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”Engineering teaches problem solving”: Teachers’ perceptions of student learning through engineering lessons

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"Engineering teaches problem solving": Teachers' perceptions of student learning through engineering lessons (Research to Practice)

Introduction

Engineering in elementary school classrooms is a growing trend. Standards and assessments at local, state, and national levels are increasingly incorporating engineering into existing subjects like science or math or creating standalone engineering requirements [1, 2]. Engineering practice encompasses a multitude of technical, personal, and interpersonal skills such as engineering design and problem solving, creativity, and teamwork [3]. More research is needed to understand what engineering can provide K-12 education that is developmentally appropriate and necessary, especially at the elementary level.

One avenue to understanding more about what incorporation of engineering in elementary classes can provide is to research what teachers believe their students have learned and are capable of learning through engineering lessons. Teachers' classroom experiences and perceptions are invaluable as researchers seek to maximize the learning potential of students. While engineering standards have been developed for students in elementary grade levels[1], there is a need to also explore other learning outcomes that may be associated with the integration of engineering.

Purpose and Research Questions

The purpose of this study is to explore what learning outcomes teachers' perceive their students have experienced through the integration of engineering lessons into their classrooms. This study provides some insight into what teachers perceive their 2nd – 4th grade students have learned as a result of integrating engineering lessons. Standards, assessments, and engineering curricula provide a basic framework for possible and expected learning outcomes from engineering lessons. This study explores teachers' responses to an open-ended interview question to better understand whether these expectations have been met.

Specifically, we asked the following research questions: 1) What did teachers perceive students learned through participation in engineering lessons? 2) How did teachers' perceptions about student learning differ by grade level? and 3) How did teachers' perceptions differ by school?

Literature Review

In a document titled "Engineering for Children?!" [4], engineering is said to integrate multiple disciplines including science and mathematics, foster problem-solving skills, and increase students' awareness of and access to STEM careers like engineering. The American Society of Engineering Education's K-12 division agrees that engineering enhances math and science learning while connecting coursework to real-world applications [5]. Engineering activities are also touted as a way to reach English language learners, girls, and minorities and increasing their participation and learning in science classrooms [6-8]. Diaz has divided engineering education in K-

12 curricula into three main categories: 1) Attracting students to engineering and technology programs, 2) Increasing academic performance in science and mathematics, and 3) Increasing technological literacy [9]. Engineering education at the P-12 level is believed to provide many different learning outcomes, often with a focus on technical skills like math, science, problem solving, and engineering design.

As an increasing number of engineering programs began to appear in intra- and extra-curricular formats and STEM, an acronym for science, math, engineering, and technology, began to be an educational buzzword, engineering began to appear in educational standards [2, 10]. Massachusetts was the first state to introduce standalone engineering standards in 2006 [1]. Carr, Bennett IV, and Strobel found that 22 states had engineering standards in some form for grades K-5 as of 2012 [1]. The incorporation of engineering in the Next Generation Science Standards, based on the National Research Council's Framework for K-12 Science Education, may see many more states adding engineering education to their elementary school classrooms [7, 11]. Additionally, the National Assessment of Educational Progress is adding a Technology and Engineering Literacy Assessment to its roster of examinations, testing students' engineering skills at grades 4, 8, and 12 [12]. Many of these standards and assessments include engineering design and problem solving explicitly, while some incorporate aspects of engineering into mathematics or science standards.

There are many programs available to educators for use in their elementary classrooms using various strategies to teach engineering and promising different learning outcomes [3, 10, 13]. Few of these programs have in-depth program evaluations or assessments [3, 9]. Those that have often use surveys or simple assessment tools; the full extent of what students can and do learn from engineering lessons at the elementary level is not yet understood. A better understanding of what engineering provides for elementary school students can help teachers to choose engineering curricula to best fit their needs and integrate engineering appropriately into their overall curriculum.

Background

As part of a NSF grant, a five-year partnership between the Institute for P12 Engineering Research and Learning (INSPIRE) at Purdue University and multiple elementary schools in a large school district in south central United States was formed to bring engineering into 2^{nd} – 4^{th} grade classrooms. Teachers from participating elementary schools volunteered to implement engineering lessons for a minimum of two years. They took part in summer professional development academies to learn engineering content knowledge and pedagogy in preparation for teaching the engineering coursework. Teachers were not expected to have prior STEM experience in order to participate.

The goals of the teacher professional development were to: 1) Convey a broad perspective of engineering, 2) Articulate differences between engineering and science thinking, 3) Develop a level of comfort in discussing engineers and engineering with elementary students, and 4) Use problem-solving processes in order to engage students in open-ended problem solving. Participating teachers were provided with engineering curricula and materials to implement in their classes. Teachers were to introduce engineering into their classrooms through lessons of "What is Technology?" and "What is Engineering?" After the introductory lessons, they were asked to teach one *Engineering is Elementary* (*EiE*)[14] unit. The *EiE* units were mapped to the science standards for each grade level. Each unit was comprised of four individual lessons: 1) A story contextualizing the engineering field and design project, 2) A hands-on lesson introducing the engineering field involved in the unit, 3) An inquiry-based science lesson to teach and/or reinforce the underlying scientific principles needed, and 4) An engineering design project using the principles learned in the prior three lessons. Teachers were encouraged to implement additional design experiences if possible. Students worked in teams to solve open-ended design problems. Teachers' perceptions of student learning are based on their experiences while implementing these lessons.

Several measures were used to assess the outcomes associated with the professional development program. The Design, Engineering, and Technology (DET) survey[15, 16] was used to understand teachers' perceptions of teaching engineering and engineering design and found that teachers often had stereotypical views of engineers[17]. Students' engineering perceptions, knowledge, and science knowledge outcomes have also been analyzed using knowledge-based tests, Draw an Engineer Tests (DAET)[18, 19], and the Engineering Identity Development Scale (EIDS)[20-22]. The focus of this study is the open-ended responses from teachers during the first-year interviews to understand their perceptions of student learning.

Participants

Twenty-seven (27) grade 2 to 4 teachers from eight participating schools (Table 1). The majority of teachers, twenty-four, were female, and three were male.

Table 1. Teacher Participants by Grade and School

	School								
Grade	A	B	C	D	E	F	G	H	**Total**
2nd	2	1	1	1	1	2	2	0	10
3rd	1	1	1	2	1	3	1	1	11
4th	1	1	1	1	1	0	1	0	6
Total	4	3	3	4	3	5	4	1	27

Method

At the end of each school year, teachers participated in semi-structured interviews regarding their experiences integrating the engineering lessons in their classrooms. This study uses the first year data because it is the only year during the project that teachers were explicitly asked "What do you think students learned?" The interview protocol changed the second year of the program to focus more on implementation of lessons and classroom experiences.

Interviews were transcribed and open-coded. Based on emergent themes, a coding scheme was developed. A team of three students coded the transcripts, meeting with the researchers to ensure reliability through consensus while coding. Researchers noted eight major emergent themes and included a category, 'Other', for all responses that did not fit within the main themes. Example responses are given in Table 2.

Table 2. Representative Responses by Theme

Theme	Representative Response (*School,Grade*)
Vocabulary	I do believe they learned a lot of the vocabulary. (*G,2*) They really learned a lot of the vocabulary. (*G,3*)
Technology	Technology. They did learn about that. (*B,2*) I think they could give you a pretty good definition of what technology is. (*F,3*)
Try Again	When they started putting it together, they were, oh no, we have to start all over again and try something else. (*D,4*) I think that they learned the importance of making mistakes, continuing to try to improve things that, that you should never be completely content with the way something is, that you should always be striving to make something better, stronger, easier. (*G,2*)
Personal Responsibility	So, they had to learn responsibility. (*E,2*)
Teamwork	Most of them learned how to work together. (*A,2*) I think as they were doing a lot of the subsystem, they have learned that team work and group work is vital. (*F,3*)
Problem Solving	I think they learned some problem solving skills. (*C,4*) To talk about what they're learning, you know, to write it down and just plan things out and think about it. (*D,4*)
Other	They've learned simple machines. (*B,3*) They learned what the engineering process is. (*F,3*)
Types of Engineers	That it could be different processes, like with chemical engineers...and manufacturing, you know designing different ways to make things. (*A,2*) I think they learned what engineers do and that there's lots of different kinds of engineers. (*C,3*)
Deeper Thinking	They can't just consider one thing. (*B,4*) I think it provides a way for them to think a little differently than just...in the box. (*G,3*)

Results

Responses were viewed as a frequency count over all interviews and disaggregated by grade level and school. Participant responses may have included more than one theme, allowing for a total of greater than 27 responses.

Figure 1 shows the overall frequency count of the nine themes throughout all of the interviews. 'Teamwork' was mentioned most often, appearing fifteen times throughout the 27 interviews, followed by 'Types of Engineers' at twelve counts and 'Deeper Thinking' with nine counts. 'Personal Responsibility' was recorded the least, with only two counts, followed by 'Problem Solving' with five counts. All other themes were mentioned six to eight times.

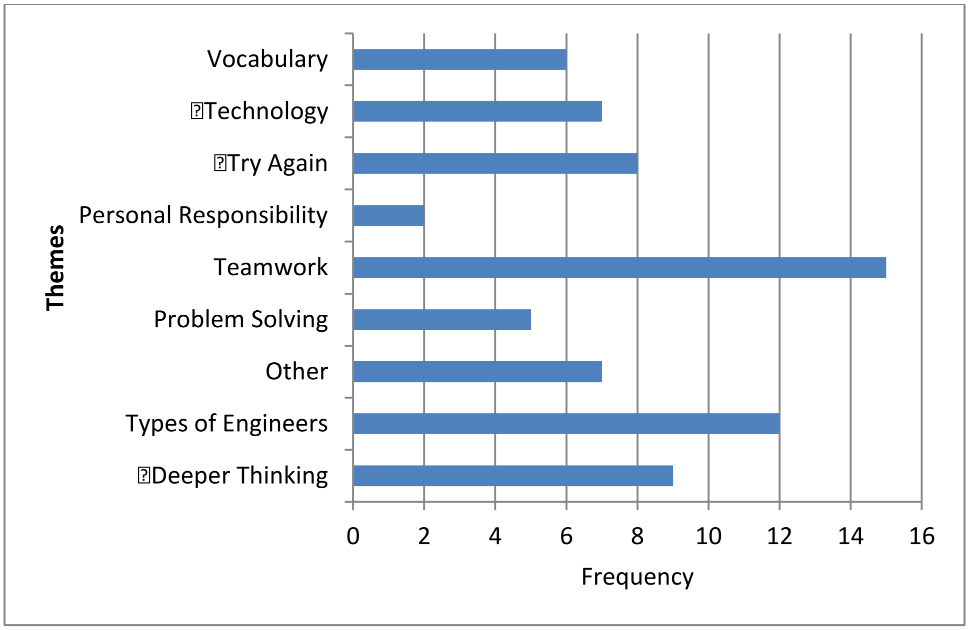

Figure 1. Overall Frequency Count of Participants' Perception of Student Learning by Theme

Figure 2 shows these themes broken out by grade. Second grade teachers mentioned 'Types of Engineers' in their interviews six times, followed by 'Vocabulary' and 'Try Again' with five counts. 'Problem Solving' was the only theme not discussed by second grade teachers. Third grade teachers perceived 'Teamwork' as the most common learning outcome at eight counts, followed by 'Technology' at four. 'Problem Solving' was not given as a learning outcome by third grade teachers. 'Problem Solving' was the most common response among fourth grade teachers, noted five times, followed by 'Deeper Thinking' with four counts, 'Teamwork' and 'Types of Engineers' at three counts, and 'Try Again' at one. 'Vocabulary', 'Technology', 'Personal Responsibility', and 'Other' were not found in responses from fourth grade teachers.

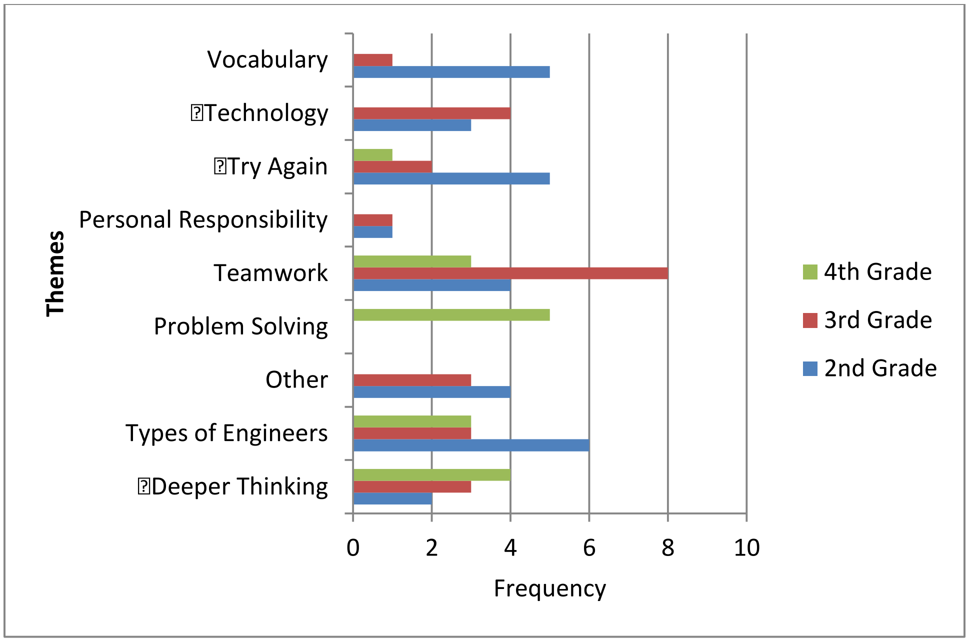

Figure 2. Frequency Count of Participants' Perception of Student Learning by Grade

Table 3 shows the frequency of each theme broken down by school. For schools with greater than one participant, themes given by all of the participants have been bolded and italicized. Teachers at School A focused on 'Teamwork', teachers at School E focused on 'Deeper Thinking', and teachers at School G focused on 'Try Again' and 'Vocabulary'. 'Vocabulary' and 'Personal Responsibility' were mentioned by teachers as learning outcomes at only two schools and 'Problem Solving' was discussed by teachers from three schools. The remaining six themes were mentioned by teachers from at least five schools, with 'Teamwork' given as a response by teachers in all but one school.

Table 3. Participants' Perceptions of Student Learning by School

School	A	B	C	D	E	F	G	H
Deeper Thinking	2	1	0	0	***3***	0	2	1
Types of Engineering	2	0	2	3	1	1	3	0
Other	2	1	0	0	2	1	1	0
Problem Solving	1	0	2	2	0	0	0	0
Teamwork	***6***	1	0	1	2	3	1	1
Personal Responsibility	0	0	1	0	1	0	0	0
Try Again	1	1	0	1	0	1	***4***	0
Technology	0	1	0	1	1	3	1	0
Vocabulary	0	0	0	1	0	0	***5***	0

Discussion

The teachers were interviewed after the first year of the program and the students had no formal engineering education before this year. Therefore, it is reasonable to expect that the introductory lessons were essential and through those, students became familiar with the vocabulary, the idea of technology, and what the different types of engineers are equally. The results indicate that there are different learning outcomes perceived by teachers of different grade levels, with an emphasis on basic information such as vocabulary, teamwork, types of engineers, and recovering from failure to try again in second grade classrooms while fourth grade classrooms focused on higher areas of cognition like problem solving and deeper thinking. This may be due to students' developmental levels or standards that push the teachers to focus more on these areas.

There also seemed to be more emphasis on certain skills like teamwork or vocabulary in different schools. 'Vocabulary' was mentioned by all teachers at School G and only one other teacher, potentially indicating a high population of English Language Learners or school-wide focus on students' vocabulary. 'Teamwork', 'Try Again', and 'Deeper Thinking' were also mentioned by all teachers at a single school and may be indicative of a school-wide focus.

Limitations

This study may not be widely generalizable. The INSPIRE summer academy and curricula were designed to focus on technology, engineering vocabulary, and the different types of engineers. Therefore, 'Technology', 'Vocabulary', and 'Types of Engineers' may be specific themes to this program and may not translate well to other engineering curricula. Additionally, the teachers may have been primed to focus on and discuss the themes that arose during the interviews due to the training during the summer academies and/or the materials they were given for this program.

Conclusions

Commonly expected learning outcomes for engineering lessons include science, math, and problem solving. Only problem solving was mentioned as a learning outcome during an open-ended interview question with teachers of 2^{nd} – 4^{th} grade students, and it was only mentioned at three of the eight participating schools. Math and science learning outcomes were not discussed in response to the interview question, "What do you think students learned?" Teachers perceived more learning of interpersonal skills than technical content by their students. In the current scholastic climate focusing on standardized testing, technical content is valued more highly than interpersonal skills in many schools. Programs that do not seem to enhance students' standardized test scores may be neglected. It may be of benefit to inform teachers of science learning gains associated with engineering, to aid in increasing their perception of the content value of engineering. In addition, helping teachers connect the learning they are seeing in class more directly to skills that are being assessed in standardized testing may increase further buy-in and support. For example, some teachers perceived their students were learning how to think "deeper" about science; standardized tests are moving toward assessing higher levels of understanding, requiring students to be able to explain their answers. Further research could examine whether students who participate in open-ended engineering design problems are equipped with the higher level skills needed for such questions.

In a prior study by the authors[23], teachers that were unable to connect the engineering materials to wider standards, curricular requirements, or standardized testing were less likely to continue implementing engineering in their classrooms. In this study, teachers' perceptions of what their students have learned include valuable skills that students are expected to learn during the course of their education, however these skills are not widely attributed to engineering. Curricula that does not offer the expected outcomes is unlikely to be seen as beneficial even if it provides other valuable skills.

This study and others like it can help to inform elementary engineering curricula, manage expectations regarding engineering interventions, and refine professional development practices to focus on teachers' actual experiences regarding what students learn from engineering instruction. This research contributes to a greater understanding of what engineering curricula can offer outside of math, science, and problem solving skills development. Teamwork, deeper thinking, and the ability to learn from mistakes are important skills at the elementary level that can be taught using engineering as perceived by the teachers involved in this project. Aligning expectations and outcomes more closely will help engineering integrate more easily into elementary classrooms. Engineering curricula that is better aligned with developmental standards and goals is more likely to remain a strong aspect of elementary education.

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