4-ESS3-2

Building a Spaghetti Structure

An upper elementary STEM challenge brings an engineer into the classroom while emphasizing cooperation, communication, and creativity.

By Douglas Llewellyn, Sandra Pray, Rob DeRose, and William Ottman

Science, technology, engineering, and math (STEM) activities come in various shapes and sizes. Some are quite involved and require students to possess some degree of prior knowledge and skills, while others are relatively simple and can be accomplished with minimal prior knowledge and skills. In this article, we provide an inexpensive, multiday STEM task that brings a local engineer into the classroom. This spaghetti structure challenge is multidisciplinary, integrating STEM disciplines with reading and writing literacy.

The spaghetti structure challenge engages students in problem-solving strategies and structural design processes in science and engineering. According to Llewellyn (2014), "Problem solving enables students to assume ownership and responsibility of the task. Problem solving is a form of both active learning and discovery learning—a combination of hands-on and minds-on education" (p. 173). In this example, we chose to describe the task to students as a challenge rather than a competition to emphasize the 3 "Cs"— cooperation, communication, and creativity. However, the decision to introduce the task as a challenge or a competition rests with the classroom teacher and whether his or her students are motivated by in-classroom peer competitions.


PHOTOS COURTESY OF THE AUTHORS

Students building their structure.

The spaghetti structure challenge is based on the TED video *The Marshmallow Challenge* (see Internet Resources). The TED video focuses solely on the construction of the structure and the nature of group collaboration, with no follow-up. We, however, also invited a mechanical engineer into the classroom to give a lesson on structural design and show students why the triangle is so effective in building bridges and towers. In the activity, students learn about how effective structures are built with triangular support and then redesign and retest their original structures, applying the information from the engineer's presentation to increase the sturdiness of the structures. In revising our STEM task from the original TED Marshmallow Challenge, the redesigned experience now aligns to the *Next Genera-*

tion Science Standards (NGSS Lead States, 2013).

The Setting

This task was given to students at the State Road Elementary School, in Webster, New York. The class has 23 mixed-ability students that loop for grades four and five. Classroom co-teachers include Mrs. Sandra Pray and Mr. Rob DeRose. Because the materials for this task are inexpensive, the teachers randomly assign students in teams of two so each team member has an equal opportunity to participate in the task. The teachers know that as the number of students per team gets larger, several negative aspects often arise. With teams of four or more, especially when students are mixed by gender, boys often assert greater access to the materials and take over as the "builder" of the structure. Teachers also anticipate more "off task" behavior and conversations with larger groups. In addition, when placed in larger groups, students with limited language skills seem to hold back on contributing ideas to the solution. Therefore, with the entire supply cost for the activity being less than three dollars, the teachers wisely keep group sizes small.

Day 1: Challenge Accepted

On Day 1, students are introduced to the STEM challenge. Because this is the first STEM experience for most students, the teachers begin by explaining what STEM stands for and that this challenge emphasizes the 3Cs. After assigning students in teams of two, students receive 1 m of masking tape, 1 m of string, 20 pieces of uncooked spaghetti, and one large marshmallow. Their challenge is to build a freestanding structure that will hold a marshmallow at the greatest height and withstand the force of a simulated "earthquake" (i.e., the teacher shaking the table on which the structure sits). Students have 25 minutes to complete the task. After that, teachers measure the individual structures, record the teams' height of the marshmallow, and test for sturdiness by shaking the table under each structure (doing his or her best to keep this variable as equal as possible). The height of each structure is recorded and whether it survives the simulated "earthquake."

Students should wear eye protection, and the teacher should exercise caution when shaking the table. CAUTION

At the conclusion of Day 1, students are provided quiet time to enter in their science journals a task reflection, including their thoughts about how well the team applied the three Cs. Excerpts of the students' reflections are posted on the classroom blog (see Internet Resources). On Day 1 of this problem-solving situation, students readily admitted that their present understanding of structural design was not enough to yield satisfactory results. The teachers use this information to formatively assess the students' initial progress and to modify the instruction for the upcoming days.

Day 2: Introducing Engineering

On Day 2, Mr. Trevor DiMarco, our guest engineer from a local engineering firm presents a 45-minute lesson on structural design and explains why the triangle is so effective in constructing towers, buildings, and bridges. The lesson includes a PowerPoint presentation featuring images of local bridges and buildings with triangular support and engaging pictures of a Ferris wheel and the pirate ship ride at local a theme park. Additional slides show scaffolding next to a building under construction as well as the Eiffel Tower. Mr. DiMarco then asks students what can be learned about structure design

FIGURE 1a.

Paper square and triangle pieces.

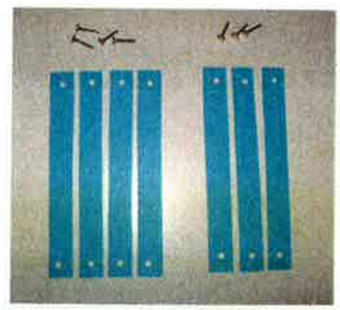


FIGURE 1b.

Paper square and triangle assembled.

from looking at these well-known examples.

To support the lesson and to provide a hands-on aspect, students are given four paper strips and four fasteners to construct a square (see Figure 1a, p. 71). Students are directed to "wiggle" the squares and describe their flexibility. Next, each student is given three more paper strips and three more paper fasteners to make a triangle. Having both square and triangle frames, students compare and contrast their differences in flexibility (see Figure 1b, p. 71). To show the relative strengths of the square versus the triangle, Mr. DiMarco asks, "What happens when you press on top of the square?" and follows up with another question, "What happens when you press on top of the triangle?" Students respond that the triangle retains its shape.

FIGURE 2.

Student holding paper square with cross member.

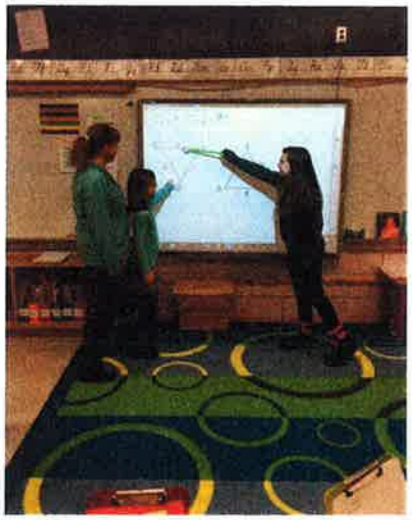
Mr. DiMarco introduces the term *cross member*, another strip of paper that can be added as a diagonal to the square. Each student is now given a cross member to attach to the square (see Figure 2) and asked to once again press the top of the square. Mr. DiMarco then poses the question, "How does the cross member improve the strength of the square?" Students quickly say that the cross member adds strength to the square and reduces its flexibility. One student observes that the square with the added cross member is now made up of two triangles. Another student shares that her father was putting together a metal shelf over the weekend and the shelf had cross members to keep it from wiggling back and forth. A third student adds that she saw something similar to cross members on a shelf when she was with her father shopping over the past weekend in a home supply superstore.

At the end of Mr. DiMarco's presentation, Mr. DeRose summarizes the lesson by asking students, "How can you use today's presentation to redesign your spaghetti structure on Friday?" Students provide verbal responses and write a reflection in their individual science journals for homework. The comments posted on the blog indicate that students are changing their conceptual understandings of strength and design. According to the National Research Council (2008, p. 42), "The easiest kind of conceptual change involves elaborating on an already existing conceptual structure." In this case, students had preexisting yet limited understandings about how to build a tower structure. Adding the triangle to their design is an easy accommodation and assesses students' growth in meeting the performance expectations.

Day 3: Research and Geometry

Day 3 is devoted to reading and researching resources from PBS to redesign the spaghetti structures (see Internet Resources). Students redesign their initial structure based on information from Mr. DiMarco's presentation, coupled with the new information they are about to find in the school library and online. The teachers have library books and online resources available in the classroom for students to research in planning their new designs. The teachers encourage students to draw pictorial models of their revised designs for Day 4. Several groups discuss possible advantages or disadvantages of breaking pieces into halves or thirds with the hopes of increasing structure height, allowing for more squares to build vertically but supported with the strength of triangle cross members or corner supports. They debate the merits of decreasing the width of the structure to gain height.

Later in the day during math class, Mrs. Pray gives students a geometry lesson describing various types of triangles—equilateral, scalene, obtuse, isosceles, and right triangles. She labels the three sides and three angles of the triangle and asks, "As side A increases, what happens to angle A?" She gives them time to talk it over privately with a partner before sharing their responses to the entire class. Providing an opportunity for argumentation and posi-



Teacher and students view a triangle with labelled sides.

tion-driven discussions, Mrs. Pray tells the students to make a prediction, claim and support the prediction, and justify the prediction and claim with evidence and reasoning. "In position-driven discussions, everyone is focused on the same phenomenon but is required to commit to one position or another and to argue for their respective predictions or theories" (NRC 2008, p. 94).

Day 4: Redesign

Day 4 arrives with much anticipation. Given the same supplies (see Day 1) student teams now use their revised designs to build their new structures. Like on Day 1, after 25 minutes, Mr. DeRose measures the individual structures and records their heights on a spreadsheet displayed on the interactive whiteboard, while Mrs. Pray again tests the sturdiness of the revised models by shaking the table under each structure. After measuring all the towers, the teachers lead a whole-class discussion on the results from Day 1 and Day 4, including the fact that more of the revised structures survived the simulated "earthquake" (see Table 1). A 0 indicates the structure fell over at the end of the time limit. There is no way to avoid this—it just happens in some cases.

At the conclusion of the challenge, students compare their previously held and newly formed skills in problem-solving, team building, and structural design. In analyzing their results, students conclude that the height between Day 1 and Day 4 was not that significant. Several students suggest that adding cross members to their structures required more construction time and their structures were not as high as they had expected. After comparing earthquake survival rates, however, students rightly concluded that the Day 4 structures were much more likely to survive this natural disaster. The teachers and students now collaboratively summarize the work of engineers in testing models and make revisions based on the new information, as well as the need to develop positive dispositions in the 3Cs.

At the close of Day 4, students conclude that during the spaghetti structure challenge, they took on engineering roles to:

- communicate possible solutions based on prior knowledge,
- collaborate with team partner to generate solutions,
- brainstorm and generate

TABLE 1.

Team data.

Team	Day 1 Height in cm	Day 1 Survive earthquake?	Day 4 Height in cm	Day 4 Survive earthquake?
1	50	No	24	Yes
2	0	No	14	Yes
3	0	No	20	Yes
4	7	Yes	20	Yes
5	0	No	25	Yes
6	17	Yes	59	Yes
7	43	No	0	No
8	53	No	20	Yes
9	39	No	9	Yes
10	39	No	26	Yes
11	22	Yes	55	Yes
Average	24.5		24.7	

- reasonable alternatives to the challenge,
- acknowledge teammates' ideas and possible solutions, and
- assess a structural model based on predetermined criteria.

Similarly, the classroom teachers summarize their roles to:

- provide a task to promote problem solving,
- act as facilitators and pose questions and prompts to foster students' critical thinking, and
- encourage students to test their solutions to STEM problems.

Conclusion

The overall focus of the spaghetti structure challenge is to create meaningful problems for students to explore. According to the NRC (2008, pp. 127–128), "If a problem fails to connect to legitimate and fundamental scientific ideas, it cannot promote science learning. And if students fail to see the problem as meaningful, there is little chance that they will engage in the range of productive science practices that result in science learning." In the case of the spaghetti structure, we found the challenge to be relevant and engaging to the students who demonstrate enthusiasm in completing the task and assuming the role of an engineer. ■

Douglas Llewellyn* (dllewellyn@sjfc.edu) *is a part-time faculty member at St. John Fisher College in Rochester, New York. Sandra Pray and Rob DeRose are grade 4/5 looping teachers at State Road Elementary School. William Ottman is the director of science and technology at the Webster School District in Webster, New York.

A teacher measures one of the structures.

Acknowledgment

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References

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Internet Resources

Build a Tower TED Talk
www.ted.com/talks/tom_wujec_build_a_tower

Building Strong Shapes With Triangles
www.rogersconnection.com/triangles

Building With Pasta
www.nasa.gov/pdf/544872main_E3_SpaghettiAnyone_C1.pdf

Designing a Newspaper Chair (PBS) *www.pbslearningmedia.org/resource/phy03.sci.phys.mfw.znewschair/triangles-designing-a-newspaper-chair*

Mr. DeRose and Mrs. Pray's Class Blog *http://mrderoseandmrspray.edublogs.org/?s=marshmallow*

Spaghetti Tower Instructions *www.kats.org/wp-content/uploads/2014/07/Spag_towers_instructions.pdf*

Triangles and Arches in Architecture (PBS) *www.pbslearningmedia.org/resource/phy03.sci.phys.mfe.triarch/triangles-and-arches-in-architecture*

Triangles and Trusses *www.teachengineering.org/view_lesson.php?url=collection/cub_/lessons/cub_trusses/cub_trusses_lesson01.xml*

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

4-ESS3 Earth and Human Activity *nextgenscience.org/dci-arrangement/4-ess3-earth-and-human-activity* 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.	
Performance Expectation	**Connections to Classroom Activity** *Students:*
4-ESS3-2. Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans.	• design, on paper, a model to build a spaghetti structure. • use the materials to construct a structure based upon their design.
Science and Engineering Practices	
Obtaining, Evaluating, and Communicating Information Constructing Explanations and Designing Solutions	• use the information gained through a presentation to redesign their structure and to compare and contrast structures pre- and post-presentation.
Disciplinary Core Ideas	
ETS1.B: Designing Solutions to Engineering Problems • Testing a solution involves investigating how well it performs under a range of likely conditions. ESS3.B: Natural hazards • A variety of hazards result from natural processes (e.g., earthquakes, tsunamis, volcanic eruptions). Humans cannot eliminate the hazards but can take steps to reduce their impacts.	• describe how their original structure compares to the redesigned model. • use data collected during the challenge to conclude whether their redesigned model withstood a simulated earthquake better than the original model. • explain how natural disasters (like earthquakes) affect the way engineers design bridges, building, and towers.
Crosscutting Concept	
Cause and Effect	• cause a change in strength of a model through manipulating the structure.