints of a problem.	Students explore heat transfer, as measured by temperature, by insulating the model astronaut. Students develop and test different space suit designs using provided materials to optimize heat transfer and cost. Students answer questions related to the flow of energy as it moves through the astronaut model.
Crosscutting Concept	
Systems and System Models	Students use a model astronaut as a system and track the input and output of thermal energy from that system via measurements of temperature.

forms of heat transfer (convection, conduction, and radiation) simultaneously take place. However, energy transfer in space, in the absence of atoms and molecules, is dominated by radiation; conduction and convection play no role. Thus, the vacuum of outer space represents a thermally insulating layer, much in the same way that a vacuum thermos resists conduction and convection and keeps liquids hot or cold. This gives rise to the statement that "nothing makes the best insulator," which is a challenging idea for students and adults alike and represents a testing challenge and limitation to this activity, of which it is important to be aware.

A look at the trajectory

This activity can be limited to about four 40-minute periods, with the first day dedicated to introducing students to the project and starting the materials testing. Days 2 and 3 can be dedicated to finishing materials testing and prototyping. The last day can be dedicated to presentations and a final wrap-up. That said, the teacher should be comfortable with the possibility that more time may be required and that this is time well spent. For example, if students have serious concerns about the testing area, how the temperature is measured, or how the materials data turned out, these can be great opportunities to harness their concerns and engage them in science practices.

This activity was developed and piloted in the classroom for a unit on heat and has been used for a middle school professional development session to model energy and engineering. It can also be used as either a summative or formative assessment. Used formatively, it can allow the teacher an opportunity to determine how much students already know about the topic and become a common activity around which they can discuss new concepts and ideas. ●

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ONLINE MATERIALS

Student worksheet, class data table, engineering notebook template, and assessment rubric—*www.nsta.org/scope1703*

RESOURCES

The Deep-Space Suit—*http://bit.ly/2g73SQV*

Ice melting blocks thermal activity—*http://bit.ly/2h4brHt*

Misconceptions about temperature—*www.youtube.com/watch?v=vqDbMEdLiCs*

NASA's assessment of damage to space suit textiles—*http://go.nasa.gov/2gA7s1X*

NASA's prototype space suit—*http://go.nasa.gov/2heIB7F*

Staying cool on the ISS—*http://go.nasa.gov/2ghJ4Va*

Teach Engineering—*www.teachengineering.com*

Upcoming spacewalks to prepare space station for commercial crew arrivals—*http://go.nasa.gov/2g7W5x7*

What is a spacewalk?—*http://go.nasa.gov/2heDFjh*

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