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Teaching Educators About Engineering: Preservice elementary teachers learn engineering principles from engineers

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Abstract

Few elementary teachers have experience with implementing engineering into the classroom. While engineering professional development opportunities for inservice teachers are becoming more numerous, engineering education is rarely required or even offered in elementary teacher-preparation programs (O'Brien et al. 2014). To prepare future elementary teachers to teach engineering, a collaborative partnership was formed between professors in Iowa State University's College of Engineering (CoE) and School of Education (SoE). The partnership included teacher education faculty in science and mathematics education and three engineering faculty who provided perspectives on content, knowledge, and skills foundational to engineering. Members of the partnership worked together to co-plan and co-implement engineering experiences across a teacher education program. These experiences included building engineering content knowledge through a Saturday short course, inclusion of engineering in methods courses, and a summer workshop that preceded a partnership with an engineering graduate student. This article describes the Saturday short course provided to prospective elementary teachers by three members of the engineering faculty and two from the teacher education faculty.

Disciplines

Early Childhood Education | Educational Methods | Engineering Education

Comments

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Engineering Encounters

Creating a classroom culture for engineering

Teaching Educators About Engineering

Preservice elementary teachers learn engineering principles from engineers.

By Kristina M. Tank, D. Raj Raman, Monica H. Lamm, Sriram Sundararajan, and Anne Estapa

Few elementary teachers have experience with implementing engineering into the classroom. While engineering professional development opportunities for inservice teachers are becoming more numerous, engineering education is rarely required or even offered in elementary teacher-preparation programs (O'Brien et al. 2014). To prepare future elementary teachers to teach engineering, a collaborative partnership was formed between professors in Iowa State University's College of Engineering (CoE) and

School of Education (SoE). The partnership included teacher education faculty in science and mathematics education and three engineering faculty who provided perspectives on content, knowledge, and skills foundational to engineering. Members of the partnership worked together to co-plan and co-implement engineering experiences across a teacher education program. These experiences included building engineering content knowledge through a Saturday short course, inclusion of engineering in methods courses, and a sum-

mer workshop that preceded a partnership with an engineering graduate student. This article describes the Saturday short course provided to prospective elementary teachers by three members of the engineering faculty and two from the teacher education faculty.

Overview

The short course sought to educate prospective teachers about several fundamental aspects of engineering highlighted in the NGSS, including defining a problem, synthesizing and evaluating solutions, and performing tests and analyzing results. We wished to build upon prior research recommending that teachers understand engineering design and be able to explain what engineering is, what engineers do (Diefes-Dux 2014), and similarities and differences between science and engineering. Furthermore, we linked engineering concepts to real-world examples to emphasize the importance of iteration and failure and provide reflection time around incorporating this content into the elementary classroom. The course was delivered as half-day sessions on three consecutive Saturdays due to constraints within the four-year teacher preparation structure, limited prospective teacher flexibility, and instructor availability.



PHOTO COURTESY OF THE AUTHORS

Preservice teachers test their bridge as part of the Day 1 bridge design competition.

Day 1: Engineers and Engineering Design

To set the context for the course, we discussed the recent NGSS adoption within our state, highlighting connections of course goals with the engineering practices and engineering design components of the standards. The next piece was to develop an understanding of the field and “What Do Engineers Do?” with a discussion around multiple definitions of engineering (see Internet Resources). For instance, Albert Einstein once said: “Scientists investigate that which already is; engineers create that which has never been.” As a group, we continued this idea through a discussion around the scope of engineering, which is often not appreciated outside of the discipline (e.g., research and development and design [Eide et al. 2012]).

To illustrate the many facets of engineering, we discussed how the accidental discovery of microwaves (*research*) led to the initial commercialization of microwave technology in the 1940s (*development and design*). Initially, these devices were too expensive for the general public; however, after 70 years of iterations through the engineering design process, the cost dropped exponentially, and it became a household staple. The discussion also delved into how fundamental scientific inquiry regarding the nature of matter was a key first step in the development of the microwave oven and how science and engineering complement one another.

Following an introduction to the field, prospective teachers engaged with an engineering design task that included multiple stages of engi-



An arch activity explores tension and compression forces.

neering: problem formulation and needs assessment, idea generation, analysis, building and testing, and evaluating and iterating. They did this through a small-group bridge design competition asking them to create a bridge that met the following constraints: one piece of copier paper, one mailing label, limited time, and must support 200 g weight for 10 seconds. The competition also had one criterion: the end-to-end length, or span, needed to be as long as possible. After building and testing their bridges, we revisited the concepts of criteria and constraints to reiterate the importance of creating realistic engineering design scenarios. We also discussed approaches to restructure the competition to include important concepts within engineering that are also suitable for students in grades 3–5. We ended

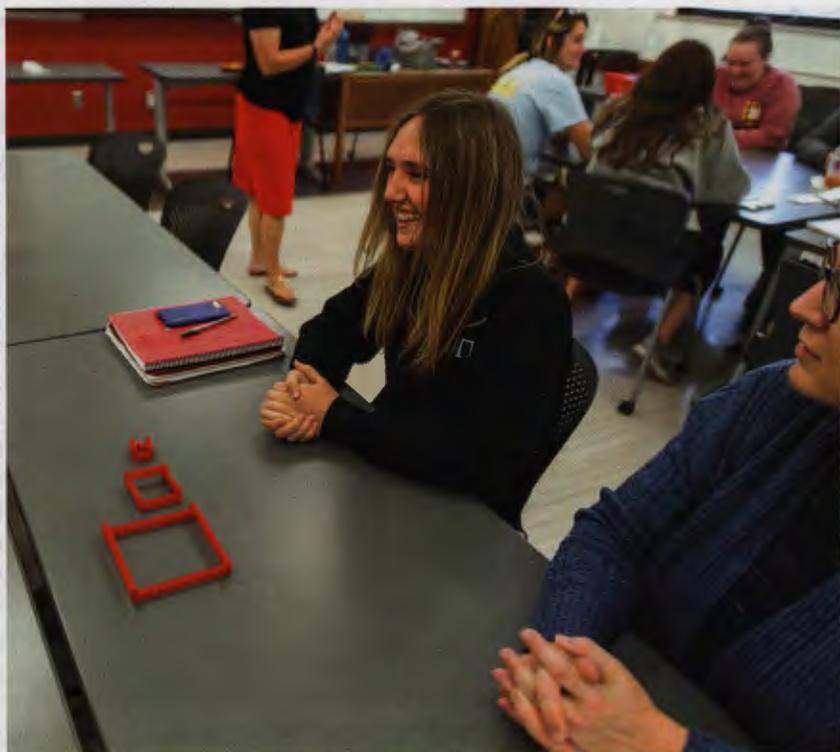
with a reflective discussion about approaches to making meaningful engineering exercises for elementary students, focusing on the importance of:

- tying math or science into the existing curriculum,
- providing a real or imaginary context for the exercise, and
- offering opportunities to test and redesign.

Day 2: Test Engineering and Data Analysis

We began Day 2 by emphasizing that engineering encompasses more than building bridges and airplanes. Chemical engineering—the disci-

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Teachers try out a batch assembly line approach.

pline of the Day 2 instructor—produces much of the material for our technological civilization and is one of the most gender-diverse engineering fields, but students seldom realize that this discipline even exists. The chemical engineering context, created by the engineering faculty in this partnership, illustrates the engineering design aspects of the NGSS that focus on performing tests and analyzing results.

Specifically, the scenario involved a local bakery wishing to scale up production of quick bread to sell to grocery stores in the area. Since this was a new venture for the company, the data for the best formula for scaling up its recipes was not available. To generate data,

prospective teachers engaged in test engineering, which includes testing proposed concepts in prototype format, testing devices coming from an assembly process to ensure they are meeting specification, and evaluating new materials that may be used in a design. This provided an opportunity to highlight the similarities between test engineering and science. We also emphasized the importance of collecting data and documenting the processes used, which are important engineering practices within the NGSS.

Prospective teachers then engaged in a hands-on laboratory exercise to test how quick bread leavening agents (e.g., baking powder, baking soda, cream of tartar) inter-

act with water and vinegar to create bubbles. This provided evidence of chemical reactions during the testing of these different agents. Prior to the start of this exercise, prospective teachers learned safety protocols for the lab and were provided safety goggles to be worn throughout the investigation.

We coached prospective teachers to devise their own trials and data collection schemes. The prospective teachers worked in pairs and all teams used a strategy for data collection that demonstrated the concept of varying the amount of one ingredient while holding the amounts of the other ingredients constant. Midway through the lab, they used their data to develop an explanation for the chemical reactions as they tried different combinations of ingredients. The laboratory session ended with a debriefing by the instructor on the fundamentals of acid-base chemistry.

The prospective teachers then moved to a computer lab for a lesson on data entry and analysis in Microsoft Excel. They created a table presenting the leavening agent test data to help choose the best formula for scaling up their recipes. The instructor concluded this exercise with a discussion of the law of conservation of mass, process scale-up, and other types of engineering and expertise needed within the context of this challenge. This led back to course goals around engineering and what engineers do. Day 2 concluded with an open-ended discussion involving the career paths of the three engineering faculty, driven by questions about why instructors chose a career in engineering.

Day 3: Creating Science and Math Connections

One of the more challenging aspects of integrating engineering into elementary classrooms is teaching meaningful connections to math and science (Capobianco and Rupp 2014; Diefes-Dux 2014). Therefore, the third day focused on three concepts:

- including a real or imaginary context within engineering design challenges,
- helping prospective teachers see possible math and science connections in the engineering design challenge from Day 1, and
- introducing students to another uncommon field of engineering—industrial engineering.

Students repeated the Day 1 bridge design challenge with a focus on including a math and science connection for the activity as well as placing the challenge within a realistic social context. The modified design challenge began with a discussion of the importance of scaling (beginning with a review of the largest bridges in the world) within mathematics and the concepts of compression and tension within science. To further their understanding of compression and tension, prospective teachers formed an arch with a partner, which allowed them to feel tension and compression forces, as a third student pulled on the arch. The activity highlighted how this challenge could be placed

in a social context related to designing a bridge over a river. We closed the activity with a discussion of how including a realistic context changed the participant experience of this bridge design challenge.

The next part of Day 3 focused on industrial engineering and explored approaches for making an assembly line more efficient. After examining several real-world examples of assembly lines—including images of automobile, washing machine, and bottle assembly lines—three teams of teachers were given identical collections of Lego bricks. The teams were also shown a diagram of a “target” structure that could be built with the bricks. The teams competed to produce the maximum number of error-free (i.e., exactly matching the target) structures in a fixed amount of time.

After our initial “free for all” approach, we discussed a station-based approach, where each individual at a station assembled one or two pieces before passing it onto the next station. We also explored a batch production model where each individual needed to complete a batch of three to four assemblies before passing them on to the next station. Teams participated in the task again to demonstrate how this type of approach was superior to their initial approaches.

Prospective teachers asked to create their own assembly line structure, and a final competition was held, yielding the highest rates of error-free structures. Some examples of changes made to the assembly lines included ensuring sub-assemblies were moved from one station to another in order to minimize errors and redistribute tasks between stations.

This last phase of the activity allowed prospective teachers to use what they had learned in previous iterations as well as creativity and originality in designing the assembly line process. Day 3 ended with a review of characteristics of good engineering activities and examples—namely that they tie into math and science content, have a real or imaginary context, and allow for iteration within an engineering design process.

Conclusion

We learned several lessons from planning and implementing the partnership. There was a pre/post assessment of teacher perception and understanding of engineering based on the Design, Engineering, and Technology (DET) Survey (Hong, Purzer, and Cardella 2011). After completing the course, prospective teachers reported feeling more confident and prepared to integrate design, engineering, and technology into their instruction. These are crucial attributes for teachers. To promote student learning and engagement within the classroom, teachers must have the confidence and motivation to enhance their own learning of content and enactment skills (Blumenfeld, Kempler, and Krajcik 2006). As a result of participating in the course, prospective teachers also showed a positive gain in their ability to define an engineering problem, synthesize and evaluate solutions, and clearly explain and express what engineers do.

Based on our experience with the design and delivery of the course, we came up with key takeaways for those planning, facilitating, and delivering

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engineering experiences with prospective teachers. First, the partnership with engineering and education faculty was a crucial component. Prior to this course, the facilitators had not regularly worked with prospective teachers, and the education faculty had limited experience within engineering. For example, assumptions of working within Excel and using data to develop explanations for the lab were made based on experiences working with undergraduate engineering students. Second, it was important that this course help prospective teachers to better understand engineering design as well as being able to explain what engineers do. Third, prospective teachers reported that while they learned a lot about engineering, they felt there was a missing link between the standards and classroom application. Therefore, it was important to have a connection back to standards and classroom practice while also delivering content.

Each of these factors provides a foundation for prospective teachers to enact and integrate engineering into their future classrooms. As prospective teachers gain a deeper understanding of engineers and engineering, this knowledge will help them to better understand what the integration of engineering can look like in the elementary classroom. Further, having insight and experience with purposeful engineering activities will support these teachers as they introduce and engage students in learning about engineers and engineering. As we work to support teachers with integrating engineering into their classroom and curriculum, partnerships become important to provide learn-

ing experiences that model integration across content areas. ■

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Internet Resources

Definitions of Engineering

www.design.caltech.edu/erik/Misc/design_quotes.html

Yale New Haven Teachers Institute
<http://teachersinstitute.yale.edu>

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

3–5 ETS1 Engineering Design

www.nextgenscience.org/dci-arrangement/3-5-ets-1-engineering-design

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 Expectation	Connections to Classroom Activities <i>Preservice Teachers:</i>
3–5-ETS1-3: Plan and carry out fair tests in which variables are controlled and failure points are considered to identify aspects of a model or prototype that can be improved.	<ul style="list-style-type: none"> engaged in a model bridge design competition to meet specific constraints on materials and criteria for success. planned and carried out fair tests of bridges, controlled variables, and failure points, and gathered data and assessed results.
Science and Engineering Practices	
Asking Questions and Defining Problems Analyzing and Interpreting Data	<ul style="list-style-type: none"> revisited the bridge building to highlight the importance of setting a context and identifying criteria and constraints when defining engineering problems. analyzed data generated from the revisited bridge building investigation.
Disciplinary Core Ideas	
ETS1.A: Defining and delimiting engineering problems <ul style="list-style-type: none"> Possible solutions to a problem are limited by available materials and resources (constraints). The success of a designed solution is determined by considering the desired features of a solution (criteria). Different proposals for solutions can be compared on the basis of how well each one meets the specified criteria for success or how well each takes the constraints into account. 2-PS1.A: Structure and Properties of Matter <ul style="list-style-type: none"> A great variety of objects can be built up from a small set of pieces. 	<ul style="list-style-type: none"> designed and built bridges that met constraints and criteria, and compared solutions based on how well each met specifications. reiterated the importance of creating engineering design scenarios that are realistic to engineering and therefore bounded by criteria and constraints.
Crosscutting Concept	
Scale, Proportion, and Quantity	<ul style="list-style-type: none"> reiterated the importance of creating engineering design scenarios that are realistic to engineering and therefore bounded by criteria and constraints.