Balancing Engineering and Science Instruction

Teaching third graders about balanced and unbalanced forces

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Since the adoption of the *Next Generation Science Standards*, we have been including more engineering activities in our third-grade curriculum. During these activities, our students have been embodying many science and engineering practices and even testing out new ideas without our prompting. Yet, when we asked students what they learned about the activity, they said, "We learned to make a bridge" or "We learned how to make a good parachute." Students had learned seemingly little about science or engineering from the activities—and that bothered us. Sometimes classroom activities that appear to be effective on the surface do not help students deeply understand science concepts, which Moscovici and Nelson (1998) refer to as "activitymania." We wanted our students to go deeper.

To move beyond "activitymania," we engaged our students with nature of technology and engineering (NOTE; Figure 1). The nature of technology and engineering refers to what technology is, what engineers do, how engineers function as a group, and how society and technology interact (Kruse et al. 2017; Clough, Olson, and Niederhauser 2013). While some NOTE ideas can be abstract for elementary students, many are developmentally appropriate (Kruse and Wilcox 2017; Kruse and Wilcox 2013). NOTE can help students come to understand how technology affects their lives and better understand engineering.

Additionally, we want students to understand how the engineering task relates to science disciplinary core ideas. This activity has students solve an engineering problem of moving a marshmallow from the floor to a table. We use this experience to explore how unbalanced forces are necessary to move objects (NGSS Lead States 2013) and how simple machines can make tasks easier.

FIGURE 1

NOTE concepts and questions for elementary (Bolded questions and days indicate where we address these questions in the lesson.)

- **Defining Technology: What is technology? (Day 2)**
- **Creativity: In what ways are engineers creative? (Day 3)**
- **Collaboration: Why do engineers collaborate? (Day 1)**
- **Models: How do you think engineers use models? (Day 1)**
- **No Step-by-step Design Process: Why do you think engineers don't always follow the same steps to solve problems? (Day 2)**
- **Technology and Society: How does technology affect society? (Day 4)**
- **Optimization: Why do you think engineers sometimes change their designs? (Day 3)**
- Cues: How do designers help us know how to use the technology they create?
- Constraints: How do you think engineers' work is affected by money, materials, and time?
- Evolution of Technology: Why do you think new technologies are like old technologies?
- Trade-offs: What are the pros and cons of using technology?
- Value-laden: How do you think technology changes the way we act and think?
- Limitations of Technology: What are some things technology can't do?

DAY 1: PLANNING AND BUDGETING

We start the engineering task by telling students they need to create a technology to transfer a marshmallow from the floor to a table. We emphasize the technology has to move the marshmallow to avoid students simply picking up the marshmallow with their hands. Students are told that they will eventually be presenting their solutions to the problem.

Students are then split up into teams of four based on personality and mixed ability levels. To help students understand how engineers collaborate, we ask, "We have you in groups. Why might engineers also want to work in groups?" Students often say, "We share ideas and so do engineers" or "Talking to people helps engineers do their job."

We give students a list of materials with prices (Table 1) and we discuss safety concerns. To provide support for our ELL students, the materials list has pictures along with the words. Students purchase the materials using $100 of fake money provided by the teacher, and then sketch their ideas on a blank sheet of paper while keeping the $100 in mind. After students share their ideas with their team members, we guide them to come to a consensus by asking, "How can you make sure all group members have a say?" and "How might the $100 cap help you decide?" Based on this conversation, students often decide to combine ideas among their group members.

Once students have discussed their ideas with their groups, we help them create a budget. We ask, "How could this sheet help us keep track of how much money we are spending?" Students often say, "We can add it up." Students then work on creating a "portfolio," which includes a finalized group sketch of their plan along with a completed budget as an exit ticket. Toward the end of class, we all come back together as a whole class to help students see the connection between their project and engineering by asking the following explicit/reflective NOTE questions.

Defining Technology

- What are some examples of technology? (Students often say: computer, phone, iPad.)
- Why might things like pencils and clothing also be a technology? (Students often pause for a moment, then say, "Those things help us.")
- So, technology can be thought of as things that help us. Why would our designs then be considered a technology? (Students often say, "The designs help us solve a problem.")

Models

- Why is it important that we drew a picture before creating our technology? (Student often say, "Drawing a picture helps us see what we want our technology to look like.")
- Why do you think engineers draw pictures before creating a technology? (Students often say, "It helps them decide what to do.")
- Why might drawing a picture be an example of making a model?
- How do you think engineers use models? (Students often say, "Making a model helps engineers save money by not making mistakes on the real thing.")

DAY 2: BUILDING THE MARSHMALLOW MACHINE

We hand back the groups' portfolios and have one student from each group come up to the "store" to purchase the materials. While students work, we differentiate for groups by asking scaffolding questions, doing think-alouds, and encouraging experimentation. For example, if a group was stuck, we differentiated by asking scaffolding questions such as, "What if you tried attaching the string somewhere else?" or "If what you tried didn't work, how could you use other materials to help you?"

TABLE 1

Materials list.

MATERIALS	COST
Popsicle stick	$5
Rubber bands	10 for $10
Toy truck	$30
Wood	$60
Pulley	$40
Plastic Spoon	$30
Toothpicks	$10 for 10
String	$10
Paper	$5
Scotch Tape	$5 per piece
Duct Tape	$10 per piece

Once students had completed their prototypes (Figure 2), we do a gallery walk, using a two-stay, two-stray strategy, so students can see other group's designs. This strategy is where two group members stay behind while the other two walk around and look at other group's designs. Then, they switch places so all students have a chance to look at other students' designs. Afterward, students go back to their groups to share ideas on how to improve their designs. Students then individually write: one thing they liked about their technology and one thing they wanted to improve.

Finally, we discuss connections to the NOTE such as:

- Why is it good that each group had a unique way of making a technology to solve the problem?
- Why do you think it is good that engineers don't always follow the same steps to solve problems?

FIGURE 2

Student prototype.

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We use our class discussion to bring up the design process. Students might share that they know there isn't a design process because some groups needed to make changes and others didn't. Also, they might use the previous day's lesson to share that not all engineers draw pictures or make models to begin their ideas.

DAY 3: REFLECT, BUDGET, AND BUILD

At the beginning of the lesson, students receive their index cards, a new budgeting sheet, and an additional $100. We help students see the importance of changing one variable at a time by asking, "I saw you had a lot of good ideas on how you wanted to change your design. If you changed a bunch of things at once and the design didn't work as well, why wouldn't you know what went wrong? Why might you only want to make one change at a time?" Once students decide on the change they wanted to make, they work to optimize their designs. Toward the end of class, we have each group describe how the redesign went. We then ask NOTE questions:

Optimization

- Why did you make changes to your design?
- Why would engineers also make changes to their designs?

Creativity

- In what ways were you being creative during this activity?
- Why might engineers have to be creative?

Students typically share that they made changes to their design so it is in its best form. When it comes to creativity, students share that they were creative in how they wanted to build their technology and how they were going to pick up the marshmallow from the ground.

DAY 4: EXPLORING BALANCED AND UNBALANCED FORCES WITH SIMPLE MACHINES

We transition students from the engineering task toward understanding the DCI by asking students to describe the different technologies they made. We guide students toward different simple machines by asking, "What did you use the wood to do?" or "How did the truck help make the task easier?" We formalize the list of simple machines, which included: ramps, wheels, pulleys, and levers.

Once we have the list, we ask students to turn to their elbow partner and discuss where they might see these types of machines in their everyday life. After a minute of discussion, we pull students back to the large group. Students often mention things like, "We see a ramp in the parking garage" "Lots of things we use have wheels" "I saw a pulley on a tow truck" and "The lever is like a seesaw." We deepen these connections by having groups of two students categorize photographs of a crane, a wheelbarrow, scissors, a stapler, a bicycle, and a fishing reel.

Once students categorize simple machines, we help them generalize by asking, "How do all of these simple machines help us?" Students say, "They help us move things from one place to another." We connect this to NOTE by asking, "What would happen to our society if we didn't have these machines?" Students say we would not be able to drive cars, build things, or make our lives easier. We then ask, "How do you think technology helps society?" Students often say, "Technology makes things easier. Like we can look things up on Google." To push students' thinking, we ask, "How can technology hurt society?" Students often say, "Sometimes my mom looks at her phone too much." and "Cars cause pollution."

After making connections to NOTE, we work to connect their ideas to forces by asking, "Why would moving things be harder if we didn't use those machines?" Students often say, "It's hard to lift something that's heavy" or "it wouldn't move without help." We play off of their ideas to help students see the connection to gravity by holding up a box with some books in it and asking, "When something is heavy, what do you have to do to keep it from falling?" Students say, "push up" or "lift it." We then ask, "What would happen if you stopped pushing up?" Students note the object would fall because of gravity. We made connections to the crosscutting concept by asking students, "How could we label these in terms of cause and effect?"

We then draw a picture of the box on the board and draw an arrow pointing down. We ask, "What might the arrow represent?" Students quickly note the arrow is gravity pulling down. We then place the box on a table, add the table to our drawing, and ask, "If gravity is still pulling down on the box, why doesn't the box fall?" Students say, "the table keeps it from falling." We draw another arrow, of the same size, pointing up, and ask, "Why does this arrow make sense?" Students often tentatively say, "The table pushes back?" We ask, "What would happen to the box if the table wasn't pushing back?" Students note it would fall.

We then tell students if gravity is pulling down but something is pushing up just as much—in this case the table—we call that a *balanced force*. "If we have balanced forces where a force is pulling down and a force is pushing up, how much movement happens?" Students note that the box didn't move, and we record this idea that balanced forces result in no movement. We begin lifting the box up and ask, "How would arrows be different in this case?" Students note that we are pushing the box up more than gravity, and we draw the "up" arrow longer leaving the down arrow representing gravity the same. We ask, "What are you noticing about the movement of the box?" Students say, "It's moving up." We note that when we lift up the box, we are pushing up more than gravity is pulling down, and we label that as an *unbalanced force*. We then have students work with an elbow partner to summarize what they have learned.

Finally, we connect our discussion back to simple machines by demonstrating pulling a marshmallow up a ramp with a string. We ask: "If the marshmallow is moving up, what can we say about the force?" Students note that it's unbalanced because the marshmallow is moving. We then ask, "Why might it be easier to push things up a ramp than to lift them from the ground?" Students say, "It's not straight up and down." We say, "When you lift something from the ground, you have to push hard." We follow up with, "So, why is pushing something up a ramp easier?" Students note you get to push over time rather than all at once. To ensure our students understand this, we do an exit ticket where they draw arrows on their designs and label the force as balanced or unbalanced along with a sentence explaining their drawing.

DAYS 5 AND 6: PRESENTATION PREP AND PRESENTING

On day 5, we allow students the entire class time to prepare for their summative presentation. To begin, we gave students a list of questions (Figure 3) to use as a framework and explained

FIGURE 3

Presentation requirements.

- Explain your technology.
- Why was your design a technology?
- What type of simple machine is most like your technology?
- Explain a cause-and-effect relationship.
- How did your group act like engineers?
- How did your technology make an unbalanced force?
- Why should your client use your technology?

FIGURE 4

Principles for avoiding "activitymania" and balancing science and engineering.

- Ensure to ask explicit/reflective questions about NOTE and all three dimensions of the *NGSS*.
- Plan some questions in advance to ensure they are effective.
- Use students' ideas to push the conversation further.
- Let go of some of the control. You can still structure the environment, but try not to overstructure students' thinking.
- Ask yourself, "What decisions can students make?" to help the environment be more student-centered.
- Make sure students know it's okay to make mistakes and make adjustments.
- Structure the task into segments to ensure students aren't overwhelmed.
- Provide connections to the real world as much as possible (e.g., pictures of simple machines).
- Remind students the process is more important than the final product.
- Keep making small changes over time.

and modeled how they would give a pitch to their "clients." As we walked around the room, we heard active listening statements such as "that's a good idea" or "maybe we can do it like …" As students progress, we provide scaffolding to groups who needed assistance, which often included helping the groups process how to decide who was going to present which part.

On day 6, each group presents their technology to the class. Students enjoy showing their classmates their final product and their optimized technology. The students were accurately connecting their technology to the NOTE and forces objectives. We assess students' ideas using a standard-based grading approach and work to provide effective feedback by giving specific examples focused on the learning targets (Edgerly, Wilcox, and Easter 2018). Overall, we noticed much more depth in their understanding of science and NOTE with this process than when we just did engineering tasks.

CONCLUSION

As we transitioned from "activitymania," we noticed we had to be more intentional about helping students see the connections between the activity, the *NGSS* standard, and NOTE.

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

Standards

3-PS2 Motion and Stability: Forces and Interactions

www.nextgenscience.org/pe/3-ps2-1-motion-and-stability-forces-and-interactions

- 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 expectation listed below.

Performance Expectations

3-PS2-1. Plan and conduct an investigation to provide evidence of the effects of balanced and unbalanced forces on the motion of an object.

DIMENSIONS	CLASSROOM CONNECTIONS
Science and Engineering Practice	
Planning and Carrying Out Investigations	Students make iterations to their designs changing only one variable at a time. Students plan and build a simple machine and then present how their machines relate to balanced and unbalanced forces.
Disciplinary Core Ideas	
PS2.A: Forces and Motion Each force acts on one particular object and has both strength and a direction. An object at rest typically has multiple forces acting on it, but they add to give zero net force on the object. Forces that do not sum to zero can cause changes in the object's speed or direction of motion.	Students draw pictures of forces and describe how forces act on their simple machines.
Crosscutting Concept	
Cause and Effect	Students were asked questions about cause and effect and address cause and effect in their presentations. For example, students were asked how making the forces unbalanced would change how their technology moved.

This intentionality required us to ask explicit/reflective questions about NOTE and to connect to the *NGSS*. As we wrestled with how to effectively teach engineering alongside science content, we developed a list of principles that guided our decision-making (Figure 4, p. 66). While incorporating NOTE into lessons takes effort, gains our students made in the understanding of NOTE and the *NGSS* was worth it. ●

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