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Engineering in the K-12 Classroom

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Engineering in the K-12 Classroom (works in progress)

Abstract

Engineering in the K-12 classroom has evolved at an increasingly steady pace for several decades and is now building greater momentum with the inclusion of engineering design and engineering practices in the Next Generation Science Standards[1]. In-service educators have sought engineering content knowledge through professional development, coursework and self-study. The foundational underpinnings of this advancing educational sphere are still in development. Contributions to the emerging base of knowledge include elements such as the integration of STEM content[2], an orientation towards engineering design, and engineering habits of mind[3], including systems thinking. Yet how educators autonomously integrate engineering into their own classroom is not completely understood.

This paper describes a collaborative School of Engineering and School of Education program focused on engineering education[4]. This research focuses on a capstone course in a series of engineering education courses, and new knowledge gained and used by both the instructors of the course and the students involved in the course. This course was taught using the NGSS science standards as an overarching guide for K-12 science/engineering performance expectations. These expectations were then framed by the Lesh Model[5] for curriculum development as teachers were guided to create their own curriculum unit. The course focused on events that would allow teachers experience in engineering design. Teachers debriefed after activities based on specific areas of focus. While the integration of STEM elements is key to course content, the coursework in this program focuses on how engineering influences the student learner with an eye to academic standards.

The inclusion of engineering in Next Generation Science Standards (NGSS) has allowed educators to consider science education in student empowering contexts. Performance expectations for engineering design weave together the science and engineering practices, disciplinary core ideas and crosscutting concepts in an environment that may allow students to understand integrated subjects (including engineering and mathematics) at a deeper level. By diving deeply into a limited number of content areas students will be able to transfer the "big ideas" into a connected construction. It is anticipated that the number of states adopting NGSS will grow in the near future, yet the current status is that a limited number of states have actually adopted NGSS. Teachers integrating NGSS are balancing state academic standards expectations while considering new content contexts including engineering design.

This paper will provide an overview of the capstone course content, specific teachers' experiences throughout the course based on written reflections, and the preliminary analysis of the implementation of a teacher created integrated STEM unit in their own classrooms. Written reflections were gathered throughout the course. These reflections, in conjunction with the course goals, provide the framework for classroom observations. Preliminary data collected from written reflections, surveys, interviews and classroom observations are included.

Introduction and Research Question

The preliminary research described in this paper explored the impact a course on engineering education may have on participants and the subsequent impact that participants may have on students in the K-12 classroom. Participants in the course explored engineering design, engineering practices, NGSS and the application of these to the K-12 classroom. This paper highlights preliminary results on teachers and their K-12 students through teacher reflections, student work, and class observations focused on the following questions: *What key ideas from the engineering education capstone course (engineering design, engineering practices, etc.) are used in a teacher created unit for the K-12 classrooms? What do teachers' reflections and actions suggest are the benefits of the engineering capstone course? How are the key aspects reflected in students' understanding of engineering after completion of the unit?*

Engineering in the P-12 Classroom Course Details

Engineering in the P-12 Classroom is the capstone course for both an undergraduate minor in engineering education and a graduate certificate in engineering education. The course, co-taught by professors in the School of Education and the School of Engineering, provides students with a comprehensive survey of existing engineering education programs, engineering education research, and a critical stance for evaluating existing and self-created curriculum. Emphasis is placed on NGSS and mathematical thinking, including the Lesh model, as a way to think about curriculum design. Courses that students take prior to the capstone course include a fundamentals of engineering course, an engineering design course, and at least one engineering focused elective. In summer 2013, the course referred to in this paper included 12 graduate students (in-service educators) and 2 undergraduate students (pre-service educators).

The course objectives are for the students to do the following:

- demonstrate required engineering knowledge, skills and dispositions;
- delineate P-12 engineering education programs;
- evaluate successful engineering programs for educators;
- **develop an instructional unit or module that incorporates engineering into their licensure are, including assessment plans**;
- analyze engineering education content and pedagogy;
- list appropriate academic standards and resources.

Multiple readings and discussions continued throughout and after the term online. Required readings included:

- *A Framework for Science Education: Practices, Cross Cutting Concepts and Core Ideas,*[6]
- *The NSTA Reader's Guide to A Framework for K-1 Science Education,*[7]
- *Next Generation Science Standards*[1],
- *How People Learn: Brain, Mind, Experience and School*[8] and
- *Engineering in K-12 Education*[3].

Course Content Modules

Course content reflects experiences created to help the course participants construct a high quality engineering unit for K-12 students. Experiential learning was included in each module and expert voices were presented for several modules. Considering engineering education concepts in terms of living through the students' own engineering design problems was more than an exercise in presenting many engineering design scenarios; rather living through the frustration and elation that engineering design presents was critical in order for participants to consider practical lessons that would need to be transferred to their own students. Modules included: historical development of and research on engineering education; engineering curriculum materials and programs; the role of competitions, challenges, camps and informal engineering; learning theory and engineering; lesson planning, assessment and engineering; engineering practices in the K-12 classroom; the influence of engineering and technology on society; participant microteaching and curriculum unit development; *A Framework for K-12 Science Education*; and final project discussion.

Preliminary Findings

A case study of classroom to practice allows for a preliminary understanding of the course strengths and weaknesses. Data was gathered from multiple interventions including reflections from the summer course, classroom observations while the teachers were teaching in the K-12 classroom, teacher interviews, and student interviews. Teacher reflections from the summer course were studied to identify key understandings and areas of interest. Observations focused on teacher pedagogy and student engagement in the engineering design process. Student interviews focused on how the students understood engineering and their role as an engineer.

Case Study of Educators Experiences

Three teachers enrolled in the capstone course with the intention of working as a group to learn about engineering. They are a kindergarten teacher, third grade teacher and sixth grade math teacher, who all teach in the same school. These teachers and their educational setting provided a unique look at the implementation of an engineering design experience for several reasons. First, the setting is a small K-8 school with limited resources. Second, this school and these teachers had never created an engineering or STEM project before this point. Third, the three teachers were interested in creating an engineering project that would span the kindergarten, third grade and sixth grade classes. And fourth, the unit studied was created based on a need these teachers identified in their own school. This was of special interest for the researchers since a key focus of the capstone course was to understand that engineers solve real problems. These teachers agreed to serve as a case study and the following findings focus on these in-service educators.

Teacher reflections, student interviews, classroom observations, and teacher interviews corroborated the findings. The case study allowed for the following data collection: student interviews, classroom observations, and teacher interviews. Themes which surfaced include an understanding of the necessity of an engineering design process; a recognition of the importance on redesign; evidence of increased interest and efficacy; integrated learning; connections to real world problems; and engineering habits of mind including systems thinking, creativity, optimism, collaboration and communication.

Case Study Curriculum: The Engineering Design Unit

The teachers created a unit that focused on students creating a machine or method for reducing the waste of the small milk cartons used in schools for snack and lunch. Each grade focused on a different part of the project, always attending to the overarching goal of reducing waste and the space of that waste. They talked about the environment, the custodian, and the need for change.

Case Study Data: Teacher Interviews

Once engaged in the engineering project, the teachers were interviewed. Jan, a Kindergarten teacher with nine years of experience, shared apprehension early in the project with a focus on redesign and content integration, "It feels a little overwhelming at this point. We are recycling in our class, but that is easy, the student just walks over to the sink, rinses it out, and put it in the recycling bin. We are working with the third graders and they are creating the crushing system. We tested it out and we found out that 5-6 years old are not exactly strong enough." Jan hinted at a new understanding of engineering for her students "Sometimes I think engineering is such a big thing. And I think we have to create something; and it has to be mechanical; and it has to be all those things that I think of when I think of engineering; but these students think that everything that they build and create is engineering." Jan also pointed to the math concepts that the project was allowing her to reinforce in a different context, "We talk about volume and space in our mathematics curriculum but we talk about it to a new extent with the milk cartons." Jan's reflections show the complexity that engineering tasks can present to teachers but highlights the benefits and the connections with mathematics that students can take away.

Carry, a third grade teacher with 20 years of experience, shared her surprise and delight in how the project had progressed, the real world aspect of the project, and the integration of content. She shared, "what really amazed me at how easy it was to tie the project into different subject areas. The math - they made two different graphs. Then we brainstormed how many things we already do at school... Another thing that really impressed me is how creative they were. We talked about all the factors you need to consider if you're going to build or design, for example, safety, expense and simplicity... At the very end of our process they wrote a little reflection on the whole process." Carry also spoke of how individual student learning was different with the engineering project, "You may not do as well as you planned and that's just a life lesson. And [a strong student who experienced redesign] was fine with it. I just remember her saying 'oh that didn't work very well' under her breath'." Carry shared her own evolution in considering engineering projects, "I thought engineering was something way beyond what I would ever be able to do to. It was much too difficult math. I did fine with math in school but it now it seems a lot more feasible; especially when you think of the creativity of it; and like you said it's ok if something doesn't work the first time; you try to alter it so it will work." These lessons of engineering being accessible to all and the importance of an engineering design process that allows for rethinking an idea are critical for teachers to understand.

Lori, an experienced middle school mathematics teacher, reiterated her colleagues' observations of surprise and delight in her students' learning. "The project has been going very well. Had we not taken the class we wouldn't have even ever approached a project like this." She also focused on the collaborative aspect of this project and used some of the language from the summer course, "It has been nice to ask the other teachers, 'how are you approaching this and how are your students thinking about this or that?' Students have really gotten into it. They came up with great ideas, even students who I thought were quiet came up and shared their ideas... Just figuring out what the environmental problem was could be was interesting and eye opening for the students. Students came up with their own constraints and they surprised me. They came up with constraints that I hadn't even thought of. It's interesting to see that they are pulling in ideas from what they learned last year on simple machines." It is clear she saw her students working to define problems, develop models, and looking at factors outside the initial problem.

Case Study Data: Student Interviews

Student interviews were conducted at various points through the engineering project. Students noted a high level of interest in working on the project, an enthusiasm for working with other grades on the project and the importance of helping: helping the environment and Bob, the janitor, whose work load would be reduced. Students in each grade demonstrated a wide range of engineering language, habits of mind and engineering design competence. The kindergarten students relayed real-world needs for their project. Students shared "we are recycling the milk cartons because Bob has a lot of work to do", "I don't want to leave all the milk in (the carton)... it's like pouring 50 cents down the drain." and "it's bad for the landfill". These real world needs, specifically helping Bob and the environment, were echoed by the third and sixth grade students.

The kindergarten students talked about science and engineering practices. May began with science observations and continued with her understanding of engineering design, "The apple didn't die. The lettuce died. And the foam didn't die. We drew pictures about the rinse [station]. We have ideas on how to do the garbage. We drew some pictures about ideas and we shared the papers. I worked with Mitchell." Mitchell described steps in the engineering design process, "We had special engineering paper. We had those little tiny squares on them. We had partners so I was May's partner; Kay was Ethan's partner. We all worked together. Then we did it again on the whiteboard to make it bigger. Then Alex's idea was that there would be sprayers on the side."

The third graders focused on their part of the project. They described the pre-project gathering of information: learning about recycling and waste, calculating the number of milk cartons they were using, and using an engineering design process to create a milk carton crusher. They were aware of the environmental and personnel reasons that this project was important. They were able to describe the many pieces of the project. All of the students interviewed said they enjoyed the project and would like to do more work like this. In addition, all students that were asked understood that it was acceptable to have failure and they even described how they redesigned their work after initial failure. Interestingly, most of the students were not able to articulate the mathematics and science involved in this project, even after they described those elements.

Appropriately, the sixth grade students engaged in and described the engineering project with a nuanced understanding. While the need was consistent with the two younger grades, their engagement in the design process was refined, "we were trying to figure out a way to build a prototype. So we can figure out how it can work and how the other classes would crush the cartons. Then we would dispose of them." "We have done our own drawings and drawn with other classmates. We were trying to mix the ideas into one full idea. We got close but I don't think we are done yet. There are disagreements on whether we should do one thing or another, but we will figure it out." When asked if math or science has been part of the project one student responded, "Yes we had to figure out how much it would weigh for all of the cartons and then how many cartons we would dispose of. I would much rather do this than math. Math is hard, (laughing) and I don't like it but, well it gets kind of hard at times, but we were still doing it." Clearly this project has reinforced engineering design and engineering habits of mind, including systems thinking, creativity, optimism, collaboration, communication and attention to ethical considerations, but it has also allowed for deeper engagement.

Case Study Data: Classroom Observations

Students were observed in their classrooms while they were engaged in various stages of their engineering projects. The Kindergarteners' observation came at the beginning of the project as the teacher facilitated a conversation. Students reiterated comments that they made during interviews and displayed an understanding of the steps they had completed in the engineering design process. The third grade class also relayed the steps that they had completed in their engineering design process and shared what they believed were the next steps in their engineering process. The sixth grade class was in the process of consolidating individual design ideas into small group proposals with preliminary engineering sketches. Students shared their individual and group processes, as well as their initial analysis of their designs. Most interesting was the unsolicited sixth grade algebraic modeling of options. All of these observations reflect ideas from the summer course, from sharing group ideas to creating sketches to understanding the steps in the engineering design process.

Lessons Learned and Next Steps

Important lessons on the course strengths and weaknesses were gleaned from this small study. Lessons learned for future course offerings include the need to identify and reinforce the web of learning which occurs with engineering design. In their own classrooms, some teachers were able to identify learning objectives far beyond the scope of the course. For example, one teacher connected science, math, reading, writing and social studies into a single engineering design unit. However, her students were not all able to explicitly articulate or even identify the mathematical connections that they were making as they completed the unit. This lack of connection by students identifies the need for teachers to make explicit connections and the need for professional development to focus on this need. Improving our ability to help teachers create a common language regarding engineering and its connections to other content areas is an important point for consideration as the course evolves.

Exploratory data provides a preliminary understanding of factors necessary to answer the research questions: *What key ideas from the engineering education capstone course (engineering design, engineering practices, etc.) are used in a teacher created unit for the K-12 classrooms?* The students in these classes demonstrated the ability to execute engineering design as defined by grade appropriate NGSS Engineering Design performance expectations. *What do teachers' reflections and actions suggest are the benefits of the engineering capstone course?* Teachers' reflections and actions indicate their participation in the engineering capstone course allowed them the knowledge and efficacy necessary to construct and execute an engineering design experience for their students. *How are the key aspects reflected in students' understanding of engineering after completion of the unit?* Students demonstrated grade appropriate abilities to execute engineering design. Future study will focus on more detailed examples of these preliminary glimpses into engineering curriculum construction.

Research on the teacher and student engineering design experience allows practitioners a nuanced understanding of the benefits and pitfalls that this experience may hold. The researchers of this work-in-progress look forward to continuing this work in order to better understand the integration of engineering in the K-12 classroom.

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