

Preparing Teachers and University Students to Translate Engineering Research to K8 Students in an After-school Program

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Abstract

Translating Engineering Research to K8 Students (TEK8) is a university-K8 partnership that has been designed and implemented as part of an outreach collaboration between the Colleges of Engineering and Education at The Ohio State University. The program aims to advance the broader impacts of federally funded engineering research while increasing urban middle school students' interest in engineering and preparing practicing teachers and engineering students to introduce middle school students to the engineering design process. This paper describes the *TEK8* university-school partnership and presents results from a preliminary study conducted to examine the partnership's effectiveness for preparing teachers and engineering students to interest middle school students in engineering. Data were collected using interviews, observations, and a teacher self-efficacy survey. The survey was appropriated to focus on teachers' and engineering students' self-efficacy to interest middle school students in engineering. Methods of analysis included discourse analysis, the constant comparative method, and the nonparametric 1-tailed Wilcoxon signed rank test. Results reveal that the university course increased teachers' and engineering students' self-efficacy to interest middle school students in engineering. A discussion is provided on pre-engineering education in after-school settings and realizing broader impacts of STEM research through K12 outreach.

Introduction

Providing K12 students early exposure to engineering education is an effective way to increase their interest to pursue STEM-related careers¹⁻³. Two common exposure strategies include project-based learning and informal learning environments⁴⁻⁵. Although partnerships between universities, engineers, and teachers help provide students with engaging and relevant learning experiences⁶, they may present challenges. Teachers who have pedagogical knowledge often lack practical engineering experience to help students learn the real-world significance of projects⁷⁻⁸. Similarly, partnerships that emphasize engineers working directly with students may be limited if engineers, who possess technical and engineering practice knowledge, lack pedagogical skills. The development of engineers' and teachers' self-efficacy may help address these challenges, thereby facilitating pre-engineering teaching and learning.

Self-efficacy has been described as the most powerful teacher attribute⁹. It is defined as a teacher's belief in his or her capacity to organize and execute a course of action to successfully accomplish a teaching task, even in highly complex settings⁹⁻¹¹. Teacher self-efficacy has been positively correlated with student achievement¹², student self-efficacy¹⁰, and teacher motivation to improve practice¹¹. Teachers who report higher levels of self-efficacy are those who attribute classroom success to their efforts¹³. It can be developed through exposure to mastery learning experiences where teacher-learners receive explicit instruction on how to perform a task, can observe modeled performance, and receive feedback on practice¹⁴. Social support¹⁵ and encouragement to attribute instructional success to the teacher's efforts¹³ also leads to increased self-efficacy. Engineering educators, regardless of whether they primarily have a teaching or

engineering background, can benefit from increased levels of self-efficacy to introduce K12 students to engineering.

Translating Engineering Research to K8 Students (TEK8) is a university-school partnership that has been designed and implemented as part of an outreach collaboration between the Colleges of Engineering and Education at The Ohio State University. The program aims to advance the broader impacts of federally funded engineering research while increasing urban middle school students' interest in engineering and preparing practicing teachers and engineering students to introduce middle school students to the engineering design process.

This paper describes the *TEK8* university-school partnership and presents results from a preliminary study conducted to examine the partnership's effectiveness for preparing teachers and engineering students to interest middle school students in engineering.

About TEK8

TEK8 attempts to address a projected long-term shortage of talent in the engineering field and an immediate problem of too few women and minorities engineers. These problems have two associated challenges: career awareness and preparation. On the career awareness front, students in K8 have relatively few opportunities for genuine exposure to engineering that might encourage them to consider the field as a viable future course of study and career path. Engineering generally does not garner the media attention and television focus commonly given other professional careers such as those in law or medicine. As well, teachers and guidance personnel generally do not have training that would lead to deep insights into engineering careers. The net result is that K8 students enter high school with very little idea of "what engineers do." This lack of awareness is further exacerbated by an associated lack of academic preparation, particularly in math and science, that would place students "on track" to be college-ready for engineering. For example, while exposure to, and sometimes experience with, the scientific method is part of formal K8 science instruction, students usually have no exposure to the 'engineering corollary' of the scientific method: the design process. The problem is accentuated in urban communities where there are likely to be fewer STEM mentors in the lives of students contributing to the underrepresentation of minorities in engineering programs.

TEK8 Partnerships

The inspiration for the design of the *TEK8* Program came from the Engineers as Teachers-Family Science Program at Iridescent¹⁶⁻¹⁷, an informal science education non-profit based in Los Angeles, CA. In this program, engineering students from USC (Los Angeles, CA) and Cooper Union (New York, NY) develop design challenges that are delivered to underserved families in after-school settings. *TEK8* differs from other after-school engineering programs in several ways. First, the engineering students involved all had internships in engineering research laboratories on campus. The internships were in a wide range of engineering disciplines. Second, the program involved current middle school teachers who contributed their expertise in working with middle school students, including knowledge of what middle school students know and are capable of doing. The teachers, in turn, learned more about the engineering design process and how it is

applied in a variety of engineering disciplines. The teachers also provided a further opportunity to refine the design challenges that were created.

The *TEK8* program is designed as follows: High-achieving undergraduate engineering students with interest in both research and outreach are identified and recruited. These students are matched with faculty who have funds (from NSF Broader Impacts or other sources) to mentor them as part of a 10-12 week paid summer internship in their research labs. The students meet several times during the summer with the *TEK8* program instructors to discuss their internships and how to gather photos and information that can be used in the autumn. Then in autumn, the students take a course (ENGR 4194) that guides them through the process of developing a series of age-appropriate, open-ended, mini-design challenges that are inspired by their research experiences. They are joined in the course by in-service K8 teachers taking courses in the College of Education and Human Ecology (enrolled in EDUTL 8890) who are interested in learning more about integrating the engineering design process into their classroom experiences. The engineering and education students form teams that develop, document, and deliver the design challenges once a week in a 6-week after-school program at an underserved partner K8 school, KIPP Journey Academy, in the university community. During the first week of the after-school program, one of the course instructors introduces a design challenge to middle school students while the engineering students and teachers observe the presentation and assist students with completing the project. During the remaining 5 weeks of the program, teams of engineering students introduce and lead design challenges with middle school students. The K8 teachers complement the teams with knowledge of classroom management and teaching pedagogy.

The specific goals of the program (not the study) are to:

- Improve engineering career awareness at the K8 grade levels. Introduce, and thereby encourage, underserved youth to consider engineering as a viable college/career pathway
- Increase knowledge of, and experience with, the design process
- Give engineering faculty, who want to have an impact in K8, an effective outreach venue to accomplish broader impacts of their research in the university community
- Give undergraduate engineering students an exposure to university research and potentially interest them in advanced study and/or research careers
- Improve communication skills of engineering students (i.e., how to relate technical experiences to the general public and/or children) and instill in the students the desire to be ambassadors of their careers
- Give in-service K8 teachers the skills to facilitate open-ended projects with their students that teach the engineering design process, explain the societal impact of the projects, and use low-cost, everyday materials

TEK8 University Course

In the autumn ENGR 4194 course, the engineering university students are joined by practicing teachers enrolled in the College of Education and Human Ecology in a course that teaches them how to translate the engineering research experience into a series of age-appropriate mini-design challenges that are team-delivered in an after-school program at an urban middle school. These challenges focus on the Design Solutions and Improving Solutions aspects of the Next

Generation Science Standards (NGSS) while utilizing everyday, low-cost materials to solve a research-inspired problem.

The *TEK8* course (ENGR 4194) is divided into 3 sections: Preparation, Delivery, and Reflection. The preparation portion of the class focuses on the academic understanding necessary to achieve the goals set for the delivery portion. The teams are challenged with readings and videos that focus on the relationship of engineering with society, engineering education efforts, and engineering outreach and diversity efforts. The in-class portion is spent preparing the students for leading a classroom of middle school students through a design challenge. The final part of the preparation portion is the subject of what constitutes a good design challenge that represents the engineering research and is appropriate for a middle school environment.

The delivery portion of the class involves going to the partner middle school and working directly with the students in their after-school program once a week. The delivery portion is meant to be a learning experience for the undergraduate engineering students and the middle school students. The engineering students gain more and more autonomy as they begin with two pre-made design challenges where they learn how to work with the students before they deliver the research-inspired challenges they developed. The learning experience for the middle school students is also scaffolded by successively exposing them to more about the engineering design process and what they are expected to do in the subsequent sessions. During the delivery portion of the class there are no additional assignments beyond preparing the design challenges and the additional class session each week is reserved for discussion and reflection in a learning community setting.

The final portion of the class is devoted to the reflection and to finalizing the documentation in light of experiences at the middle school. The materials created during the class are valuable and worth preserving so that others can facilitate the design challenges independently. Time is spent to hone the lessons learned during the semester and to produce a polished design challenge documentation set that can live on after the class has ended. A central part of this documentation is the production of a 2-3 minute ‘amateur’ video narrated by the engineering students that communicates the research inspiration for the design challenge and the societal significance of the research. Documentation is created in view of after-school or in school partners that are interested in incorporating the design challenges that showcase the research and lead the students through using the engineering design process.

The design and delivery of the university course aligns with best practices in teacher professional learning¹⁸⁻¹⁹, providing multiple opportunities for dialogue, collaborative and iterative lesson design²⁰, practice, and feedback¹⁴, all of which are likely to positively influence teachers’ and engineering students’ self-efficacy (**Figures 1 and 2**).

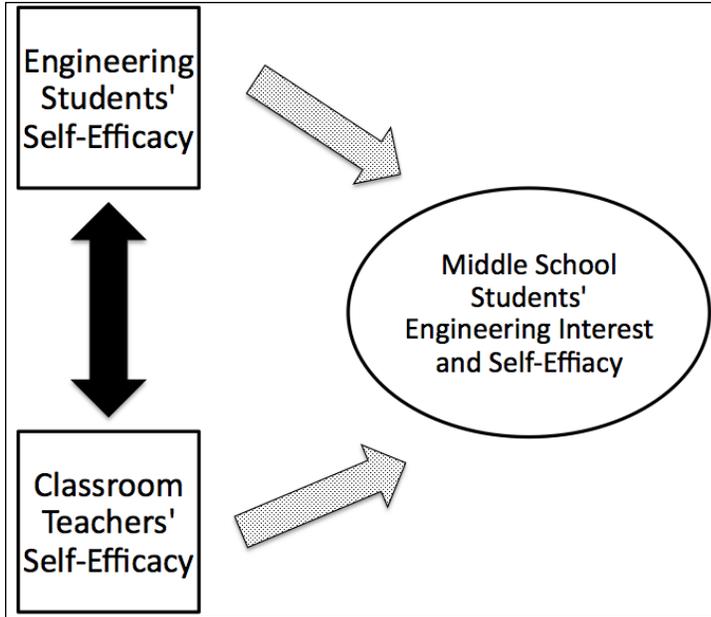


Figure 1. Relationship between engineering students' and teachers' self-efficacy and middle school students' engineering interest and self-efficacy.



Figure 2. Engineering students leading middle students through an engineering design project.

Methods

A study was conducted during the 14-week semester-length course to evaluate *TEK8*'s effectiveness for preparing teachers and engineering students to engage middle school students in an engineering after-school program. The present study examined the following questions:

1. Did the *TEK8* program increase teachers' and/or engineering students' sense of self-efficacy to interest middle school students in engineering?
2. Do teachers and university engineering students learn from one another through collaboration?
 - a. What, if anything, do teachers learn from engineering students?
 - b. What, if anything, do engineering students learn from teachers?

As explained in the Discussion section of this paper, future research may examine whether a positive relationship exists between teachers' and engineering students' preparation to engage middle school students in pre-engineering activities and middle school students' increased interest in engineering. The present study was unable to ascertain this due to insufficient middle school student participation under the IRB, due to lack of signed consent waivers.

Participants

The study employed a mixed-methods approach that combined quantitative and qualitative methods of data collection and analysis. Fourteen university students (12 engineering students and 2 practicing teachers) enrolled in the *TEK8* course and participated in this study. The teachers each had 12 years of experience teaching middle school students a variety of design topics that evolved over the years from woodworking, to computer applications for problem-solving, and now introductory engineering design. The engineering students represented a variety of programs, including chemical, civil, electrical, environmental, mechanical, and systems engineering. Six participants (4 engineering students and 2 practicing teachers) reported previous exposure to an engineering education professional learning experience (e.g., workshop attendance, assisting with an engineering education project, classroom experience) prior to enrolling in the *TEK8* course.

Data Collection

Data were collected using interviews, observations, and a self-efficacy survey. All teachers and engineering students were interviewed about their experiences in *TEK8*. Interviews were audio-recorded for transcription. Researchers attended university class sessions and the after-school program to take hand-written field notes and video record teachers' and engineering students' efforts to develop, refine, and enact the design challenges in the after-school setting. Researchers recorded over 35 hours of video footage; however, in order to present rich examples of engineering students' progression throughout the *TEK8* course, this study focuses on a detailed week-by-week analysis of two representative groups of engineering students.

A pre-survey was administered to the *TEK8* teachers and engineering students in October 2013, and a post-survey was administered in December 2013. The pre- and post-surveys included items

from the Teachers' Sense of Efficacy Scale. Validity and reliability of the instrument have been well documented²¹. Participants indicated their response to each statement on a 9-point Likert scale. The Student Engagement sub-scale (4 items, $\alpha = .81$) was appropriated to focus on self-efficacy to interest middle school students in engineering and included the following questions:

1. How much can you motivate students who show low interest in engineering?
2. How much can you do to get students to believe that they can do well in completing engineering design challenges?
3. How much can you do to help students value learning about engineering?
4. How much can you assist families in helping their children learn about engineering?

Data Analysis

Discourse analysis²² and the constant comparative method²³ were used to examine themes from interview and observation data. Researchers began the qualitative data analysis by recording notes of emerging themes as they read one interview transcript and viewed one video recording. The emerging themes focused on factors university students and teachers believed supported their development of self-efficacy as well as the type of support teachers provided university students while enacting design challenges during the after-school program. These foci were selected for analysis given the study's focus on the development of self-efficacy to engage middle school students in engineering activities. After developing an initial list of emerging themes, researchers read additional interview transcripts and viewed additional videos, all the while comparing and contrasting the list of emerging themes with corresponding data. Researchers continued conducting within- and between-case comparisons to refine and discover theme patterns. Due to sample size, the nonparametric 1-tailed Wilcoxon signed rank test was used to analyze paired survey data from each participant to examine whether course enrollment resulted in significant gain in self-efficacy.

Results

Survey results indicate that participation in the *TEK8* course increased teachers' and engineering students' sense of self-efficacy to interest middle school students in engineering. Analysis of interviews and observation video recordings suggest that the collaborative nature of the course supported their self-efficacy development.

Gain in Self-Efficacy

Assessment of the student engagement self-efficacy scores showed an overall mean value of 6.77 (range, 5.00 – 8.50; SD, 1.15) at baseline, and a post-survey overall mean score of 7.39 (range, 5.75 – 8.50; SD, 0.88). As displayed in **Table 1**, teachers began and ended the *TEK8* course with higher levels of self-efficacy than engineering students. Across all groups (students overall, teachers, engineering students, and students with previous exposure to engineering education), the minimum self-efficacy score increased between the pre- and post-survey. Also, across all groups, the standard deviation decreased over time. Key elements of the course design may have played a significant role in increasing the group's homogeneity and reducing the standard deviation. Such elements include shared reading assignments, students working in groups to develop design challenges, after-school program debriefing sessions that enabled all students to

speak and listen to one another’s experiences, and after-school program practice sessions where all students critiqued and offered one another suggestions on how to improve design challenge presentations.

Table 1. Descriptive Statistics for University Students’ Pre- and Post-Survey Self-Efficacy Scores

	Overall (n=14)		Teachers (n=2)		Engineering Students (n=12)		Prior EE Training (n=6)	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
Mean	6.77	7.39	8.13	8.25	6.54	7.25	7.04	7.83
SD	1.15	0.88	0.53	0.35	1.07	0.86	1.37	0.70
Median	6.75	7.25	8.13	8.25	6.75	7.13	7.25	8.00
Minimum	5.00	5.75	7.75	8.00	5.00	5.75	5.00	6.75
Maximum	8.50	8.50	8.50	8.50	8.25	8.50	8.50	8.50

As displayed in **Table 2**, the increase in the overall self-efficacy score between baseline and the end of the *TEK8* course from a mean of 6.77 to 7.39 was significant (Wilcoxon signed rank test, $P=.03$).

Table 2. Teachers’ and Engineering Students’ Self-Efficacy Scores at Baseline and End of *TEK8* Course (n=14)

	Mean (SD)		Gain	P Value
	Oct 2013	Dec 2013		
Student Engagement Self-Efficacy	6.77 (1.15)	7.39 (0.88)	0.62	.03*

* $p<0.05$

Along with a gain in self-efficacy survey scores, participants shared during interviews that their confidence to interest middle school students increased over the 14-week course. Prior to *TEK8*, many engineering students felt confident about their engineering content knowledge; however, they felt less confident about giving presentations, leading design challenges, middle school students’ preparedness for completing design challenges, how to establish rapport and relate with students, and strategies for keeping students on task. Students stated during interviews,

“I had no idea how I was going to talk about engineering to middle school students. High school students, maybe, but not middle schools students! ... I learned how to talk about engineering with relevant analogies, explaining things so [middle school students] could understand. ... Going in, working with the middle school students, I felt confident about my content knowledge, and I knew I would have to make adjustments to help them understand. I’m an engineering teaching assistant, so I already know my content, but how do I teach them that? Practicing the presentations ahead of time really helped. ... The teachers and course instructors gave us suggestions on how to adjust our presentations. And, the teachers suggested strategies for reducing nervousness. ... Also, going back to the same group of students week-to-week helped me get more comfortable. You get used to the students. They get used to you. Everyone starts to open up. ... Once we established personal connections, it was easier to get them to participate in the design challenges.”

– Engineering Student A

“The discussions we had in class helped us prepare for what we were getting ourselves into. Before working with the students, we read a lot of papers that gave us a basic understanding that engineering education is needed [in K12]. ... Having one of the school administrators come and tell us about where the kids were coming from helped a lot. She talked about [the school’s] history and demographics and how the school works with the kids to monitor their behavior. ... Working with the same group of students helped us work with students one-on-one. We could tell which students caught onto things faster and who we should look out for to help them along. ... My confidence grew over time because I was building relationships with the students. ... The teachers’ participation was definitely helpful. Having their perspective on things was always, always, always helpful. As we got closer to going to the school, a lot of us were concerned about how to deal with and interact with the students. We didn’t know how easy or watered-down – I hate to say that – we should make our design challenges. [The teachers] helped us understand what a typical 6 – 8 [grade] student should know because they know the state’s academic standards and they teach middle school students.” – Engineering Student B

Along with visiting the same group of middle school students every week, the *TEK8* course included multiple opportunities for collaboration with fellow engineering classmates, teachers, and course instructors, which engineering students felt supported their increased self-efficacy or confidence over time. The next section of this paper reports findings on how collaboration between engineering students and teachers facilitated both groups’ learning about leading engineering design challenges with middle school students.

Learning through Collaboration

Study findings suggest that engineering students’ interactions with experienced teachers helped them learn how to more clearly communicate the engineering design process and implement targeted strategies for connecting with middle school students. The most helpful interactions were co-teaching and receiving feedback from teachers during practice and debriefing sessions. **Table 3** summarizes categories of support teachers provided engineering students during their visits to middle school classrooms.

Table 4 displays a week-by-week count of incidences of the types of support teachers offered engineering student while they enacted design challenges with middle school students. As shown in the table, with the exception of Support Category 3, “Getting individual students or groups started or attempting to maintain engagement,” incidences of all forms of teacher support decreased over the 5 weeks of enactment. It may be that this form of support increased at Week 5 because teachers felt the need to spend less time offering engineering students other forms of support as their self-efficacy to lead design challenges increased. It may also be that the Category 3 form of support increased at Week 5 due to that week’s specific design challenges’ needs.

Table 3. Categories of Support Teachers Provided Engineering Students

Category	Examples
Modeling enthusiasm and ways to engage the whole class	Challenging boys versus girls during testing Excitedly saying, "Four grams is winning!" during testing Asking the class, "Did it work? Are you going to make it better?" Then, pointing to his <i>TEK8</i> t-shirt graphic that displays the engineering design process and animatedly saying, "Here it is! Here are the steps! Here's what you need to do!"
Asking students conceptual questions	Asking a student, "Where's the weak spot?" Asking students, "What does micro mean? What does encapsulate mean?"
Getting individual students or groups started or attempting to maintain engagement	Walking around the room and talking to students who are outliers to the group, encouraging them to participate Explaining the design challenge goal to students so they understand what they are doing and can consider how to approach it Encouraging a student by saying, "There you go!" and "You have to consider this!"
Re-engage students who have stopped participating	Visiting a student who has stopped participating, squats to the student's level, and starts joking with her. Returns later to check in and encourage her. Returns again and gives the student a slightly altered task. Stands by a student who is not participating, not saying much. Walks away when the student begins to participate again. Saying to a student, "I'm coming back and I want to know how that worked out because that's a smart way of looking at the problem."
Audibly endorsing engineering students	Directing a student to go check their design with the engineering students in the room Asks an engineering student at the end of the orienting presentation for the design challenge, "Mr. [Last Name], can I ask you question? What happens when...?" Exclaiming after an engineering student's demonstration to the class, "That is awesome! That is awesome!"

Table 4. Incidences of Teacher Support by After-School Program Week

	Week 1	Week 2	Week 3	Week 4	Week 5
1. Modeling enthusiasm and ways to engage the whole class	8	2	2	3	1
2. Asking students conceptual questions	3	2	1	0	1
3. Getting individual students or groups started or attempting to maintain engagement	5	1	2	1	5
4. Re-engage students who have stopped participating	3	3	2	0	0
5. Audibly endorsing engineering students	2	0	1	1	0

Over the 5-week enactment period, engineering students increasingly attempted to engage all students. For example, during the first week of enactment, analysis of classroom observations

revealed multiple occurrences of middle school students not paying attention, moving desks, arguing and rough-housing with one another. Engineering students were stiff presenters who hovered near the front of the classroom and refrained from comfortably walking around the room. During the first two weeks of enactment, engineering students relied heavily on teachers to assist with classroom management and modeling how to interest students in participating in the design challenges. By Week 3, most groups of engineering students knew students by name and would call on them to respond to questions during presentations. By Week 5, middle school students in one classroom could easily recall engineering students' first and last names. Throughout enactment, engineering students increasingly used more youth-friendly analogies to explain engineering concepts. Examples included relating 'micro-encapsulation' to marbles and water, explaining the relationship between graphene and electronic devices, and using a water park metaphor to explain electro-magnetism. Corresponding with this trend, teachers gradually shifted their support from modeling enthusiasm and classroom management to checking on middle school students' design challenge testing progress and encouraging them individually or in small groups.

Through working with engineering students, teachers reported learning more about how to offer middle school students richer examples of engineering problems that link larger societal concerns, engineering research, and hands-on design challenges. The teachers stated,

“The knowledge these engineering students are bringing provides me with a stronger basis for what we are doing in our class. We've been teaching design for the longest time – kind of the same – design, build, evaluate – that whole cycle. But, now we are able to explain, 'Ok, why are we doing this?' To make that real life connection, to put that in the hands of the kids. We can say, 'The reason we are doing this design is because this is something someone had to do in a research study to fight cancer.' Now you make that connection. ... It gives the kids more ownership over 'Why am I trying to do this?' Especially when you talk about cancer, that's an instant connection. So, it gives a stronger rationale.” – Teacher A

“We wanted to take this course because it directly impacts us. We have already taken some of the design challenges and implemented them in our classrooms. ... As teachers, you kind of get bored doing the same thing over and over. *TEK8* provided the purpose, terminology, vocabulary, and direct application of what college students are doing to how it can be related to a middle school student. ... The design challenges explain, 'The problem is.' This is not something we are making up. This is a real research problem that researchers at the University are working on.” – Teacher B

Teachers' and Engineering Students' Influence on Middle School Students

As described in the Introduction section of this paper, previous studies have found a positive correlation between teacher self-efficacy and students' self-efficacy and achievement. Thus, an implicit assumption of the model for this study is that teachers' and engineering students' increased self-efficacy would positively influence middle school students' interest in engineering and self-efficacy to complete the design challenges. Observation and interview data suggest that the *TEK8* Project positively influenced middle school students. For example, during Week 4 of the after-school program, while working on a design challenge, one middle school student told

an engineering student, “I think [engineering] could be a career for me.” Engineering students also mentioned during interviews,

“One student told his mom that *TEK8* is really cool. And, he told me that he asked her to purchase some of the materials for him. I told him, ‘LEDs are really cheap. They are only about \$2 for a lot of them.’ And he was like, ‘Oh really?’ ... I think [*TEK8*] really exposed them in a positive way to what engineering is.” – Engineering Student A

“They learned the whole design process. They were able to repeat the *TEK8* motto. We would say, ‘Identify!’ The kids would say, ‘Design!’ We’d say, ‘Build!’ They’d say, ‘Test!’ We’d say, ‘Make it good!’ And, they’d say, ‘Make it better!’ ... Some students seemed to be thinking more critically every week, and their designs were getting better. ... We would ask them what they wanted to study in college. None of them said engineering, but if we asked them if they liked the design challenges, they would say, “Yeah!” ... I think this will impact them in the future. Maybe when they’re taking science and math classes in high school, they’ll think back to this engineering experience, and think ‘hey, I can do this.’” – Engineering Student C

Although few students identified engineering as a career choice as a result of *TEK8*, the experience introduced them to the engineering design process, provided a different avenue for pursuing interests, and may serve as a reminder in the future that they can persist through STEM-related courses.

Discussion

Importance of Collaboration to Professional Learning

Study findings indicate the importance of collaboration to pre-engineering professional development. Both teachers and engineering students reported how collaborating with one another supported their increase in self-efficacy to lead design challenges. Teachers gained vocabulary, a broader understanding of engineering research and practice, and the ability to provide students more motivating rationales for completing design challenges. Engineering students increased confidence to lead presentations, connect with middle school students, and keep them on task. Undergraduate engineering students’ and in-service teachers’ collaborative efforts contributed to a rich and beneficial intersection that supported increased self-efficacy. Furthermore, engineering students reported that the course improved their overall communication skills.

The model used for *TEK8* can inform efforts to design effective professional development for pre-engineering education in other contexts. Providing teachers exposure to individuals who have practical experience in problem solving and engineering design can lend authenticity to teachers who are learning to teach K12 students about engineering. Conversely, teachers can help engineering students or practicing engineers relate to youth and learn some instructional strategies as well as the skills of translating engineering research for youth to have a greater likelihood of increasing the meaningfulness and effectiveness of the pre-engineering experience. Such a professional development model may become increasingly important as states begin to

adopt the Next Generation Science Standards that assume that educators have an engineering mindset.

Engineering Education in an After-School Setting

There are unique opportunities and challenges to leading pre-engineering programs in after-school settings. As researchers of a different after-school program found, one of the biggest challenges was after-school staff with little or no formal training in STEM subjects attempting to enact curriculum designed by engineering students²⁴. Although one product of the *TEK8* Program is design challenges that can be implemented by others, a unique aspect of the model is that the engineering students who developed the design challenges participated in enacting them in classrooms. Many K12 schools are beginning to extend the school day through after-school programming; however, implementation may still be an issue with the adoption of this project if staff members who do not have a technical background enact the design challenges. In that case, it is good if the written design challenge materials are accompanied by an introductory video to explain both the design challenge and its research inspiration. Other advantages of the *TEK8* Program include teacher support provided by the local Boys and Girls Club that helped with keeping students engaged and addressing discipline issues. It was also valuable for engineering students to repeatedly visit the same classroom because it improved their familiarity with students and strengthened their confidence to interact with students.

One specific challenge of implementing *TEK8* in an after-school setting is the contrast between *TEK8* and the other after-school programming, which includes sports and other ‘club-style’ non-academic activities offered by the school. Some of the middle students complained that they did not expect to have to do more schoolwork after-school. While working on design challenges, middle school students could over-hear students enrolled in other activities sounding as if they were having lots of fun. Thus, it is important for schools to consider how pre-engineering programs fit with their after-school programming so that there is continuity concerning extent of academic focus across offerings.

STEM Research Broader Impacts

The National Science Foundation (NSF) sponsors considerable research in STEM fields. Its founding mission is “To promote the progress of science; to advance the national health, prosperity, and welfare; and to secure the national defense”, which suggests that there may be both direct and broader impacts of funded research. Indeed every NSF proposal is evaluated on both its intellectual merit as well as its “broader impacts”. *TEK8* was specifically designed to address NSF broader impacts in K8 in a sustainable way. While NSF broader impacts are not limited to the K8 (or even K12) environment, many researchers see significant opportunities in K8 to impact society more broadly, communicate societal issues and translate the benefits associated with their research.

Study Limitations and Future Efforts

The main limitations of the present study were the small sample size and the inability to investigate the correlation between changes in university students’ self-efficacy and middle-

school students' increased interest in engineering. As the next iteration of *TEK8* is taught, efforts to recruit additional engineering students and teachers may yield a larger sample size. However, because of the considerable after-school partner staff and facility requirements, the *TEK8* course can only reasonably scale to about 24 participants maximum. Although researchers attempted to more systematically study the impact of the after-school program on middle school students, researchers encountered challenges with gaining informed consent from a critical mass of students. Future efforts to recruit middle school students will be completed earlier, so that significantly higher participation can result. This will enable researchers to examine how the program affects student outcomes, particularly the outcome of increased interest in engineering. Future studies can also investigate how other facilitators in other pre-engineering settings take up the design challenges developed by university students in the *TEK8* Program. To be sustainable in the long-term, *TEK8* will need to more efficiently recruit university students and research faculty, including the matching of one to the other for the internships that form the foundation of the program. Presently, the course is "by permission of instructor only" and the teacher recruitment and internship matching process are tedious manual operations requiring considerable staff time.

The *TEK8* program consists of undergraduate student research internships followed by a 14-week course at a public university. In order to duplicate the design and results of this program at other public, research-based universities, the following should be carefully considered:

1) Program planners should ensure that training and after-school programming include numerous opportunities for teachers and engineering students to collaborate; 2) After-school programming should incorporate hands-on, open-ended engineering design challenges; and 3) Program designers should adjust program length and training focus, as necessary, to account for context-specific needs.

Conclusion

This study reports findings on a preliminary study of 14 individuals enrolled in a university engineering education course. Analysis of classroom observations indicate that engineering students and practicing teachers collaborated with one another in their efforts to develop, refine, and enact engineering design challenges with urban middle school students participating in an after-school program. Teachers' and engineering students' average self-efficacy scores increased over 9% above the baseline value by the end of the course. Engineering students explained during interviews that opportunities for dialogue, practice, and feedback were critical factors in their self-efficacy increasing by the end of the *TEK8* course. Teachers described how the partnership improved their ability to teach engineering design to middle school students by broadening their awareness of engineering research and practice, strengthening their vocabulary and enabling them to provide students motivating and authentic contexts to better situate design challenges.

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