Engineer It, Learn It: Science and Engineering Practices in Action

Step into an elementary classroom to see what *Next Generation Science Standards* practices look like.

By Cathy P. Lachapelle, Kristin Sargianis, and Christine M. Cunningham

Children in America today spend most of their time in human-built spaces: home and school, playgrounds and city streets, public parks and even farms. Children also spend most of their time interacting with technologies, from the banal (pencils and desks) to the new and flashy (iPads and cell phones). To succeed as citizens in the modern world, children need to know how such things come to be. When they understand that engineers design technologies—and when they understand the wide range of challenges that engineers address—children open their minds to new career possibilities.

Engineering is prominently included in the *Next Generation Science Standards* (Achieve Inc. 2013), as it was in *A Framework for K–12 Science Education* (NRC 2012). The National Research Council, authors of the *Framework*, write, "Engineering and technology are featured alongside the natural sciences (physical sciences, life sciences, and Earth and space sciences) for two critical reasons: (1) to reflect the importance of understanding the human-built world and (2) to recognize the value of better integrating the teaching and learning of science, engineering, and technology" (p. 2).

For nine years, our team has been developing and testing engineering curricula for elementary students. We're engaged in this endeavor because, like the National Research Council, we recognize the importance of technological literacy. In this article, we'll show how science and engineering practices can be integrated into the elementary classroom by providing snapshots of activities from one of our STEM curriculum units. The unit, focused on aerospace engineering, challenges students to design parachutes for a spacecraft that will land on a planet with an atmosphere thinner than Earth's.

Science and Engineering Practices

The *Next Generation Science Standards (NGSS)* specifies that children should engage in eight science and engineering practices. In the following sections, we present scenes from an elementary school classroom that show children engaging in all eight engineering and science practices while they work on engineering parachutes. The activities we describe have been done successfully with students who are both experienced and not experienced with these practices. We also present examples in which these children, as they are engaged in engineering design, apply their scientific and mathematical knowledge and skills. We do this to illustrate how science, technology, engineering, and mathematics can be integrated, as the *NGSS* advocates.

Asking Questions and Defining Problems

The *Framework* notes that science and engineering have different goals. The goal of science is to create theories that explain how the world works, so scientists begin with questions related to this topic. The goal of engineering is to find a solution to a need or want, and so engineers begin with questions that define the problem, describe what success will look like, and identify constraints on how the problem can be solved (NRC 2012, p. 56). The *NGSS* states that elementary students are expected to ask both kinds of questions (disciplinary core idea ETS1.A: Defining and Delimiting Engineering Problems) (Achieve Inc. 2013, *NGSS*, p. 53; Achieve Inc. 2013, Appendix F, p.51).

In the "Designing Parachutes" unit, students ask both science and engineering questions. They ask about scientific phenomena related to parachutes, and they also ask about the criteria for (and constraints on) their parachute designs (performance expectation 3-5-ETS1-1: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost) (Achieve Inc. 2013, p. 53). Now, let's go into the classroom and see what actually happens.

Mrs. A asks her third-grade students, "What information do you need to make sure that your team's parachute design is 'mission-ready'?" The students ponder this question. One girl responds, "Where is the parachute going? What planet?" Another girl jumps in, asking, "What can we use to build it?" A boy asks, "What is going to be attached to it? What are we dropping?" A girl adds, "How do parachutes slow you down, like a skydiver?" Mrs. A responds to this remark by adding another question to the list: "What does atmosphere have to do with how a parachute works?" Mrs. A tells her students that before they build their parachutes, they will explore all of these questions. The information they gather will help them design more effective parachutes.

Developing and Using Models

Scientists develop and use models to help them understand how the world works. Engineers use models to help them design effective solutions to problems (NRC 2012, p. 58). The *NGSS* expects young children to use concrete models to communicate their findings, develop their understanding, and present their ideas (Achieve Inc. 2013, Appendix F, p.53).

The guiding question for the third lesson in "Designing Parachutes" is "How do the thickness of an atmosphere and the design of a parachute affect the speed of a falling parachute?" (Museum of Science, Boston 2011). Mrs. A begins by asking her third-grade students for their ideas about models: What are they, and why are they important?

Next, she shows them two plastic jars: one filled with water and a few drops of food coloring, and one filled only with air. She explains that the jars model two different atmospheres, one thick and one thin. "How could we figure out which jar models which type of atmosphere?" she asks. "Feel inside the jars," one student suggests. "Drop something in each of the jars," says another. "That's what I'm going to do," Mrs. A confirms.

She holds up two golf balls, and then drops them simultaneously into the two jars. "Which jar models a thicker atmosphere?" she asks. "The one where the ball fell more slowly!" students answer. "Because there's more stuff to bump into," one girl posits. "Good thinking! The water is thicker, or denser, than the air, so it creates more drag on the ball. Which planets might this jar model?" Mrs. A

FIGURE 1.

Parachute design data sheet.

Canopy Size: Testing Parachutes

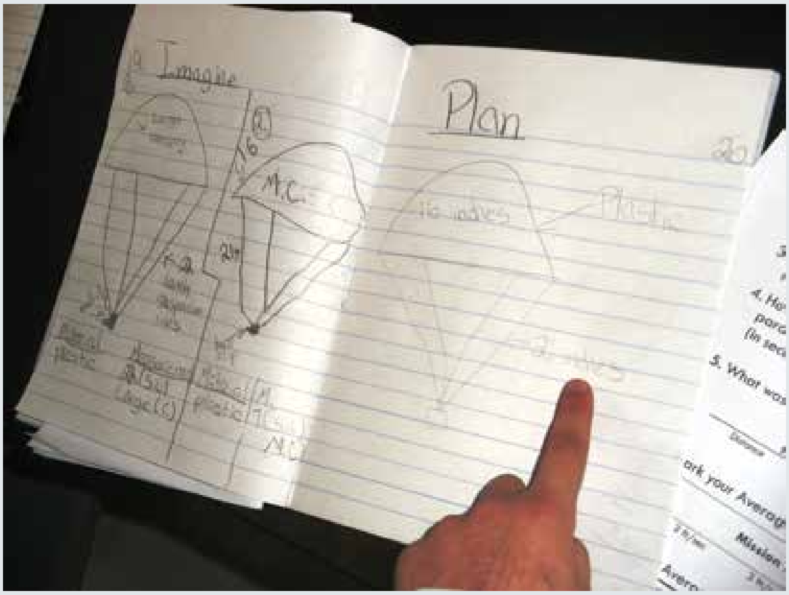
Directions: Construct your parachutes. Drop them three times, recording which landed first, second, and third. Then answer the questions below.

Variable	Constants	Trial 1	Trial 2	Trial 3	Observations
Small Canopy (8 inches)	Material: Paper Suspension Line Length: 21 inches				
Medium Canopy (14 inches)					
Large Canopy (18 inches)					

1. Which canopy size fell the **fastest**?__________
2. Which canopy size fell the **slowest**?__________
3. Why do you think that canopy size fell the slowest?__________

FIGURE 2.

Student parachute plans.



asks. Students recalled their solar system knowledge: "Venus!" "Neptune!" "Jupiter!"

Mrs. A has students summarize what they learned from the models that would help them understand why parachutes fall more slowly through denser atmospheres. One boy answers, "It's like the food coloring in the water; when things drop through the atmosphere, they push through, they move it out of the way." Models of atmospheres help students understand how the thickness, or density, of an atmosphere affects falling objects such as parachutes.

Planning and Carrying Out Investigations

Scientists plan and carry out systematic investigations to answer questions about natural phenomena. They identify what data should be recorded and what the variables are. Engineers, however, use investigations to gather data that help them specify design criteria and test their designs (NRC 2012, p. 60). The *NGSS* says that teachers should support children as they engage in these practices (Achieve Inc. 2013, Appendix F, p. 55).

In Mrs. A's class, the children investigate how a parachute's design affects its drop speed. She has each group of students test one of three parachute features—canopy material, canopy size, and suspension line length—while keeping the other two constant. "You're going to control all of the variables except the one you're testing. What do you think that means?" she asks. "We all have to use the same thing on the bottom of our parachutes," offers a girl. "That's right," says Mrs. A. She explains that each group will drop its parachute from the same height, so they can compare the rates at which each falls. "Do you think we should drop each set of parachutes just once?" Mrs. A asks. "No!" shout several children. "Why not?" she probes. "It might not drop right the first time; you want to make sure it's right," says a boy.

Each group of students creates three parachutes for the investigation, changing one variable and controlling the others. For example, the "canopy materials" groups build three parachutes using three different canopy materials, while keeping canopy size and suspension line length constant.

Mrs. A then shows the class how to record their data. The students simultaneously release their three parachutes from the same height and record the order in which they hit the ground (see Figure 1, p. 71). Each group conducts three trials of the experiment and writes the results for each trial on a recording sheet. Once all groups have completed their tests, Mrs. A has them share their findings with the class. She records everyone's findings on a data table on chart paper, so everyone can see. Therefore, even though each group focused on a single parachute variable, all students now have access to a larger data set that they can use to draw conclusions about parachute features and drop speed.

Analyzing and Interpreting Data

Scientists analyze and interpret data to generate evidence for scientific theories. Engineers analyze and interpret data to better understand design flaws and strengths and how they can be improved. Our elementary students engage in these practices as they collect data, tabulate or graph it, and share it with the class. The teacher supports them in these processes, especially in sharing and interpreting data, as the *NGSS* specifies (Achieve Inc. 2013, Appendix F, p.57).

After conducting the investigations and sharing their data, Mrs. A's students discuss their findings. "Why did the large canopy work better?" Mrs. A asks. "It had to push more stuff out of the way as it fell," one girl answers. "It's like the jar with water." "The small parachute doesn't open that big, so it falls fast," says another. They've seen clear patterns in the data and are able to posit explanations about what's happening.

The students need more help interpreting the investigations that compared different lengths of suspension lines. Mrs. A asks, "What happened when we dropped a parachute with really short suspension lines?" "It didn't open that much; it fell like a rock!" a boy answers. "Longer lines let the parachute open, so it goes slower," argues another boy. "There's more air resistance and drag," Mrs. A clarifies. Students will use what they learn from this class discussion within their teams as they juggle the benefits and trade-offs of each design feature to create parachutes that not only fall slowly, but also fit on a spacecraft.

FIGURE 3.

Parachute testing results.

Engaging in Argument From Evidence

Scientists engage in argument from evidence to test and strengthen their ideas. Engineers engage in argument to compare and strengthen their designs (NRC 2012, p. 73). According to the *NGSS*, elementary students should practice advocating for their own ideas. They need the teacher's support to learn the difference between opinion and evidence-based argument (Achieve Inc. 2013, Appendix F, p.63).

To help students engage in argumentation before they create and test their parachute designs, Mrs. A challenges students to individually brainstorm at least two different parachute designs, taking into consideration canopy size, canopy material, and suspension line length (see Figure 2). Students then share their ideas with their groups.

Mrs. A encourages groups to combine ideas from multiple students into their designs. She also reminds them to use their data on how design variables affect drop speed to inform their decision-making.

"So what's your team thinking?" Mrs. A asks one group. "He thinks we should use coffee filters for our canopy," a girl replies. "But we saw they have holes in them, so air can go through," says one of her group members. "What do the rest of you think?" Mrs. A asks. "Remember to look back at your data." The students check their notebooks. "The plastic bag fell the slowest; I think we should use that," one boy says.

By reminding the group to rely on the information collected during prior investigations, Mrs. A helps develop students' capabilities to consider teammates' ideas, argue from data and evidence, and compromise when selecting design ideas—skills that are central to engineering design (performance expectation 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) (Achieve Inc. 2013, p. 53; see Connecting to the Standards).

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A student measures and cuts circles for his parachute canopy.

Constructing Explanations and Designing Solutions

To meet the goals of both science and engineering, the NGSS requires that elementary students have opportunities to construct, test, and evaluate their understanding of the world (based on their observations) and to design, test, and evaluate solutions to problems (disciplinary core idea ETS1.B: Developing Possible Solutions) (Achieve Inc. 2013, *NGSS*, p. 53; Achieve Inc. 2013, Appendix F, p.61).

We've already presented one example of how students construct explanations in the section "Analyzing and Interpreting Data." Here is another. As each group drops its parachute in the stairwell of the school, Mrs. A times the descent (while also making sure that students behave safely while in the stairwell). One team's parachute crashes to the floor. Their short suspension lines prevented the canopy from opening. "What do you think the problem is?" Mrs. A asks. "Could be the suspension lines," one child answers, "or the canopy might be too small." As they test and observe their parachutes and share their findings with the class (see Figure 3, p. 73), groups construct an understanding of how parachutes work and how different design elements impact parachute performance.

Obtaining, Evaluating, and Communicating Information

Scientists and engineers obtain, evaluate, and communicate information through scientific texts, graphs, and data and by evaluating presentations and design prototypes (NRC 2012, p.76). The *NGSS* advocates that the process of learning to obtain, evaluate, and communicate information begin in the earliest grades, as children read age-appropriate science texts, write in science journals, and create design plans for themselves, their peers, and their teachers (disciplinary core idea ETS 1.B: Developing Possible Solutions) (Achieve Inc. 2013, *NGSS*, p. 53; Achieve Inc. 2013, Appendix F, p. 65).

Using Mathematics and Computational Thinking

Mathematics and computation are vital to both engineering and science. They enable the communication of precise ideas and the ability to make inferences and draw conclusions from data (NRC 2012, p. 66). The *NGSS* says that elementary students should begin engaging in these practices by making measurements, identifying patterns in data sets, and mathematically describing data sets using simple statistics (Achieve Inc. 2013, Appendix F, p. 59).

In the "Designing Parachutes" unit, students measure and cut circles for parachute canopies and string for suspension lines, find the mean of three timed trials, and calculate the mean rate at which their parachutes fall (see Figure 4). They round decimals and learn when and why rounding is appropriate, putting their math skills into practice.

FIGURE 4.

Parachute design data sheet.

Design #

Designing a Parachute
Engineering Design Process:
Create!

Parachute Packing Score

1. Mark your Parachute Packing Score with an X on the bar below:

Bonus Space

0	30	60	90	120	150	180	200+

2. Is your Parachute Packing Score "Mission Ready"? ____________

Reminder: If your Parachute Packing Score is not "Mission Ready," you need to redesign your plan.

3. How far did you drop your parachute (in feet)? ____________
(distance from load to floor)

4. How long did your parachute take to fall (in seconds)?

Trial 1	Trial 2	Trial 3	Average

5. What was the Average Drop Speed of your parachute?

______ ft ÷ ______ sec = ______ ft/sec
Distance ÷ Average drop time of 3 trials = Average Drop Speed

6. Mark your Average Drop Speed with an X on the bar below:

Mission Ready				Almost There	Needs a Redesign
1 ft/sec or slower	2 ft/sec	3 ft/sec	4 ft/sec	5 ft/sec	6 ft/sec	7 ft/sec or faster

7. Is your Average Drop Speed "Mission Ready"? ____________

Value of Engineering Beyond Science

Engineering asks students to apply their science knowledge in meaningful ways and to engage in engineering practices. However, the value of engineering in classrooms goes far beyond this intersection of subject areas. By tackling engineering design challenges, students practice 21st-century skills (see Internet Resource) such as creativity, collaboration, critical thinking, and problem-solving. Engineering design challenges are also inherently open-ended, with many possible design solutions. The open-ended nature of engineering design challenges encourages students to tap into their creativity and think outside of the box. Working with their peers, students communicate their design ideas and collaborate with teammates to arrive at a final design. Finally, at its core, engineering is a problem-solving process.

Connecting to the Standards

Standard: 3-5-ETS1 Engineering Design

Performance Expectations:
3-5-ETS1-1: Define a simple design problem reflecting a need or a want that includes specified criteria for success and constraints on materials, time, or cost.
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.

Science and Engineering Practices:
Asking Questions and Defining Problems
Developing and Using Models
Planning and Carrying Out Investigations
Analyzing and Interpreting Data
Using Mathematics and Computational Thinking
Constructing Explanations and Designing Solutions
Engaging in Argument From Evidence
Obtaining, Evaluating, and Communicating Information

Disciplinary Core Ideas:
ETS1.A: Defining and Delimiting Engineering Problems
ETS1.B: Developing Possible Solutions

NGSS Table 3-5-ETS1 Engineering Design
www.nextgenscience.org/3-5ets1-engineering-design

Students simultaneously release their three parachutes from the same height.

As students gain experience with engineering and science practices, they also become more effective—and creative—problem solvers. ■

Cathy P. Lachapelle* (clachapelle@mos.org) *is the director of research and evaluation for the Engineering is Elementary project at the Museum of Science, Boston. Kristin Sargianis is the professional development director of the Engineering is Elementary project at the Museum of Science, Boston. Christine M. Cunningham is the founder and director of the Engineering is Elementary project at the Museum of Science, Boston.

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Internet Resource

Partnership for 21-Century Skills
www.p21.org