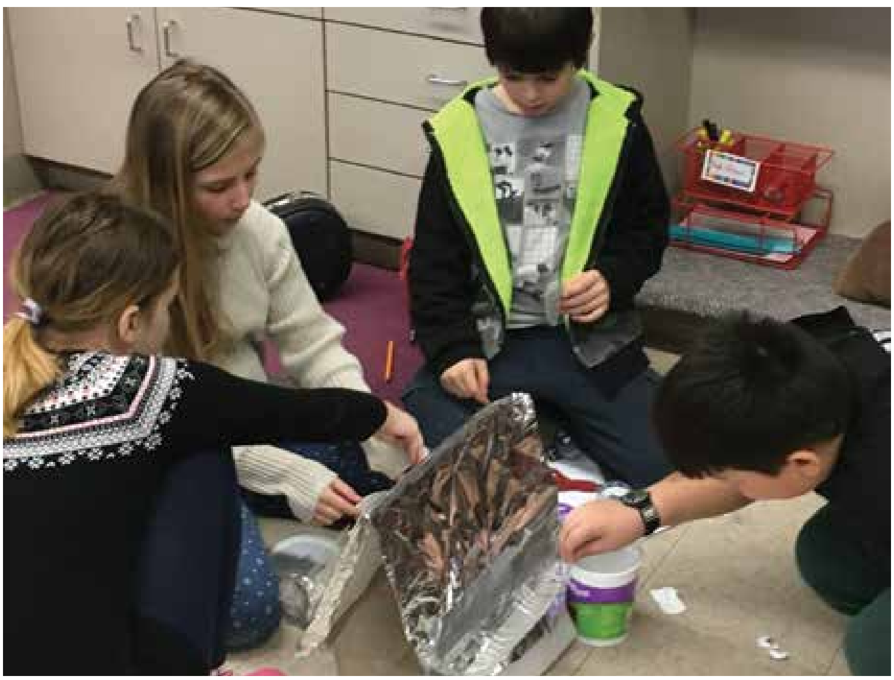
How Can We Store Water During a Drought?

A sustainability engineering design problem for fourth graders

By Edward Watt and Gillian Andrews

Last summer our area, which has a strong agricultural economy, experienced a severe drought. We chose to explore this issue in-depth with our students, who understood firsthand the importance of water as a resource and of conserving water in their communities. Our unit arose from the significant focus in the *Next Generation Science Standards* (*NGSS*) for fourth grade on forms and transfer of energy (see Connecting to the *NGSS*, p. 72). We taught our unit in a rural fourth-grade classroom in partnership with a local environmental learning center. The learning center provided us with a real-world example of a building that was designed as a teaching tool to model sustainable approaches to resource production and use. This net-zero energy, solar-powered building also harvests and recycles its own water. The building's design encourages students to think about constructing explanations and designing solutions to real-world problems, associated with the *NGSS* standard 3-5-ETS1Engineering Design.

Before visiting our building as a class, we wanted to engage students' thinking about lower-impact ways to design human living and working spaces. So we presented students with a design problem: to invent a means of capturing and storing water for human consumption in a model building of specified dimensions. At the end of this unit, students are asked to reflect on their process. We recommend having students take pictures throughout the lesson because taking pictures and documenting the various stages of the learning process enables students to reflect with evidence (Neumann-Hinds 2007).



PHOTOS COURTESY OF THE AUTHORS

This team is constructing a V-shaped roof based on what they observed on their field trip and other team designs.

PART 1: EXPLORING MATERIALS AND THEIR RELATIONSHIPS WITH WATER

On Day 1, students were told that they were going to solve a problem but weren't given any information about the problem. We did this intentionally so students could explore the materials during the activity without having previously conceived ideas or plans for how they would use the materials. Students were then directed to think and write specifically about the properties of the various materials and how they interacted with water. It was important for students to explore freely without teacher direction. This activity was designed to encourage students to think about the varied design elements for possible incorporation into their models.

Before we began the exploration, we discussed safety issues with the class, making sure they were using materials appropriately (e.g., water was to be used for exploration only and plastic wrap, foil, and other materials were to be kept away from faces.) Students worked in small groups of three to four and were given a small sampling of the materials that would be used in the engineering design project: Two cups of water and a large plastic bin to contain the water (see Table 1 for complete materials list). During the exploration, students can take pictures of the materials and choose one image they want to discuss with the class. Students have 20 minutes to write about how the materials interact with water.

As students wrote, teachers circulated among the groups, noting student observations of properties and language they used on their charts (Figure 1, p. 70; see NSTA Connection for a blank form). The teachers used this opportunity to informally assess student vocabulary and scientific language. One teacher created a chart with terms that students used to describe what they saw, with words and phrases such as "water rolled off," "bendy," "soaking wet," and "fell apart." Teachers then provided students with relevant science vocabulary: "water-resistant," "flexible," "saturated," and "deteriorated." Students greatly benefit from opportunities to practice scientific language in both speaking and writing. In the following days, students would be required to use appropriate language. The vocabulary chart (see NSTA Connection) was hung in the classroom so that students could access the new vocabulary throughout the process.

PART 2: DESCRIBE THE PROBLEM

Students were next introduced to a real-life problem that occurs not just in their town but also globally. They were given the following scenario:

> *Western Massachusetts is having a BIG problem. There has been a lack of rainfall for the last two months, and we are suffering from a water shortage. Our reservoirs are getting low, and our local water department has officially determined that there is a drought. Most local towns have lawn-watering restrictions or outright bans. To conserve water, residents and businesses have been asked to stop using water for anything except drinking, cooking, and washing.*

At this point, students were directed to formulate questions centering on how their lives would be impacted by a drought and how they might conserve water. This lead them to defining a possible engineering problem—that is, how they can respond to not having enough water available for their community.

How We Use Water

Students were tasked to list all of the things that we use water for. In one column, they wrote down the uses that they considered essential, such as brushing our teeth. In the middle column, they took notes about what we use water for but that they think is not essential, such as filling water balloons. In the third column, they jot-

TABLE 1

Materials list.

Note: Prices on the Materials chart are not real-world cost. Prices/numbers are chosen to help students with appropriate fourth-grade math.

MATERIAL	COST PER UNIT	QUANTITY	$ SPENT
Bin (building)	free	1	$0.00
Scissors	free	1	$0.00
Roof panel (poster board)	free	1	$0.00
Straws (large)	$0.10		
Water storage bottles	$5		
Water storage tanks with lids	$5		
Plastic wrap	$3		
Wax paper	$5		
Aluminum foil (large sheet)	$10		
Aluminum foil (small sheet)	$3		
Popsicle sticks	$0.50		
Tape	$1 per ft.		
Total Spent	**xxxxx**	**xxxxx**	

FIGURE 1

Student chart (academic language added by teacher).

Exploration: How do the Materials Interact with Water?

What do you notice? Think about:

- how different materials interact with water
- the properties of the various materials you worked with
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Material	What You Notice
Roof panel (poster board)	dye bleeds out, becomes saturated w/ H_2O, stronger when dry, can provide structural stability (weight bearing), floats
Straws (large)	can hold H_2O
Water Storage Bottles	holds H_2O, no leaking
Water storage tanks with lids	?
Saran plastic wrap	repels H_2O, flexible, + structural stability, transparent, less dense than H_2O
Wax paper	?
Aluminum foil	strong, malleable, repels H_2O, sinks in H_2O, opaque
Plastic sheet	?
Popsicle sticks	floats (less dense than H_2O)
Tape	loses adhesion if wet, if adhered first to a waterproof surface can retain adhesion

ted down ways we can conserve water for essential uses such as turning off water while we are brushing our teeth (see NSTA Connection for student sheet).

Engage

Students were next introduced to a YouTube video (see Internet Resources) in which a reporter discusses the drought in western Massachusetts. Local internet news clips were also used to engage students about the drought. Subsequently, we read *What Do You Do With a Problem?* (Yamada 2016), a beautifully illustrated picture book about a problem that won't seem to fade. The child in the story tries avoiding it, but that only exacerbates the problem. In the end, the child learns an important lesson about meeting a challenge head-on. This book serves as a nice introduction to problem solving.

PART 3: ENGINEERING A SOLUTION

Students were next engaged in finding a solution to the drought problem. They were told that while the engineers can't change the weather, they can design innovative ways of conserving water. Each team of student engineers was tasked with creating a model building design with a roof to catch rainwater and snowmelt. Their design would model an entire system from rainwater landing on their roof, entering their capture system, and reaching their storage location (crosscutting concept: Systems and System Models). The stored water is to be used during possible drought conditions; residents and businesses will have a reserve of water. Students design, test, and then redesign their roofs. This activity incorporates the science and engineering practice Planning and Carrying Out Investigations (3-5-ETS1-3).

Before students went to work on the design problem, we discussed safety precautions, including the need to wear goggles when using scissors for cutting materials. Goggles were made available at workstations, and students were reminded to use them throughout the process.

Students were put in mixed-ability groups of three to four and were reminded that everyone in the group would have an active role during the process. Roles included budget officer, lead design engineer, construction manager and safety engineer. Students would decide together how to design and build their roof; after construction they would test their model in front of the class. After the first round of testing, they would take a field trip to the net-zero building. Then, they would have the opportunity to redesign a new and improved roof.

To create their model of a roof rainwater catchment system, students were given the following goals/criteria:

- Catch as much of the rainwater/ snowmelt (1 cup) that falls on the roof as you can.
- Create a roof with no leaks. The inside of the building should remain dry.
- Maximize square footage inside the living space. In other words, make as much space available inside your building as possible as long as your building fits inside the tub.

They were also given a few constraints:

- You will choose from the materials (see sidebar) listed on your chart. Each material has a cost.
- You have a budget of $50. You cannot go over the budget.
- You must work within the time given.

Design

Students had 20 minutes for this design phase. They worked in their groups, brainstorming ideas about what materials to use and how to build it, and then jotted down on paper what they thought would work best and sketched their design. Students were instructed to include in their diagram all the materials they would use, the quantity, and the cost, and were reminded to stay within budget. If they went over budget, the design would be rejected. In this part of the unit, students directly designed solutions to solve a defined problem, a portion of the science and engineering practice Constructing Explanations and Designing Solutions (3-5-ETS1-2).

Before they began constructing, teams needed to get their designs approved by the Supervising Engineer (teacher). Supervising Engineers were able to help ensure that all students were participating and to intervene if any students were taking over the process or not participating. This also allowed teachers to review the designs and address larger issues that arose. One group's first design, for instance, neglected to use any waterproof material. Another group had gone over budget and needed to adapt their choice of materials. We did not use a formal rubric here because we wanted students' creativity to direct the process, but we have provided one online (see NSTA Connection). Our main goal in moving students to the construction phase was to ensure that all of them actively participated in the design and were satisfied with the outcome.

Gathering Materials

After each group got the Supervising Engineer's sign-off, students gathered their materials as specified in their materials budget chart (see Table 1, p. 69). We developed this chart modeled after ones we discovered on the Teach Engineering website (see Internet Resources). Students were given play money for purchasing their materials, adding an important math component, including budgeting and computation using the decimal system.

Construction

Students had 45 minutes to construct their roof. We provided students with the following tips to help things run smoothly:

- Make sure everyone is working. Assign tasks and delegate someone to supervise the construction.
- Work together, not against one another.
- Be efficient. Forty-five minutes tend to go by quickly.
- If you choose not to use something that you have purchased and it is in its original condition, you may return it for full credit.

(*Note:* Every five minutes, the teacher can give a time remaining signal and instruct each group's designated photographer to take one picture of their building/roof.)

Students watch with anticipation as the rain pours down on their building. This group's design used six water containers to capture as much rain as possible.

Testing

After the Construction phase, students began to observe testing of each team's design, one by one. Students were equipped with note-taking materials to help analyze and evaluate other groups' roofs. Teachers advised them to note something specific that another group tried that they might like to try in the next round.

After the testing, the groups discussed their process with the rest of the class, sharing the challenges of agreeing on a plan in the Design phase and then adapting the plans as they started to build. "It was hard to compromise with my team, but we all agreed that we could change our plans if the design wasn't working," one student shared. "That made it easier for me to work with people." Some students raised questions while other groups shared their processes. "Why did you decide to put the water container in the interior of the building

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.

Standard

3-5-ETS1 Engineering Design

www.nextgenscience.org/dci-arrangement/3-5-ets1-engineering-design

Performance Expectations

3-5-ETS1-2. Generate and compare multiple possible solutions to a problem based on how well each is likely to meet the criteria and constraints of the problem.

4-ESS3-2. Generate and compare multiple solutions to reduce the impacts of natural Earth processes on humans.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Planning and Carrying Out Investigations	Students make decisions about experimental variables such as which materials (foil, sand paper, straws…) to use, how to construct the design with chosen materials, and how to carry out a fair test of the various roof designs.
Asking Questions and Defining Problems	Students ask scientific questions such as, *How do we design a roof under the given constraints that will meet the criteria?* and *How can we revise the roof to make it more effective?* Students also define problems such as: finding a solution to a lack of water during a drought and revising their roof designs to solve problems such as leaks, efficiency, and space issues.
Analyzing and Interpreting Data	Students create with a teacher a table summarizing each group's results. In addition, student groups use the data to inform them of revisions that are needed in the second design iteration.
Disciplinary Core Ideas	
ESS3.A: Natural Resources All materials, energy, and fuels that humans use are derived from natural sources, and their use affects the environment in multiple ways. Some resources are renewable over time, and others are not.	Student groups discuss and analyze the consequences of decisions on human-made constructs and natural ecosystems.
ETS1.B: Developing Possible Solutions What is the process for developing potential design solutions?	Student groups work together to design and diagram their ideas of how to capture the runoff water from the roof of their model building.
Crosscutting Concept	
Systems and System Models	Students create a model of a system for catching roof rainwater and then test their model to see how well it matched their understanding of the system and the stated design criteria.

instead of outside, since we needed to end up with as much space inside the building as possible?" one student asked.

The process of testing models and observing how different designs worked provided clear evidence of the crosscutting concept Structure and Function. In conjunction with the design criteria, group constructions were evaluated by the amount of water collected, how dry the inside of the structure remained, and how much of the living accessible space remained. Here students were actively engaged in carrying out an investigation and gathering objective data to make comparisons as described in the science and engineering practice Planning and Carrying Out Investigations. Every group should record data on each of the different models being tested. Groups may take up to three photographs of their own models. These images were used to later reflect on so that they could evaluate their buildings and their design process with evidence, ultimately helping them to revise their original buildings.

OBSERVING A "GREEN" BUILDING

We intentionally decided to schedule our trip to the environmental learning center after students had already designed, constructed, and tested their first model. The visit to the center came after their first iteration because we wanted students to come up with their own creative design without any preconceived ideas. The field trip experience proved to be more relevant to students after engaging with these ideas as was born out by their excitement and lively questions during the visit. Our field trip included an evaluation of the center's roof rainwater capture system (for photos on the Hitchcock Center website, see Internet Resources). Students investigated the shape, angles, the position, and the materials used, asking questions as defined in science and engineering practice Asking Questions and Defining Problems.

REDESIGNING AND RETESTING

Student groups next reviewed their first designs and the overall project goals and students evaluated the materials used and the construction techniques. The teacher explained to groups that they had 30 minutes to revise and improve their first design. Afterward, teachers tested their second iteration rainwater capture systems. All groups were successful in improving upon their original designs and capturing more water.

The redesigns enabled students to meet the science and engineering practices of comparing multiple solutions to a problem based on how well they met the criteria and constraints of the design problem. Students also completed a self-evaluation form about what they noticed in their group's design (see NSTA Connection). This writing piece provided teachers with a direct, measurable summative assessment of each student's grasp of the process and its goals.

CONCLUSION

Students exhibited a high level of interest and excitement in inventing roof rain catchment system of their own. Visiting our local sustainable building provided an opportunity for students to see a real-world example of a building relying on water captured from its own roof. They compared their invented designs to what they saw in the building and considered the pros and cons of the various approaches, adding many dimensions to our problem solving. Surprisingly, one group's before-the-field-trip design had many similarities to the design of the real building! Supporting students to explore their surrounding community and to view how engineering design is used there greatly enriches the classroom experience.●

REFERENCES

Neumann-Hinds, K. 2007. *Picture science: Using digital photography to teach young children*. St. Paul, MN: Redleaf Press.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press.

Yamada, K. 2016. *What do you do with a problem?* Seattle, WA: Compendium.

INTERNET RESOURCES

Drought video
www.youtube.com/watch?v=fHqknfMJ8_M

Hitchcock Center for the Environment
www.hitchcockcenter.org/our-living-building-project

Teach Engineering
www.teachengineering.org

NSTA Connection

Download the observation sheets, rubric, checklist for students, vocabulary chart, and the self-evaluation form at *www.nsta.org/SC0818*.

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