Planting the Seeds of Engineering

Preschoolers think about, talk about, and solve a real problem in the garden.

By Hagit Mano, Kathleen Molina, Alissa Lange, and Irena Nayfeld

It is a hot June day in Passaic, New Jersey, and a small group of preschool children are gathered around their teacher. She presents her students with a problem: "The faucet in our greenhouse is broken, but we need to water the plants. What can we do? How can we get water up there?" A few weeks before, the class planted tomato seedlings in raised beds in the greenhouse on the rooftop. They were watering them regularly using a hose attached to the sink faucet. Could the children engineer a way to transport water from their classroom to the rooftop?

In this article we document how Ms. Molina's preschool classroom began an engineering investigation by addressing a real problem that requires a solution. This group of 15 three- and four-year-olds was no stranger to the engineering process. The teacher participated in a research project that tested an evidence-based Science, Technology, Engineering and Math (STEM) Professional Development model for preschool educators (Brenneman, Lange, and Nayfeld 2018), in a district serving predominantly Hispanic/Latino population whose home language is Spanish. For two years, participating teachers worked with researchers and Early Childhood STEM experts to employ an inquiry-based approach to teaching scientific and engineering processes to all young children, including dual language learners (DLLs). Teachers implemented the STEM activities during their small-group time, where half of the students worked with the teacher and the other half with the teacher assistant. To make the engineering process more accessible to preschoolers, teachers followed Christine Cunningham's (Cunningham 2018) approach of simplifying the process by breaking it down to three steps: Explore, Create, and Improve. First, children are provided time to explore the problem and access to a variety of materials to spark brainstorming. Children then build on these explorations to create potential solutions. Trying them out, improving on them, and trying again until a satisfactory solution is reached is what engineering is all about!


PHOTOS COURTESY OF THE AUTHORS

Documenting with cameras was part of the process.

Our goal was to work together with Ms. Molina to develop an engaging engineering learning experience that tied into her curriculum while simultaneously creating opportunity for formative assessment of children's understanding of STEM content, concepts, and processes (Brenneman 2011). We decided to integrate the engineering experience into Ms. Molina's science unit on plant life cycle since the class was invested in keeping the tomato plants alive, and would be motivated to find a solution for watering them. Here we describe the three-day investigation, in which six children explored disciplinary core ideas in science and engineering, crosscutting concepts, and the engineering process.

Marking measurements

PHASE 1 – EXPLORE!

The first step was to draw on children's prior knowledge and experience with familiar materials as children suggested solutions to their problem. They immediately came up with the idea of filling containers in the classroom with water from the sink and carrying it up to the greenhouse. They gathered a cup from the dramatic play area, a cereal bowl from breakfast, a water bottle, and a bucket from the sand table. Ms. Molina purposefully supplemented with other objects to enhance their critical thinking about form, material, and volume: a Styrofoam tray, a plastic pot with holes in the bottom, an eyedropper, a sieve, and a cardboard tray. She was sure to ask the children to justify their choices of container, making notes of their responses. Children observed the objects carefully and described their thinking. One student chose a bucket "because you could put water in, and it don't come out." Another agreed, "It makes a good container because there are no holes."

Ms. Molina used open-ended questions throughout to elicit more complex dialogue and to gather information on what her students were thinking, and on what connections they were making (Lee and Kinzie 2012). She also asked children why they didn't choose the eye dropper as a solution. One child noted that it would work, but another said, "No, because a little bit of water will not work." Another countered that "The plants only need a little bit of water." Children wondered out loud how much water the plants need. She didn't jump in with the answer. Instead, she gave them time to share ideas and create collaborative dialogue within the small group (Webb 2009). She reminded the children of the scale of the problem and the amount of plants to be watered by showing them a photo of the plants. This led to the conclusion, "This (eyedropper) is not gonna work enough for this much plants because the water is just little bit." A discussion of the Styrofoam tray revealed similar nuanced thinking about structure and function (crosscutting concept): "It's going to drip water on the stairs," one preschooler pointed out. Another chimed in, "It's going to be jiggly." A third classmate agreed, "It's gonna go tippy."

PHASE 2 – CREATE!

The next day, children moved into the creating and testing phase of the engineering design cycle. Engineers often test their ideas on a model or simulation before trying it out in the real setting. Similarly, we wanted children to create solutions on a small scale by pretending that the water table, placed about 10 feet away from the sink, was the greenhouse. This was yet another chance for the teacher to observe and informally assess the children's thinking about structure and function, as well as their progress in developing scientific and engineering practices such as designing solutions and planning and carrying out investigations.

Ms. Molina provided children with containers made of different materials and shapes—some materials that repel water, some that absorb it; some that are flexible and others rigid; some with holes, some without. She also exposed the children to containers with different widths and openings so they could experience how easy or hard it would be to fill it, to carry it without spilling, and to pour from it. In addition, children considered the container's volume, which would determine how much water could be carried at once, and how heavy it would be to carry. These are all variables that need to be considered in order to choose a container that would successfully carry water efficiently to the rooftop.

To test these qualities, one by one the students took turns filling different containers and walking with them to the water table. Some of their findings were that a plastic planter didn't work "because it has holes." The Styrofoam tray carried only a little bit of water and required careful balance. The water bottle was harder to fill because of its narrow opening, and the bucket was heavy. A child who had predicted that a cardboard box would hold water found out that, "It did a little bit," but "It cannot because it has holes in here,"—referring to the slits where the box was folded. Ms. Molina kept brief informal records to identify children

English to Spanish

Although Ms. Molina isn't a native Spanish-speaker, she looked up key words such as *agua* (water) and *plantear* (plant) to infuse into the lessons to make connections for students between their home language and English. When asked why the container does not hold water, a child replied, "It is broken." The teacher then provided the child with the vocabulary for holes in English and in Spanish (*huecos*).

who struggled to identify a container and at least one reason why it might be good for this purpose.

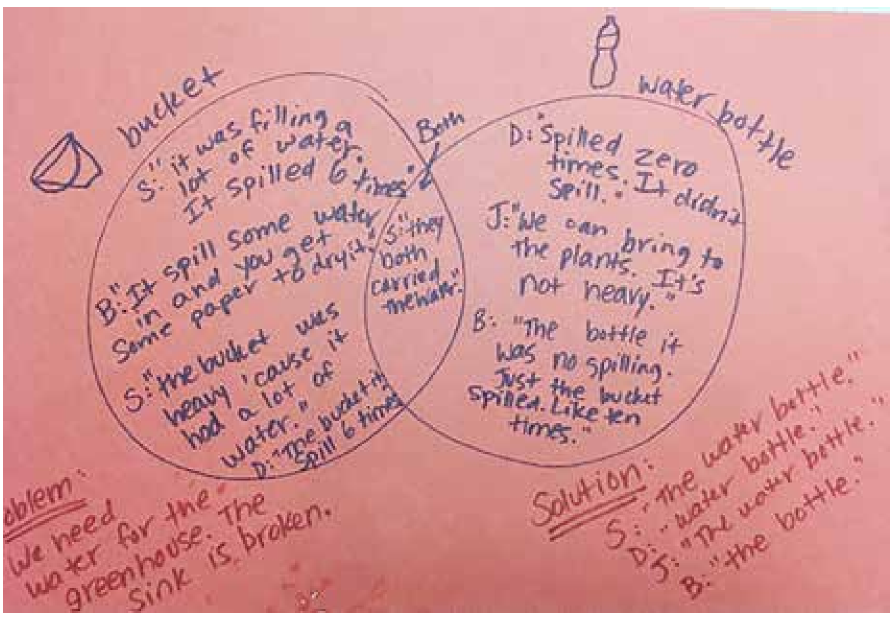
She then took an important step: bringing the children back together to draw conclusions from their observation and testing. She asked them to identify features of a good container such as "long, long sides" (child gesturing showing tall sides), and features of a not-so-good container, asking, "Should it have holes?" The response was a unanimous "NO!!!" This conversation provided valuable feedback on what children learned, how their thinking has evolved since the start of the project, and their progress toward the science and engineering practice of obtaining, evaluating, and communicating information.

PHASE 3 –IMPROVE!

The next day, Ms. Molina asked the group to recall their preferred containers so far. Which did they think would work best and why? Discussing the possibilities, children disagreed about which container held more water. Ms. Molina seized the moment to introduce them to a way of measuring and comparing how much water there was in each container. She brought a tall transparent food container, instructing them to pour the water from their containers into the food container and mark the line with a marker. This allowed them to compare the volume of the containers. Based on these results, students decided to test the bottle and the bucket to carry water to the greenhouse.

Children reviewed safety rules while walking in the hallway, such as carrying the containers carefully and alerting the teacher to any spills to avoid slippery floors. On the way to the elevator, they immediately noticed that water was spilling from the bucket, but not from the bottle. They also noticed that the bucket was heavier than the bottle. When they tried to water the tomato plants, which were planted on chest-high raised beds, it was difficult to hoist the bucket and more water spilled. Returning from the greenhouse, they discussed what they learned from trying out their ideas, taking into account weight, volume, and size (given the task at hand) to reflect on which container was the best overall solution to their problem. Given the evidence, they concluded that the water bottle worked best for them because it wasn't too heavy and it didn't spill.

Safety first: If trying this lesson in your classroom, please make sure the containers are not too heavy for a child to carry and that any spills are cleaned immediately to avoid slipping.



The class created a Venn diagram to compare experiences.

DOCUMENTATION

Scientists and engineers keep detailed records of their hypotheses, their results, and their conclusions. Similarly, this class documented the engineering process and communicated their findings throughout the process. Children used a tablet to photograph all the different tools and sorted the prints according to tools that were suited for carrying water and those that were not based on the children's findings. Ms. Molina was able to assess children's understanding of key concepts in this multiday exploration by observing children's success in sorting images into the correct group.

Each child also used an engineering journal, or a paper separated into quarters, with each quarter numbered 1–4. In the first segment, each child drew the problem. In the second, they depicted their proposed solution. The third part of the paper showed their representation of the testing process. Last, they drew the final solution in the fourth segment. This was another opportunity for individualized assessment of their learning.

After trying both a bucket and bottle, the students discussed their experience with each of the final tools. Ms. Molina used quotes from students to highlight what they found and to display their conclusions in the classroom. The class summarized their findings in a Venn diagram, a recording technique that was familiar to them. Ms. Molina encouraged students to express their thinking throughout in the language that each child feels most comfortable using. Teachers who speak the home language of the child can write down what they share in that language, or acknowledge their participation by asking a bilingual child who speaks that language to translate for the class (Goldenberg, Hicks, and Lit 2013). Creating the Venn diagram, the class was able to summarize everything they learned with a visual representation of their findings to display in their classroom. Children were proud of their work and eager to share their learning with families and class visitors, as well as to tackle future problems!

DISCUSSION

Children engage in informal engineering when they explore materials, when they take things apart and put them back together, and when they create their own solutions to real problems. In this article we described how preschool children, with their teacher's guidance, engaged in three-dimensional learning. First, they employed core science and engineering practices by considering different containers, asking questions, designing solutions, testing them on a small scale, refining their choices, and testing again. Second, the learning experiences were designed in a way that would expose children to the physical structure and properties of matter (the containers), a disciplinary core idea in science, essential for designing a solution like carrying water. As children observed, tested, and talked about materials, they were constructing their own knowledge about how different materials, their characteristics, and how they behave differently. They then represented their ideas using sketches and digital photos, and summarized their findings using diagrams and charts. Third, these science and engineering experiences enhance children's understanding of the relationship between the form or structure of an object (the containers) and its function (carrying water).

Our example shows that an engaging engineering experience need not require special materials or expensive tool kits. It can be done in the natural environment, with tools and materials children already use. Once a project has started, it may involve all learning domains. It may require that children find more information about the physical properties of matter (science!), compare measurements (math!), record their findings (literacy!), and work together to try out solutions (socioemotional development!). And, these hands-on and minds-on experiences are language-rich opportunities for all children to build their English (and Spanish!) skills as well as content knowledge.

A project like this one can create an atmosphere of genuine excitement about learning while incorporating skills and knowledge across all domains. You need not have a greenhouse in order to find "problems" that need "solutions." Have a wobbly table in your classroom? Ask your students how we can fix it! Do the crayon containers make all of the colors mix together? Ask the class to design a solution! Do the plants in your room need to be replanted in a larger pot? Instead of doing it yourself, ask the children to help figure out what kind of pot you should use, what size and material is best, and what is the best strategy for transferring the plant without damaging the roots or making a giant mess might be? Children deserve the gift of time to dive deeply into a meaningful problem, in which THEY ARE the scientists and engineers, and in which their own thoughts, ideas, and solutions are celebrated. Try out engineering with your preschoolers using the Explore, Create, and Improve cycle and using three-dimensional learning and see how the adventure of engineering can evolve over hours, days, or even weeks.

About Engineering

Engineers create solutions within given constraints by learning about the concepts involved, and then inventing new technology or optimizing existing technologies. Similarly, young children can learn relevant content in the context of the problem and use existing tools in new ways, or design their own tools. By closely observing a tool first, noticing its design, and using it in different contexts, children can connect the form of a tool to its function, then use that knowledge to inform solutions.

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INTERNET RESOURCES

EiE - Engineering is Elementary
www.eie.org

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

Standard

K-2-ETS1 Engineering Design

www.nextgenscience.org/dci-arrangement/k-2-ets1-engineering-design

The materials/lessons/activities outlined in this article are intended for use in pre-K classrooms. Science experiences in preK by their nature are foundational and relate to early elements in learning in learning progressions that facilitate later learning in K–12 classrooms. As the NGSS performance expectations are for K–12, we have not included specific performance expectations but have identified the disciplinary core ideas that are addressed to show the link between these foundational experiences and students' later learning.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practices	
Planning and Carrying Out Investigations	Students predicted what would be a good container, tested their choice, and revised thoughts based on results.
Using Mathematics and Computational Thinking	Students sorted containers according to their ability to carry water, measured the amount of water each container holds, and concluded that containers with holes cannot hold water.
Obtaining, Evaluating, and Communicating Information	Students communicated their choice of container and reasons for the choice verbally.
Disciplinary Core Ideas	
ETS1.B: Developing Possible Solutions Designs can be conveyed through sketches, drawings, or physical models. These representations are useful in communicating ideas for a problem's solutions to other people.	Students considered possible containers around the classroom to carry water to the greenhouse and communicated why they thought each tool would be a good choice or not.
PS1.A: Structure and Properties of Matter Different properties are suited to different purposes.	Students gained an understanding of the structure of different containers (shape, volume), the properties of the materials they were made of (rigidity, absorption), and whether they are suited to carry water.
Crosscutting Concept	
Structure and Function	Students make the connection between the form of the object and the material it is made of to its function as a potential vessel suitable for watering plants in the greenhouse.