RELATIONS AMONG STUDENTS' CAREER CHOICES AND TEACHERS' AND PARENTS' ENGINEERING KNOWLEDGE, ATTITUDE, AND BEHAVIOR

A Dissertation

by

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Submitted to the Graduate and Professional School of
Texas A&M University
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

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December 2021

Major Subject: Curriculum and Instruction

ABSTRACT

The overarching purpose of this dissertation was to understand and improve teachers' and parents' understanding of engineers and engineering. The purpose of the first study was to investigate the effectiveness of a two-week-long, engineering-focused professional development (PD) for teachers. In the first study, I utilized a mixed-methods research approach to explore and document the effects of the PD activities on the engineering knowledge and skills of 12 teacher-participants.

In the second study, I captured and documented the characteristics of the mental images teachers had regarding engineers and engineering. In this study, I focused on understanding how 24 teachers' perceptions of engineers and engineering changed after they completed the engineering-focused PD. I utilized a qualitative research approach to explore the teachers' perceptions and mental images of engineers and engineering.

In the third study, I investigated 45 parents' knowledge of and attitudes towards engineering and how they engaged their children in engineering-related programs. In this study, utilizing a quantitative approach, I focused on understanding the relations between the parents' knowledge, attitudes, and behavior in regard to engineering and their perceptions of their children's summer camp learning experiences.

The results from the first study suggest that participation in the engineering-focused PDs effectively enabled teachers to understand some advanced technologies and engineering concepts and to improve their knowledge about how to teach these concepts.

The findings of the second study show that the teachers gained a better understanding of the skills needed by engineers, including computer programming and

collaboration. The teachers increased their awareness of the activities engineers engage in, for example, coding and problem solving, and they became more knowledgeable about the tools engineers use. For example, after their participation in the PD activities, they named or drew electronic devices and hand tools more often than laboratory equipment, which is associated more often with scientists than with engineers.

In the third study, the students participated in a summer camp and then gave presentations to their parents on Science, Technology, Engineering, and Mathematics (STEM) Night. The findings indicate that the parents improved their knowledge of engineering and technology topics after they participated. Their perceptions of their children's knowledge of engineering and technology topics also increased. Moreover, even though the parents' knowledge of engineering was relatively low, they showed positive attitudes and behavior towards engineering.

I further examined whether there were any significant differences in how the parents of different demographic groups rated knowledge, attitudes, and behavior constructs. While I did not observe any statistically significant differences on the three constructs among the parents of different education level, ethnicity, and gender, or among parents whose children's grades differed or whose children attended school in different locations, there was a statistically significant difference among parents in different age groups in the engineering behavior scores, with the older parents registering higher scores.

In addition, parents' engineering knowledge and their engineering behavior displayed a statistically significant and moderately positive correlation, and their engineering attitudes showed a statistically significant and moderately positive correlation with their engineering behavior. No significant correlation was observed among the other variables.

Overall, the finding from the three studies is that participation in the engineering-focused PD and other activities impacted teachers' and parents' engineering knowledge, skills, and awareness of engineering-related occupations in a positive way. This finding is critical because there has been a concern about U.S. students' lack of interest in STEM careers, and parents and teachers play an important role in shaping students' STEM career choices.

DEDICATION

To my kids, Emir Mert Cevik and Bahadir Eren Cevik: Your existence gave me strength and led me continuously toward my dreams. I love you to the moon and back.

To my parents, Osman Kalem and Altin Kalem and my brother, Yucel Kalem: Your support enabled me to complete this journey and means the world to me.

To all my friends: Your encouragement and belief in me throughout my studies and most difficult times have made you like part of my family.

ACKNOWLEDGEMENTS

I am sincerely grateful to the many people who have supported, encouraged, and assisted me during my doctoral studies. First, I would like to express my deepest appreciation to my committee chair, Dr. Bugrahan Yalvac, and co-chair, Dr. Michael Johnson, for their dedicated mentorship, scholarship and wise guidance and encouragement. I thank you both for setting high standards of excellence and for providing your guidance and support throughout this challenging process. I would also like to thank my committee members, Dr. Sara Raven and Dr. Jeffrey Liew for their guidance and support throughout the course of this research.

This dissertation is dedicated to my family and friends, but additionally I owe a special thanks here for everything they have contributed to my life and my work. I wish to thank my father, Osman Kalem, for being a loving and devoted father all my life. You have been my role model and your rigorous work ethic, strength of character, integrity, and ability to overcome hardship have given me the internal power to overcome the most difficult tasks. To my loving mother, Ayten Kalem, I thank you for making me believe in myself and giving me the power to be all that I can be. You both have set an example of exceptional parenting. My brother, Yucel Kalem, I thank you for your eternal devotion to and confidence in me. Your support, encouraging words, unconditional love and support helped me to stay on this path through the most difficult times. My two beloved sons, Emir Mert Cevik and Bahadir Eren Cevik, I am deeply and eternally grateful to you for your existence, love, support, and belief in my dream. You each shared my dream, lived through it, and helped me to realize the purpose of my life in your own unique ways. I could not have accomplished this milestone without your sacrifices, love, and warm hugs.

Finally, I would like to extend many thanks to my Teaching Learning and Culture classmates, friends and colleagues and to the department faculty and staff for inspiring me, encouraging me, and making my time at Texas A&M University a marvelous experience.

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a dissertation committee consisting of Dr. Bugrahan Yalvac [chair], Dr. Michael Johnson [co-chair], and Dr. Sara Raven of the Department of Teaching, Learning, and Culture [Home Department] and Dr. Jeffrey Liew of the Department of Educational Psychology [Outside Department] in the College of Education and Human Development.

The data analyzed for chapters 2, 3, and 4 was provided by Dr. Michael Johnson and Dr. Bugrahan Yalvac.

All other work conducted for the dissertation was completed by the author, in collaborations with Dr. Bugrahan Yalvac of the Department of Teaching, Learning, and Culture and Dr. Michael Johnson of the Engineering Technology & Industrial Distribution, Manufacturing & Mechanical Engineering Technology.

Funding Sources

My first three years of graduate study were supported by assistantships from the National Science Foundation under DRL Grant Numbers 1615019 and 1614496. My last year of graduate study was supported by a College of Education and Human Development Strategic Research Fellowship.

NOMENCLATURE

ASEE	American Society for Engineering Education
ANOVA	Analysis of Variance
CAD	Computer-Aided Design
DAET	Draw an Engineer Test
DAST	Draw a Scientist Test
DET	Design Engineering Technology
IoT	Internet of Things
ITEEA	International Technology and Engineering Educators Association
ITEST	Innovative Technology Experiences for Students and Teachers
NCES	National Center for Education Statistics
NRC	National Research Council
NSB	National Science Board
NSF	National Science Foundation
OECD	Organization for Economic Co-operation and Development
PD	Professional Development
PEAS	Parents' Engineering Awareness Survey
SPSS	Statistical Package for the Social Sciences
STEM	Science, Technology, Engineering, and Mathematics
US	United States

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1. INTRODUCTION

Advancements in science, engineering, and mathematics, and innovations in technology are the driving forces of a nation's economic growth and global competitiveness (National Science Board [NSB], 2020). In the interconnected economy of the 21st century, citizens, who have sufficient Science, Technology, Engineering, and Mathematics (STEM) knowledge and expertise, are essential for improving a nation's innovative capacity due to their high skill levels, their creative ideas, and their ability to progress scientific knowledge. Citizens with sufficient STEM knowledge and expertise can transform scientific knowledge into tangible and useful products and services (NSB, 2020) and newly invented products and services contribute to improving a nation's living standards and life expectancy (Alston, Beddow, & Pardey, 2009; Baumol, 1989; Cutler & McClellan, 2001; Gordon, 2012).

Although many reports have connected K-12 STEM education to continued scientific leadership and economic growth in the United States (U.S.), there are many reasons to be concerned about the state of U.S. students' STEM knowledge and expertise (National Research Council [NRC], 2011). The previous research indicates that many students have not been well-prepared for the expectations of today's global economy and the economy of the future (NSB, 2020). In the U.S., the number of students majoring in STEM fields has been declining, which has caused a nation-wide scarcity of skilled students, teachers, and professionals in STEM fields (NRC, 2011). If the U.S. cannot develop and deliver a systematic national strategy, the number of scientists and engineers entering the U.S. workforce in the future will be insufficient to meet the demand for professionals in STEM careers (NSB, 2020).

Research also shows that students' future career choices are greatly shaped by their teachers (e.g., Mesutoglu, & Baran, 2020, National Science Foundation [NSF], 2019, Purzer, Moore, & Dringenberg, 2018). Teachers' attitudes towards engineering and awareness of STEM fields influence students' interest in STEM fields and their career choices. Thus, a successful way to increase students' interest in STEM fields is to improve teachers' conceptualization of STEM fields and careers.

Engineering is an important part of the STEM fields, yet it is not systematically taught in K-12 schools. When engineering concepts are taught in middle and secondary schools, it is generally by science and mathematics teachers. However, most science and mathematics teachers do not have sufficient training in engineering nor the pedagogical knowledge to teach engineering (Hsu, Cardella, & Purzer, 2010). It is important to improve teachers' engineering knowledge, skills and capabilities, so that they can teach engineering, and to improve their attitudes towards engineering in order to help prepare the new generation of students for future STEM careers (Cevik et al., 2018; Mesutoglu, & Baran, 2020; National Science Foundation, 2019; Purzer, Moore, & Dringenberg, 2018).

Parents also play a major role in shaping students' interest in STEM fields (Altman, 1997; Klein-Gardner, 2014; Mahmoud, 2018; Trice & McClellan, 1993). Many studies show that parental involvement and parental expectations instill in students greater ambition for school success and career development (Caplan, Hall, Lubin, &

Fleming, 1997; Jordan, Orozco, & Averett, 2002; Yun, Cardella, Purzer, Hsu, & Chae, 2010). Other studies show that improving parents' conceptualization of engineering and engineers can strengthen students' interest in STEM career choices (Altman, 1997; Klein-Gardner, 2014; Mahmoud, 2018; Trice & McClellan, 1993).

1.1. Purpose of the Dissertation

The primary purpose of this dissertation is to investigate and document how we can improve teachers' and parents' knowledge and understanding of engineering and engineers. I have conducted three different studies and generated three publishable reports. Specifically, I focused on 1) investigating the effects of the engineering- focused Professional Development (PD) activities on in-service teachers' engineering knowledge and skills, 2) understanding the characteristics of the teachers' mental images of engineers and engineering, and 3) investigating parents' knowledge of and attitudes towards engineering and their behaviors of engaging their students in engineering related programs. I have proposed submitting the reports of my studies to three different academic outlets as illustrated in Table 1.

Table 1

Articles and Journals

Articles	Journal#1	Journal#2	Journal#3
Improving in-service science and mathematics teachers' engineering and technology content and pedagogical knowledge	Cevik, E., Johnson, M., Yalvac, B., Whitfield, J., Porter J., R., Morgan, J., A. & Kuttolamadom, M. (2021). Improving in-service science and mathematics teachers' engineering and technology content and pedagogical knowledge (evaluation). *Proceedings of the American Society for Engineering Education (ASEE)*, Long Beach, California.	IEEE Transactions on Education	International Journal of STEM Education Editor- Yeping Li Peer Review Springer Open No word limit
A study of secondary teachers' perceptions of engineers and conceptions of engineering	Cevik, E., Johnson, M., Yalvac, B., Whitfield, J., Porter J., R., Morgan, J., A. & Kuttolamadom, M. (2020). A study of k-12 teachers' perceptions of engineers and conceptions of engineering. *Proceedings of the American Society for Engineering Education (ASEE)*, Montreal, Quebec, Canada.	IEEE Transactions on Education	International Journal of STEM Education Editor,- Yeping Li, Peer Review Springer Open No word limit
Exploring parents' knowledge and awareness of engineering through middle school students' summer camps	Journal of Engineering Education Editor- Lisa C. Benson SJR/SNIP 2.687/8.794 8,000-10,000	International Journal of Engineering Education Editor,- Ahmad Ibrahim, SJR/SNIP .433/.905 Dublin Institute of Technology Publications	International Journal of STEM Education Editor,- Yeping Li, Peer Review Springer Open No word limit

1.2. Research Questions

Three main research questions (RQs) guided the research conducted in the three articles:

RQ1: *What were the effects of the PD activities on teacher participants' engineering knowledge and skills?*

RQ2: *What were the characteristics of the mental images teachers had regarding engineers and engineering?*

RQ3: *What were the parents' knowledge of, and attitudes towards, engineering? What engineering-based experiences did parents engage in with their children?*

The first main research question has been addressed in the second chapter titled, "Improving in-service science and mathematics teachers' engineering and technology content knowledge." The second main research question has been addressed in the third chapter titled, "A study of secondary teachers' perceptions of engineers and conceptions of engineering." Finally, the third main research question has been addressed in the fourth chapter titled, "Exploring parents' knowledge and awareness of engineering through middle school students' summer camps." The reports presented in chapters two and three were submitted to the Proceedings of the American Society of Engineering Education (ASEE) and published. The report presented in chapter four has not yet been published. The third report will be submitted to the Journal of Engineering Education (JEE), and it may be submitted to other journals listed in Table 1 if it does not get published in JEE.

1.3. Methods

The methodological approaches that were employed in the three studies matched the research questions of each study and the characteristics of the data that were collected. For the first article, in addition to using descriptive statistics and non-parametric tests for the quantitative data, I qualitatively analyzed teachers' interviews to investigate the effectiveness of a two-week-long, engineering-focused, summer PD for teachers. For my second article, in addition to using qualitative analysis methods, I relied on descriptive statistics. For my third article, I relied on descriptive statistics, inferential quantitative analytics techniques of independent-samples t tests, one-way analysis of variance (ANOVA), and correlational analysis.

1.4. References

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2. IMPROVING IN-SERVICE SCIENCE AND MATHEMATICS TEACHERS' ENGINEERING AND TECHNOLOGY CONTENT KNOWLEDGE*

2.1. Introduction

Science, Technology, Engineering, and Mathematics (STEM) have been the foundation for innovation and technological improvement throughout the United States' (U.S.) history (National Science Board [NSB], 2018). While the number of the U.S. jobs required in the STEM fields has increased nearly 34% over the past decade, the number of students choosing a STEM position as their career goal is decreasing (National Science Foundation [NSF], 2018). Teachers are a paramount influence on students' future career choices, so it follows that an effective way to increase students' interest in STEM fields is to improve teachers' conceptions of engineering and STEM concepts and their sense of self-efficacy. Specifically, a teacher's understanding of engineering plays a critical role in increasing a students' interest in STEM fields (NSF, 2019; Mesutoglu & Baran, 2020; Purzer, Moore, & Dringenberg, 2018).

Previous research demonstrated that teachers had a limited understanding of engineering (Hsu, Cardella, & Purzer, 2010), and teacher participation in engineering- and technology-focused professional development (PD) programs showed improvement in teachers' knowledge of engineers and engineering disciplines, their relations with society, and their understanding of how engineering processes work (Autenrieth, Lewis,

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& Butler-Purry, 2018; Duncan, Diefes-Dux, & Gentry, 2011; Guzey, Tank, Wang, Roehrig, & Moore, 2014; Utley, Ivey, Hammack, & High, 2019; Yoon, Diefes-Dux, & Strobel, 2013).

Similarly, several studies reported that engineering-focused teacher PD programs and short courses were effective at developing the participating teachers' knowledge of the engineering design process and positively improves their perceptions of engineering (Cevik et al., 2019; Cevik et al., 2020; Hsu, Cardella, & Purzer, 2010; Martin, Peacock, Ko, & Rudolph, 2015; Yoon, Diefes-Dux, & Strobel, 2013).

Autenrieth et al. (2018) designed a study to educate and excite teachers about the field of engineering so that teachers could introduce engineering concepts to their students and encourage them to consider a career in engineering. The results showed that PD was successful in educating teachers about the engineering field, and even after the PD program, teachers continued to promote engineering to their students as a career option (Autenrieth et al., 2018).

In another study, Duncan et al. (2011) investigated the influence of week-long engineering summer academies on elementary teachers' recognition and understanding of engineering in the world around them. Through the designed engineering academies, the authors provided opportunities for teachers to see and experience engineering in the world around them. Duncan et al. developed a tool to measure the resulting changes. The study findings showed that teachers improved their ability to analyze and evaluate the engineering around them after participating in the engineering academy. The changes in understanding demonstrated by the teachers indicated better levels of sophistication in their abilities to discuss the nature and practice of engineering (Duncan et al., 2011).

Guzey et al. (2014) conducted a study to understand the approaches to engineering integration that teachers utilized in their elementary and middle school classrooms as a result of their participation in a year-long professional development program. Analysis of data revealed that most of the teachers who participated in the professional development were able to successfully implement engineering design lessons in their classrooms. The authors concluded that the teachers' success in implementing engineering lessons in their classroom was closely related to the structure of the professional development program (Guzey et al., 2014).

Similarly, Utley et al. (2019) examined the effect of an engineering focused professional development program on in-service elementary teachers' knowledge and perceptions regarding engineering and their self-efficacy of teaching engineering as well as their science content knowledge. In the study, elementary teachers participating in three separate engineering-focused professional development opportunities spaced over the course of a semester. The study results showed that attending the PD program enhanced teachers' understanding of engineering and technology, science content knowledge, and engineering teaching efficacy. Utley et al.'s results were consistent with findings from other studies of elementary teachers participated in engineering education professional developments (Duncan et al., 2011; Guzey et al., 2014).

In their study, Yoon et al. (2013) attempted to deliver a positive impact on students' engagement and performance in class by improving teachers' content and pedagogical content knowledge and changing their attitudes towards engineering through an engineering focused teacher PD. The study results indicated that teachers were satisfied with the engineering PD program. Teachers' participation in the PD activities significantly increased their engineering design process knowledge, and teachers became more familiar with engineering (Yoon et al., 2013).

Hsu et al. (2010) examined elementary teachers' perceptions of and familiarity with Design, Engineering, and Technology (DET). Hsu et al. (2010) collected data from 192 elementary teachers using the DET teacher survey. While these elementary teachers thought that teaching DET was important, most of the teachers, regardless of their backgrounds and teaching experiences, had limited understanding of DET. These study results showed that there was a need to improve elementary teachers' familiarity with design, engineering, and technology. Given that increased emphasis on engineering in the K-12 science education standards (National Research Council [NRC], 2011), Hsu et al. (2010) indicated that there was an increased need for research on teachers' familiarity with and perceptions of DET (Hsu et al., 2010).

Cunningham, Knight, Carlsen, and Kelly (2007) introduced a model that was successful for incorporating engineering concepts and activities into middle and high school courses. The model of professional development helped teachers to understand one of the core aspects of engineering and the engineering design process, by directly engaging teachers in the process. Science, mathematics, and technology teachers participating in the program attended a two-week summer institute focused on engineering concepts and the engineering design process. As the final project for the summer institute, each of the teachers adapted a unit or lesson that they had previously taught to incorporate engineering concepts. Cunningham et al. explained that they adopted this “modify the existing lesson” approach because they did not want to place extra pressure on teachers’ shoulders since their instructional time was limited and their school curricula were already heavy in content. Analysis of data revealed that teachers expressed that they learned much about engineering concepts and became more comfortable with teaching engineering as a result of their professional development participation. In addition, after having the experience of modifying a lesson or unit to contain engineering, the majority of the teachers decided to involve themselves in these activities again to improve their lessons and to thoroughly incorporate engineering concepts into other science, mathematics, and engineering lessons that they taught.

Consistent with the previous research, these studies noted that PD programs successfully provided the knowledge, motivation and skills needed for teachers to improve their perception of engineering and, incorporate engineering concepts and practices into their curricula (Cunningham et al., 2007; Guzey et al., 2014; Nadelson, Pfiester, Callahan, & Pyke, 2015).

2.2. Research Summary

In this paper, I investigated the effectiveness of a two-week long teacher engineering-focused summer PD which was implemented at a Research 1 University campus. The PD activities were a part of a NSF-funded Innovative Technology Experiences for Students and Teachers (ITEST) project. The project goals were to enhance in-service teachers’ knowledge and skills of engineering and cutting-edge technologies including Internet of Things (IoT), additive manufacturing, and Computer-Aided Design (CAD) tools. Participating teachers learned the fundamental principles of the engineering design and gain practical knowledge about these cutting-edge technologies. The teachers also received training on how to incorporate the engineering and technology content into the existing mathematics and science school curricula.

2.3. Research Questions

The main research question I asked in this study was:

What were the effects of the engineering-focused PD activities on teacher participants' engineering knowledge and skills?

I asked the following sub-questions to help answer the main research question:

SRQ1: *How did teachers' confidence in understanding of the cutting-edge technologies and concepts related to engineering change after participation in engineering-focused summer PD?*

SRQ2: *What were the engineering knowledge and skills participants believed that they gained from the engineering-focused summer PD activities?*

2.4. Study Context: Engineering-Focused Summer Teacher Professional Development

In the current study, the project team designed, planned, and implemented a two-week engineering-focused summer PD program for middle school science and mathematics teachers. The PD featured ten sessions, each lasting eight hours. Through these engineering-focused PD activities, teachers were trained to understand and use state-of-the-art connected devices, also known as the Internet of Things (IoT), and they worked with building automation and additive manufacturing technologies. In addition to gaining technical knowledge about engineering design process, IoT and additive manufacturing, they had an opportunity to gain pedagogical knowledge and develop lesson plans aligned with science and mathematics. Pedagogical knowledge is defined as the ability and knowledge to teach effectively (Shulman, 1986). Content knowledge is the understanding of subject matter. Shulman (1986) defined pedagogical content knowledge as the knowledge teachers should possess to teach subject matter effectively to their students.

At the end of the PD, the teachers were provided with the hardware and software resources needed to implement the activities in their own classrooms. The research team met with the teachers online on several occasions throughout the year to provide support and continual guidance.

2.5. Methods

I conducted a concurrent mixed-method study including both qualitative and quantitative data collection methods to explore the effectiveness of the PD activities (Creswell & Plano Clark, 2011). Quantitative data were collected using a questionnaire. At the completion of the PD, I formally interviewed the participants about their experiences over two weeks. The teachers' perceptions of the content knowledge and skills they gained from the PD activities were explored and documented. Walther, Sochacka, and Kellam (2013) argued that research reports should follow a systematic process and make actual knowledge claims. In my data collection and analyses, I systematically used both qualitative and quantitative paradigms, and I attempted to make knowledge claims about the participants' experiences with the PD activities.

2.5.1. Participants

The study participants were in-service science and mathematics teachers who participated in the engineering-focused summer PD program. The demographic and background information of all participants were collected.

Various middle school and high school science and mathematics teachers who reside in Texas were sent information via email on the requirements and benefits of participating in the two-week engineering-focused summer PD activities. However, recruiting was targeted towards Houston. Approximately, 250 teachers were invited to participate in the engineering-focused summer PD program.

Teachers interested in participating completed an online application that required general information, a letter of commitment from the teacher and his or her principal, and an essay that describes: (a) why the teacher wants to participate in the program, (b) what the teacher hopes to gain from participating in the program, and (c) how the teacher plans to use the information gained in the two-week summer experience to improve student learning. The project team designed a selection rubric to give preference to teachers who were clustered within a single campus, and who were employed by the partnering district. The strategies used to select the participants were both purposeful and convenient (Creswell & Plano Clark, 2011). The team selected around 12 teachers to participate in the PD activities.

To select the PD participants from all the interested teachers who completed the online application, the project team worked in groups of two and each group evaluated several applications. After the groups completed the evaluation process, the whole project team came together to select the teachers to invite to the summer program. The team also selected several teachers for a waitlist in the event a selected teacher declined the invitation to the summer program. I invited all teachers engaged in PD activities to participate in the present study.

The study participants consisted of twelve in-service science and mathematics teachers. One of the teachers participated in the program in both 2018 and in 2019. The participants' teaching experiences ranged from one to 30 years, with an average of about 10.2 years. The highest level of education of the teachers ranged from a bachelor's degree to a doctoral degree. Sixty-six percent had a bachelor's degree, 25% percent had a master's degree, and one had a PhD. The gender distribution of the participants was 58.3% female (N = 7) and 36.6% male (N = 5). All of the demographic and background information of participants is reported in Table 2.

Table 2

Demographic and Background Information of Participants

Criteria	Categories	Total N (%)
Gender	Male	5 (41.7%)
	Female	7 (58.3%)
Ethnicity	White	4 (33.3%)
	Black	3 (25.0%)
	Hispanic or Latino	2 (16.7%)
	Asian	2 (16.7%)
	Two or more races	1 (8.3%)
Age	20-35	4 (33.3%)
	36-49	5 (41.7%)
	50+	3 (25.0%)
Education	Bachelor's Degree	8 (66.7%)
	Master's Degree	3 (25.0%)
	Doctoral Degree	1 (8.3%)
Teaching Experience (in years)	1-5	4 (33.3%)
	6-10	3 (25.0%)
	11-19	2 (16.7%)
	20 and up	3 (25.0%)
Teaching Grades	6-8	12 (100%)

2.5.2. Instrumentation

I use two research instruments: an evaluation questionnaire and a semi-structured interview protocol.

The project team developed the evaluation questionnaire. The evaluation questionnaire items were developed to capture the participants' confidence in the following areas: 1) knowledge of building automation, 2) engineering design process, 3) product development process, 4) using a design challenge with students/youth, 5) awareness of engineering careers, 6) how to elicit reflective decision-making in students/youth, 7) how to use industry experts and 8) Internet of Things before and after the PD participation. A copy of the questionnaire can be found in Appendix A.

The purposes of the interviews were to explore the participating teachers' perceptions of the content knowledge and skills they gained. The interview questions were open-ended so that I could collect a rich variety of responses (Creswell & Plano Clark, 2011). A copy of the interview protocol is included as Appendix B.

2.5.3. Data Collection

This study included both qualitative and quantitative data collection and analyses (Creswell & Plano Clark, 2011). To collect the quantitative data, I used the teacher questionnaire developed by the project team. In the questionnaire, participants were asked to compare their before and after perceptions in the same questionnaire. The respondents were asked to recall pre-intervention status at post-PD time.

To collect the qualitative data, I conducted semi-structured one-on-one interviews with the teachers at the completion of the PD activities (Creswell & Plano

Clark, 2011). Each interview lasted 30 to 45 minutes, and all of the conversations were audio-recorded. Because the interview protocol was semi-structured, I posed questions that emerged during the conversations, which were not listed in the protocol.

2.5.4. Data Analyses

In the analysis, I ran descriptive statistics and non-parametric tests for the quantitative data. I computed the mean scores of the teachers' responses to the evaluative questionnaire, and I ran a non-parametric Wilcoxon signed-rank test to compare the participants' responses (Wilcoxon,1945). I used non-parametric tests because the sample size was small, and the distribution of the data points was expected not to be normal. With small sample size and not-normal data distributions parametric tests are not recommended. The level of significance was set at $p < 0.05$.

The interview recordings were transcribed verbatim by the transcriptions service because the use of a professional external transcription service can contribute to the reliability of the research process (Walther et al., 2013). Then, I analyzed the interview transcriptions using the constant comparative method (Glaser & Strauss, 1967). The transcriptions were read several times, and categories and subcategories were created (Creswell & Plano Clark, 2011). I employed open coding, selective coding, and axial coding strategies in the analysis. Commonalities and differences among the participants' descriptions of their experiences were reported. Themes were created.

2.6. Results

The results are reported in the order of the sub-research questions (SRQ).

SRQ1: *How did teachers' confidence in understanding of the cutting-edge technologies and concepts related to engineering change after participation in engineering-focused summer PD?*

To answer the sub-research question 1, at the completion of the engineering-focused summer PD, using the questionnaire we had developed, I collected evaluative feedback from the participating teachers. The questionnaire was a five-point Likert-scale instrument with eight evaluative questions. While the questionnaire was administered at the completion of the engineering-focused summer PD, questions called for retrospective responses. Teachers were asked, both before and after the PD activities, about their confidence in their understanding of the following topics: 1) knowledge of building automation, 2) engineering design process, 3) product development process, 4) using a design challenge with students/youth, 5) awareness of engineering careers, 6) how to elicit reflective decision-making in students/youth, 7) how to use industry experts, and 8) Internet of Things. The responses from the teachers are listed in Table 3. The mean of the teachers' responses to the evaluation questions increased after they were exposed to PD activities. The non-parametric Wilcoxon signed-rank test indicated that the mean difference between the teachers' scores for their confidence in these topics before and after the engineering-focused summer PD was statistically significant, at the $p < 0.005$ level.

Table 3

Statistical Comparison of Teachers' Self-Assessed Knowledge Before and After the Program

		Self-assessed knowledge prior to program		Self-assessed knowledge after the program		Wilcoxon Test	
Evaluation Questions	*N*	*M*	*SD*	*M*	*SD*	*Z*	*p*
Your knowledge of building automation to maximize energy use	12	2.50	1.13	3.90	1.07	-4.22	.001*
Your understanding of the engineering design process	12	2.65	1.20	3.75	1.09	-3.69	.001*
Your awareness of engineering careers	12	3.46	1.22	4.27	0.91	-3.24	.001*
Your understanding of the Internet of Things	12	3.35	1.23	3.99	1.23	-3.34	.003*
Your understanding of the product development process	12	3.31	1.21	3.97	1.25	-3.34	.003*
Confidence in using a design challenge with students/youth	12	3.31	1.19	3.97	1.03	-3.14	.003*
how to use industry experts	12	3.41	1.24	4.35	0.92	-3.24	.001*
how to elicit reflective decision-making in students	12	2.61	1.07	3.68	0.85	-3.58	.001*

Note. *M* = Mean, *SD* = Standard Deviation. *Statistically Significant at $p < 0.05$.

SRQ2: *What were the engineering knowledge and skills participants believed that they gained from the PD activities?*

To answer the sub-research question 2, I collected qualitative data and analyzed them using the constant comparative method (Creswell & Plano Clark, 2011). I read the interview transcriptions several times. Multiple readings helped me generate more details and patterns for the themes that emerged. The three themes (Exposure to Cutting-Edge Technologies, Gaining New Skills, and Nature of Engineering) are listed below in Table 4.

Table 4

Qualitative Results

Theme 1 **Exposure to Cutting Edge-Technologies**	**Theme 2** **Gaining New Skills and Knowledge**	**Theme 3** **Nature of Engineering**
"In these two weeks, we learned so much. The most valuable experience was how technology, if you want to call it the Internet of things as we have learned it, how that is changing the world, or how it kind of controls all the things that we do on a daily basis."	"I really like to be part of this program. And then having the PD time for us to work on what we are thinking, get feedback, share with other teachers, have been very, very good. I would like to do it again."	"Learning that there's more than one way to solve a problem, I started to think as an engineer, as a scientist, you have to be a risk-taker. You have to get rid of fear of making a mistake, because in the design process and the engineering process, as they shared with us, you come up with your first prototype, and you test it, so it's an ongoing, production, refine – refinement or reiteration of version one to version two."
"I had attended a number of teacher PDs, but not an engineering PD like this. So this was a huge change for me, and I really learned something that is different, because you can imagine, I have 30 years plus experience. I have attended a number of PDs before, and most of the PDs I went to, I used to know most of the things because of attending similar ones over and over again. So, this technology was something totally new for me."	"It's amazing for me to see that all the persons are available to collaborate for us. All this information, the experience that we had, okay, what do you need? Open. What do you need? Okay. This is nice for me because I talk for another teacher, "This is your opportunity to learn a lot because we are working with real experts. It's an excellent opportunity."	"When I was in college, I knew engineers had to take a lot of math. But I didn't know why. And when I get here, I see the engineers do a lot of designing, creating, and trying to make things work and go. And so, I didn't see the numbers part when I was in college, that's what I thought an engineer did, a lot of math. I wasn't sure why but now I see okay. This is the end product."

2.6.1. Theme 1: Exposure to Cutting Edge-Technologies

During the interview conversations, teachers reported positive experiences with the engineering-focused PD activities. Their feedback suggested that the PD activities were very rewarding for them and provided excellent opportunities to learn about cutting-edge technologies, including the Internet of Things (IoT), additive manufacturing, and computer-aided design (CAD), through thought-provoking instruction and unique learning materials. They also observed that the knowledge they acquired was unique.

2.6.2. Theme 2: Gaining News Skills and Knowledge

When interviewed after the PD, teachers reported that they had gained new skills and acquired new knowledge. They also reported that they improved their views towards teaching. They said that the program was eye-opening for them; it changed the way they perceived learning and teaching, which made them more accepting of students' mistakes and a student-centered learning approach. In addition, they became more inclined to exchange ideas and work in groups, instead of working by themselves at their own pace.

The majority of the participating teachers indicated that in addition to learning theoretical knowledge in this PD, they had an opportunity to teach their newly gained knowledge to volunteer students. This rehearsal enabled them to get immediate feedback from the students, which was valuable because it guided them in thinking about how to teach this novel content to their own students. One participant noted:

> I think one useful thing would have – we worked with the students, and we get specific feedback from them in a certain way – so I would kind of – this is how

> these students responded. How can we expect other students to respond later on in the classroom?

Similarly, another participant stated:

> Having the students come in was good. Even though they are different from my population of students, it was still very good to have an opportunity to teach, which is the purpose of the program – to get the strategies that you learn and teach.

2.6.3. Theme 3: Nature of Engineering

Teachers reported that their understanding of engineering concepts, and the engineering design process, has improved by participating in this authentic, engineering-focused PD. Teachers indicated that after they joined this PD, they better understood what it took and meant to be an engineer, how it was different than the fields of science and mathematics, as well as how it had a close connection to those fields. They got a broader picture of engineering.

2.7. Conclusion

The study results showed that the teachers improved their knowledge of building automation, understanding of the engineering design process, awareness of engineering careers, understanding of the Internet of Things, understanding of the product development process, their confidence towards using a design challenge and industry experts as well as how to elicit reflective decision-making in students. In addition, the three themes that emerged from the analysis were 1) exposure to cutting-edge technologies, 2) gaining new skills, and 3) nature of engineering. These themes showed growth in teachers' understanding of engineering concepts, engineering content knowledge, and skills, through participation in the engineering-focused PD. Participants believed that participating in the PD helped them to better understand some advanced technologies and engineering concepts. They also improved their knowledge about how to teach the concepts. The majority of the participants agreed that this PD was exceptional, in that it provided very strong theoretical and practical knowledge related to engineering.

Because teachers have a paramount impact on students' future career choices, helping them to improve their experience related to engineering and engineering concepts promises to translate into more positive student interest in STEM careers. PD activities similar to the one described in this paper could be an operational solution to the STEM recruitment shortage in the U.S. Technology is advancing rapidly, and STEM careers demand a sound understanding of cutting-edge technologies. However, in-service teachers are often left behind when it comes to learning about new technologies and their role in current and future STEM careers. PD activities similar to the one portrayed in this study can improve teachers' knowledge about state-of-the-art technologies and help them design and implement integrated STEM learning environments at the middle and high school levels. Students who engage in engineering practices involving cutting-edge technologies may be more inclined to select engineering or another STEM field for their future careers.

2.8. Discussion

In addition to the data reported above, during the interviews teachers talked about their lived-experiences with the PD activities. Teachers found the summer workshop a very original, informative, and thought-provoking experience. The majority of the participants agreed that this program was exceptional, in that it provided very strong theoretical and practical knowledge related to engineering. It was a real challenge, however, to figure out how to incorporate these concepts into their curricula. Hence, the teachers said that in addition to the vast variety of resources and collaboration opportunities it already provided, they would appreciate the inclusion of structured lesson planning and curriculum development sessions in the summer camp curriculum.

Some of the participating teachers stated that the PD was challenging for them yet was a very fulfilling experience. During the interviews, one teacher noted:

> I felt we learned a lot of things. The things that I learned here were quite challenging. It was not like other PDs that I attended previously. In all my years, I never attended any engineering PD like this.

On the other hand, some of the participating teachers stressed that the PD was content-heavy. One participant stated,

> I think this program should be two separate things, still two weeks long, because we need all that time to play with the 3D printing. I still have a person out there who is still trying to 3D print his stuff. We need that time. And then that gives us more time to think about how we want to put our stuff into the curriculum.

Another participant noted:

> In the first week it's very content-heavy for me, and I lost sight of the purpose of the program. It felt like for the first four days, I was an engineering student. And that's not the goal of the program. The goal was to learn enough to be competent to educate your students on a topic. And for me, I did not do any of that the first four days of this program.

In addition, lesson planning and curriculum development sessions started during the second week of the summer camp, but some of the teachers expressed a preference to start lesson planning and curriculum implementation sessions earlier in the program. Such “how to teach” sessions might be incorporated into the PD during the first week of the PD as well. One participant said:

> We went at such a fast pace the first week – how are we going to make that last? But then seeing the second week, it’s like, “okay, I want another week of curriculum planning. Let’s see how much we can use over and over again.”

Furthermore, some of the teachers indicated that despite their overall positive experience in the PD, it was very challenging for them to study and work on the novel concepts for extended periods of time. In future implementations of the program, the team could include more frequent and extended breaks to increase the productivity and the motivation of the participants. One participant told us:

> If I look at something [for] forty-five minutes, I take a break. Come back, it still doesn't make sense. Take a break. Maybe go to bed, take a nap, and it'll solve in my head. Come back, and things like that. But here, they expected us to sit down

between 8:30 a.m. to 6 p.m., and [snapping fingers] just do it and that was quite exhausting. I would've liked it better if there were some more breakout sessions.

2.9. Limitations

This study had some limitations. First, the sample participant size was relatively small. Data that include small sample size data are not likely to yield a distribution of responses that is normal (Turner,1993). For this reason, nonparametric statistics, which do not assume a normal distribution of interval or interval-like data, are more appropriate (Turner,1993). Second, the population was self-selecting and may not be representative of the target population. Quantitative research aims to be representative of a population being analyzed. Because the data sample was obtained from participating teachers to the summer PD, the data were not normative. Therefore, the sample does not represent science and math teachers in general. Third, the evaluation questionnaire that was administered after the summer PD is a Likert scale. A main critique of Likert scales is that the spaces between the choices cannot be equidistant and so it can be problematic to achieve internal consistency (Turner,1993). These results therefore might not be a true evaluation of the teachers’ actual responses.

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3. A STUDY OF SECONDARY TEACHERS' PERCEPTIONS OF ENGINEERS AND CONCEPTIONS OF ENGINEERING†

3.1. Introduction

According to the National Center for Education Statistics (NCES), Science, Technology, Engineering, and Mathematics (STEM) fields are considered fundamental to the nation's economy. In today's world, it is critical to attract and retain more students in STEM fields (Ortiz et al., 2018). Teachers are sources of knowledge for students, and they inevitably have a significant influence on a student's self-image and perceived interests and abilities (Carol, Alberto, & Patrick, 1993). For these reasons, teachers who hold more accurate views and images of engineers and engineering tend to send more positive messages about who can be an engineer and who can get involved in STEM fields as future career choices. Rosenthal (1993) notes that when teachers have negative stereotypes of science, scientists and engineers, their views and images are transferred to their teaching in a negative manner. This can cause students to develop negative views and images towards STEM.

Because the teachers' perceptions are strongly related with their students' perceptions, understanding and improving how teachers comprehend the concepts of engineers and engineering can be used to improve students' perceptions toward the same

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concepts and improve the number of students who choose STEM fields as their future careers.

One effective way of understanding people's personal beliefs and perceptions is to investigate the mental images that they draw concerning a particular subject (Finson, Beaver, & Cramond, 1995). For example, the Draw a Scientist Test (DAST) has been developed to understand students' attitudes toward scientists through students' drawings (Finson et al., 1995). Many researchers effectively and extensively have used this instrument in their research (Barman, 1999; Finson, 2002; Maoldomhnaigh & Mhaoláin, 1990). Similarly, many researchers utilize the Draw-An-Engineer Test (DAET) instrument (Knight & Cunningham, 2004) to evaluate students' and teachers' perceptions of engineers and engineering by analyzing their drawings (Buckley, Gumaelius, Hyland, Seery, & Pears, 2019; Carreño, Palou, Lopez-Malo, 2010; Cruz-López, Chavela-Guerra, López-Malo, & Palou, 2011; Ergün & Balçın, 2018). These drawings could be used to help education researchers and other stakeholders in recognizing these potential misconceptions (Hammack & Vo, 2019) and can be utilized to measure the effectiveness of the teacher professional development programs.

Carreño et al. (2011) examined the conceptions of engineers and engineering among Mexican teachers. Their findings showed that while the number of teachers who were knowledgeable about engineers and engineering was very limited, the common misconceptions about engineers were widespread among these teachers. Similarly, Ergün and Balçın (2018) conducted a study to determine the perceptions and attitudes of fifth and sixth-grade students towards engineers and engineering. Results of their study indicated that students conceived engineers as construction workers, rebuilders, supervisors, or designers; and that they had stereotypical images about their gender. Moreover, this study reported that most students were not interested in choosing engineering as their future profession (Ergün & Balçın, 2018).

In other research, Carr and Diefes-Dux (2012) examined elementary students' conceptions of engineering before and after a curriculum intervention. This study indicated that the students' drawings at the beginning of the school year were similar to previous literature where students perceived engineering as fixing and constructing. The results of the end-of-year drawings have shown that over half of the participants' conceptions were design-related instead of the manual labor notion (Carr & Diefes-Dux, 2012).

While the DAET instrument can easily be implemented to large samples, the usage of DAET has some limitations since participants' drawing skills could heavily impact the results (Ergün & Balçın, 2018). To overcome these challenges and to understand better the students' and teachers' drawings, many researchers supported DAET results with interviews, or open-ended questions (Capobianco, Diefes-Dux, Mena, & Weller, 2011; Fralick, Kearn, Thompson, & Lyons, 2009)

3.2. Research Summary

In the second paper, I investigated the characteristics of the mental images teachers have regarding engineers and engineering through their drawings and questionnaire responses. Specifically, I focused on understanding how participant teachers' perceptions changed regarding engineers and engineering after the two-week-long professional development (PD) ends. In this study, STEM teachers participated in a two-week-long engineering-focused PD program. The STEM teachers learned about innovative engineering technologies and designing appropriate lesson plans to incorporate the newly learned content into their curricula.

3.3. Research Questions

The main research question (RQ) I asked in this study was:

RQ1: *What were the characteristics of the mental images teachers had regarding engineers and engineering?*

I asked two sub- questions (SRQ) to help answer the main research question:

SRQ1: *What were the teachers' mental images and perceptions of the engineering and engineers before the PD?*

SRQ2: *What were the teachers' mental images and perceptions of the engineering and engineers after the PD?*

3.4. Study Context: Engineering-Focused Summer Teacher Professional Development

This two-week engineering-focused teacher summer PD took place at Texas A&M University. The PD ran eight hours per day for two weeks. This summer PD used the transformational and exciting technology of connected devices, commonly referred to as the Internet of Things (IoT), and the application of building automation to promote STEM interest using authentic experiential design activities. These teachers also had the opportunity to engage in authentic experiential design activities using connected devices.

At the end of the PD, they were provided all the resources to become a STEM education champion at their campus.

3.5. Methods

I designed this study to identify the characteristics of the mental images teachers had regarding engineers and engineering and the changes in teachers' perceptions of engineers and engineering after completing a two-week-long engineering-focused summer PD. Teachers participated in data collection at the beginning and at the conclusion of the summer PD.

The participating teachers in the study were administered the DAET instrument (Knight & Cunningham, 2004). Teachers drew an engineer, and then answered the open-ended questions. Drawings and question responses were collected from all participants. I analyzed the pre-PD and post-PD drawings and open-ended questions. Question responses were helpful to clarify some of the vague aspects of the drawings.

3.5.1. Participants

The study participants were twenty-four in-service science and mathematics teachers who participated in the engineering-focused summer PD program held on campus over two years. Demographic information of the participants can be seen in Table 5. While fifty-eight percent of the teachers were female, forty-two percent of the teachers were male. Teachers' age ranged from 23 to 58 (M = 40.08, SD = 12.06). While fifty percent of the participant teachers were relatively new in teaching profession, the rest of the population had a teaching experience ranged from 6 to 25 years (M =8.36, SD

=8.23). 66.6% of the teachers had bachelor's degrees, 25% of them had master's degrees, and 8.4% of them had doctoral degrees.

Table 5

Demographic Information of the Participants

Criteria	**Categories**	**Total**
Gender	Male	10 (42.0%)
	Female	14 (58.0%)
Ethnicity	White	10 (41.7%)
	Black	6 (25.0%)
	Hispanic or Latino	4 (16.7%)
	Asian	3 (12.5%)
	Two or more races	1 (4.1%)
Age	20-35	10 (41.7%)
	36-49	8 (33.3%)
	50+	6 (25%)
Education	Bachelor's Degree	16 (66.6%)
	Master's Degree	6 (25%)
	Doctorate Degree	2 (8.4%)
Teaching Experience (years)	1-5	12 (50%)
	6-10	7 (29.1%)
	11-19	2 (8.4%)
	20 and up	3 (12.5%)
Teaching Grades	6-8	15 (62.5%)

	9-12	9 (37.5%)

During the participant selection process, the project team sent targeted emails to all middle school and high school science and mathematics teachers employed by the partnering district, and additional emails were sent to qualified teachers in other school districts who had been previously involved in other STEM programs at the university. Teachers interested in participating completed an online application. The project team established a selection rubric that intended to give preference to teachers who were clustered within a single campus, and who were employed by the partnering district. In addition, the team focused on selecting equal numbers of male and female participations. We used purposeful sampling strategy because purposeful sampling strategy was more helpful to understand the central problem under study (Creswell, Plano Clark, 2011).

3.5.2. Instrumentation

The DAET was used to evaluate students' and teachers' ideas about engineers and engineering (Knight & Cunningham, 2004). In this survey, participants "draw an engineer at work." The survey also includes several questions and prompts, which are as follows:

1. Describe what the engineer in your picture is doing.
2. What tools does the engineer in your picture use?
3. What skills does the engineer in your picture have?
4. Is your knowledge of engineers accurate?

3.5.3. Data Collection

DAET is an instrument that requires only blank paper and pencil or colored markers/crayons. Participants were provided with the instrument and were simply asked to draw an engineer at work (Knight & Cunningham, 2004). No other guidelines or restrictions were given. Teachers drew "an engineer at work" and then answered the open-ended questions on two occasions; once before the PD and once after the PD. After teachers completed their drawings, they were asked to respond to the open-ended questions.

3.5.4. Data Analyses

The pre-PD and post-PD drawings were evaluated using the DAET rubric (Knight & Cunningham, 2004), and analyzed using the descriptive statistics. The pre-PD and post-PD open-ended question responses were analyzed by using the constant comparative method (Creswell, 2013; Glaser & Strauss, 1967). Content analysis is described as any technique used to interpret written data (Neuendorf, 2017). I read and reread the text to identify the pattern and themes that emerged from the data using content analysis (Neuendorf, 2017). Drawings and teachers' responses were organized into several categories. These results were summarized using descriptive statistics.

3.6. Results

Teachers' responses to all questions were categorized based on the keywords that teachers used in the text and teachers' drawings. Analysis of question one that was "describe what the engineer in your picture is doing" and drawings showed that teachers have mixed opinions about engineers' occupations (Table 6). While the most popular answers were "designing" and "thinking/working" in pre-PD drawings, the most popular answers in post-PD drawings were “designing, “coding/programming”, “thinking/working” and “problem solving”. After the summer PD, most of the participant teachers described engineers as being “problem solvers”. While there were not any teachers who included engineering design process in their drawings prior to the summer PD, three of them included in engineering design process in their drawings after the summer PD.

Table 6

Number of times teachers portrayed the action when they describe the action their engineer does in their drawings before and after the PD

Type of Action	Pre	Post
Designing	5	7
Creating	3	5
Improving	0	1
Building	2	1
Doing Research	2	2
Coding/Programming	1	5
Problem Solving	1	8
Thinking/Working	6	6
Following Engineering Design Process	0	3
Supervising a Construction Site	2	0

Note: *N*=24

Analysis of question two that was "what tools does the engineer in your picture use?" and drawings showed that before the summer PD, teachers indicated that engineers were using mostly hand tools; however, after the summer PD, there was a bigger increase in engineers using electronic tools and software/hardware than engineers using hand tools (Table 7). In pre-PD drawings, the hand tools that teachers drew were related to building or construction. In these DAET drawings, engineers primarily used these tools to build or repair constructions and machines. On the other hand, post-PD drawings presented teachers were more likely to depict engineers using these tools to creating new products, present information, or share solutions or ideas. Finally, post-PD drawings contained more tools than the pre-PD drawings.

Table 7

Number of times teachers portrayed the type of tools when they describe the tools their engineers use in their drawings before and after the PD

Type of Tools	Pre	Post
Hand Tools	9	14
Electronic Tools	9	23
Software/Hardware	4	12
Own Skills	4	8
Laboratory Equipment	5	1
Blueprints/Models	4	3

Note: *N*=24

Analysis of question three that was "What skills does the engineer in your picture have?" and drawings indicated that there was an increase in the number of teachers' responses with regards to “type of skills” that engineers have. These results are presented in Table 8. Before the PD the most cited answers were “math”, “science” and “technology”. After the PD teachers’ most cited answers were “math”, “science” and “technology as well as “computer programming/coding”, “collaboration/communication skills” and “critical thinking skills”.

Table 8

Number of times teachers portrayed the skills when they describe the skills their engineers have in their drawings before and after the PD

Type of Skills	Pre	Post
Math	7	12
Science	7	5
Technology	5	7
Computer Programming/coding	1	10
Design	2	4
Perseverance	3	4
Building	2	3
Creativity	3	3
Collaboration/Communication	4	12
Work Ethics	0	1
Electrical/Mechanical	2	3
Critical Thinking Skills	3	5
Problem Solving Skills	4	4

Note: *N*=24

Results from question four focused on understanding the teachers' confidence level related to knowledge about engineers. While the number of teachers who described themselves as "not sure" decreased significantly at the end of the summer PD, the number of teachers who describe themselves as "sure" increased at the end of the summer PD. These results are shown in Table 9.

Table 9

Teacher responses to question "Is your knowledge of engineers accurate?"

Confidence Levels	Pre	Post
No response	5	0
Sure	7	18
Not Sure	12	6

Note: *N*=24

As indicated earlier, while fifty-eight percent of the teachers who participated in the summer PD were female, forty-two percent of the teachers were male. Even though most of the drawings that included people were stick figures, to identify the genders of the drawn engineers, I focused on identifying pronouns that teachers used to describe their engineers in their written responses. Occurrence of images of gender in teachers' drawings can be seen in Table 10.

Table 10

Occurrence of Images of Gender in Teachers' Drawings

	Pre-PD (%)	Post-PD (%)
Female	15.7	25.9
Male	31.5	22.2
Unknown	52.6	51.8

Note: *N*=24

Examples of pre-PD drawings and post-PD drawings are presented in Figures 1, 2, 3, 4, and 5.

Figure 1. A Pre-PD Image Drawn by a Teacher DAET.

Figure 2. A Pre-PD Image Drawn by a Teacher DAET.

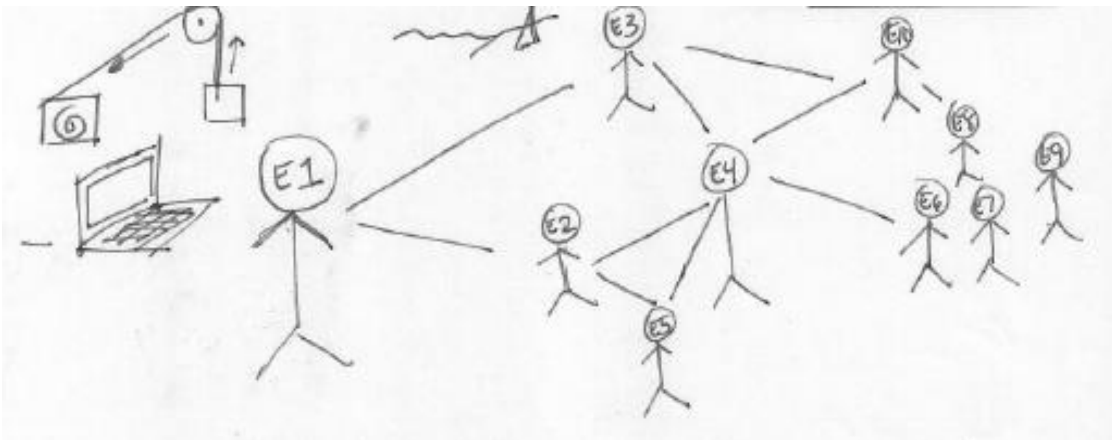

Figure 3. A Post-PD Image Drawn by a Teacher DAET.

Figure 4. A Post-PD Image Drawn by a Teacher DAET.

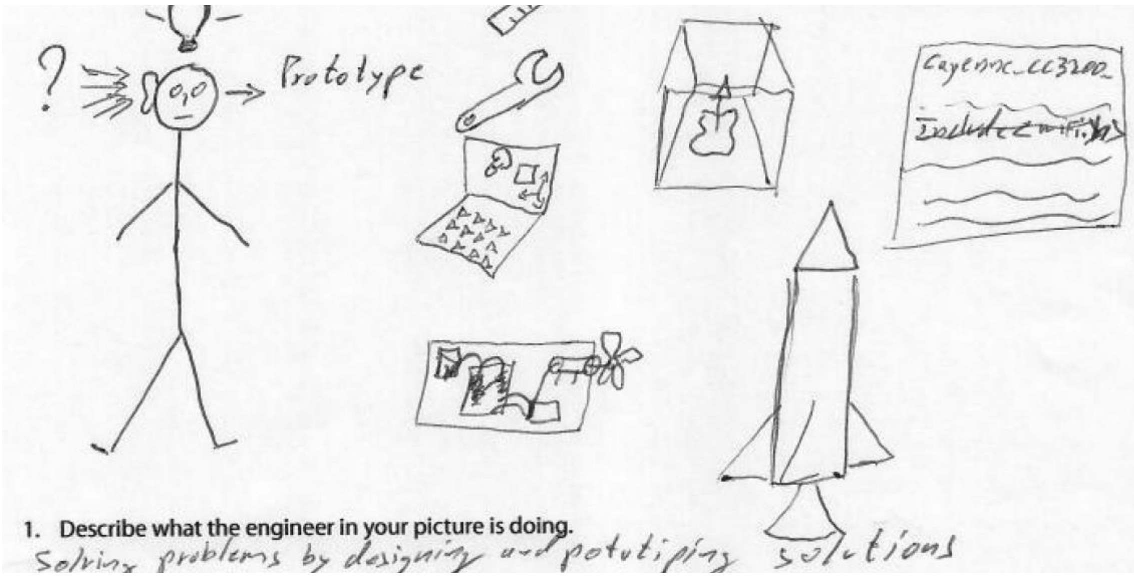

Figure 5. A Post-PD Image Drawn by a Teacher DAET.

While many of the engineers who featured in the pre-PD drawings were mostly alone in a working environment (e.g. see Figure 1 and Figure 2), in the post-PD drawings, most of them were depicted in a collaborative working environment by the teachers (e.g. see Figure 3 and Figure 4). Similarly, although most of the engineers depicted in the pre-PD drawings were related to some level of lab work (e.g. see Figure 2), in the post-PD drawings the depicted engineers were related to mostly engineering tools and equipment (e.g. see Figure 5).

3.7. Conclusion

This work examined the effects of a two-week summer PD on teachers using DAET instrument (Knight & Cunningham, 2004). The results among a diverse group of teachers showed increased awareness of the activities engineers engaged in such as computer coding and problem solving. The teachers seemed to get a better awareness of the tools engineers used such as electronics and hand tools as opposed to lab equipment more equated with science. The teachers also gained a better understanding of the skills necessary for engineering, including programming and collaboration. The teachers also improved their confidence of their understanding of engineering. The representations of the drawn engineers (that showed a gender) were also less male after the two-week program as compared to those before the two-week program. Overall, the two-week PD seemed to have an appreciable impact on the participants' understanding of engineering. Future work will examine the effects of this change on their students' beliefs and understanding of engineering.

There is a growing concern in the United States (U.S.) about the lack of interest and aptitude in STEM disciplines. While most teachers are well versed in math and science through their formal education, very few have experience and/or educational backgrounds in engineering and technology. A significant report noted the lack of engineering education at the K-12 level (National Research Council [NRC], 2009). Incorporating engineering into the K-12 classroom is getting national and international attention (Moore, Tank, Glancy, & Kersten, 2015). Engineering can be viewed as the application of math and science for the betterment of humanity. Understanding teachers' views of engineering and engineers and how certain activities can impact those views can have significant effects on the ability to increase the number of students that pursue engineering degrees and careers (Moore, Tank, Glancy, & Kersten, 2015).

3.8. Limitations

There are several limitations in this study. First, participants were chosen from a population of teachers who applied to the engineering-focused summer PD program. Because of this limitation, the sample size of participant teachers were limited by the number of teachers who participated in the study. Second, this engineering-focused summer PD program was somewhat short (two weeks of lessons), and this may deliver only limited information about teachers' perceptions related to engineering and engineers. Third, given that the PD was relatively short, the data analysis may only demonstrate slight instant changes in teachers' perceptions of engineering and engineers. Fourth, I was the only researcher who conducted the data analysis. There is a possibility that results might be susceptible to researcher bias. To overcome this challenge and to gain deeper understanding regarding the results, I requested teachers to explain their drawings by answering open-ended questions at the end of the DAET. In the future, expanding the number of researchers who conducted the analysis can improve the inter-rater reliability of the study. Finally, it should be taken into consideration that participants may provide positive results after the intervention because of being in a research study and receiving attention from the researchers (Gordon, 1993).

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4. EXPLORING PARENTS' KNOWLEDGE AND AWARENESS OF ENGINEERING THROUGH MIDDLE SCHOOL STUDENTS' SUMMER CAMPS

4.1. Introduction

A talented pool of workers competent in science, technology, engineering, and mathematics (STEM) disciplines is needed to compete in the global economy (Mahmoud, 2018). STEM workforces play an important role in advancing technology and generating new approaches and ideas (Mahmoud, 2018). However, while there is a great need for people who are proficient in STEM areas, there is a scarcity of interest in these fields on the part of students, especially in engineering (Callahan & Callahan, 2004; Kazmierczak & James, 2005). Enrollment in many STEM fields is declining, and likewise, the number of students in the U.S. who choose to pursue a graduate degree in science and engineering has been decreasing since 1993 (Heil, Hutzler, Cunningham, Jackson, & Chadde; 2012).

Research shows that parents are important models for children's decision-making regarding career and life aspirations (Mahmoud, 2018; Altman, 1997; Klein-Gardner, 2014; Trice & McClellan,1993). Many studies have shown that parental involvement and parental expectations increase students' ambition to succeed in school and prepare for a career (Caplan, Hall, Lubin, & Fleming, 1997; Heil, Hutzler, Cunningham, Jackson, & Chadde, 2012; Jordan, Orozco, & Averett, 2002). These results are echoed by many others (Conklin & Dailey, 1981; George & Kaplan, 1998; Shepard,1992; Szechter & Carey, 2009; Wilson & Wilson, 1992). For instance, Hoover-Dempsey (2005) designed a study to learn about what parents did with their children that contributed to their children’s learning and educational success. The authors reviewed the literature to understand why parents were involved in their children’s education and how their involvement influenced student outcomes. They found that parental involvement increased students’ school participation, their attention span when doing homework, their positive attitudes toward learning, and their belief that learning outcomes were related to their effort (Hoover-Dempsey, 2005).

Rosenzweig (2001) conducted a meta-analysis to explore the relationship between specific parenting practices and students' school success, and between specific parenting practices and students' achievement in school. The meta-analysis of 34 primary studies showed that seven parenting practices were positively correlated with school success and explained 18.9% of the variance (r = .352, R^2 = .189) in students' school success. Eight negative parenting practices, in combination, were negatively correlated with school success and explained 31.9% of the variance (r = .565, R^2 = .319) in students' lack of school success. In another study, Catsambis (1998) analyzed the data from the parent and student components of the National Educational Longitudinal Study of 1988 to investigate family educational involvement in secondary education. The purpose of the study was to determine whether parental involvement has an impact on the educational achievements of high school seniors. The study found that there was a significant positive effect of parental involvement on twelfth-grade academic achievement (Catsambis, 1998). In addition, the study revealed that high levels of educational expectations, consistent encouragement, and actions that enhanced the learning opportunities of students were the most important ways in which families positively influenced the educational achievements of their children. Consistent with previous research, the study also supported the idea that, regardless of socioeconomic or racial/ethnic background, families with high levels of educational expectations had the most positive effects on student achievement (Catsambis, 1998). These effects were also present when parental expectations were measured in the middle grades and in high school (Catsambis, 1998).

Some studies focused on female students. Trenor et al. (2008) designed another study to better understand the contextual and personal variables influencing female students' educational decisions related to engineering. Their analysis of survey data revealed that ethnic groups did not show any statistically significant differences in regard to perceived supports, sense of belonging, barriers, and financial influence for studying engineering, nor in regard to major choice goals, all had a value of $p > 0.05$; however, further analysis indicated that perceived social support was positively correlated with sense of belonging $r(159) = 0.57$, $p < 0.001$, and intention to persist in engineering, $r(160) = 0.30$, $p < 0.001$). In addition, perceived social supports were negatively correlated to perceived barriers, $r(160) = -0.36$, $p < 0.001$. Based on the results, it was concluded that parents, acting as role models, played an important part in female students' selection of a major and their persistence in the field.

Parents can also improve their student's interest in STEM by helping their children realize the importance of STEM courses, as well as by emphasizing their importance for a future career (Smith & Hausafus, 1998). The interest in mathematics and science as a possible career decreases for many students at a young age (Verdin &

Godwin, 2015). However, parental encouragement has been found to be very effective at cultivating students' interest in STEM (Smith & Hausafus, 1998). Dorie et al. (2014) investigated the ways that parents adopted certain roles and enacted others that promoted their children's interest in, and awareness and understanding of, engineering across the pre-college lifespan. In five distinct studies, using multiple case study analysis, they identified and underscored the roles that parents played from birth through the completion of college: engineering thinking guide, student achievement stimulus, engineering career motivator, and engineering attitude builder. Findings from all five studies showed that, at some stage of their children's lives, the parents served as engineering thinking guides. Also, from birth through high school, they served as engineering attitude builders and found a variety of ways to be engineering career motivators, depending on the developmental stage of their children. The parents also stimulated academic achievement in their children as they progressed through pre-K-12 and into college. Finally, from toddlerhood to university, the parents promoted engagement in activities that were mostly positive toward engineering education and an engineering career choice. These findings demonstrate the importance of having family members support students' STEM interests.

Previous research indicated that parental knowledge of STEM fields increased the probability of a student's pursuing a STEM major (Harwell & Houston, 2012) and that students with at least one parent in a STEM field had a higher likelihood of pursuing a STEM major (Vu, Harshbarger, Crow, & Henderson, 2019). This is mainly because the students became aware at a young age of what STEM is, were supported by their parents in taking STEM-related courses and learned about future career options in STEM fields. Children follow models set by their parents (Trenor et al., 2008), and parental knowledge and support can lead students to believe that they have the opportunity and the capacity to pursue a STEM major (Vu et al., 2019). Parents who talk to their children about the need for STEM majors in our society and the high salary potential for STEM careers increase the likelihood that their children will enter a STEM field (Harwell, 2012). Andrews and Clark (2012) designed a study to explore the possible factors that influence girls' perceptions of engineers and engineering. They found that one of the most significant barriers to engineering was a lack of awareness, and they identified three types of factors that are critical to girls' perceptions of engineering: pedagogical, social, and familial. Among those factors, parental influence was key in guiding the study and career choices of the students. Wherever parents' engineering and STEM field knowledge was limited, students expressed misconceptions about STEM fields and showed a significant lack of awareness of engineers and engineering (Andrews & Clark, 2012).

These findings are aligned with earlier research related to parental influence on student career choice and academic success, which indicated that, regardless of family income or background, students with involved parents or caretakers were more likely to get higher grades, pass their classes, attend school regularly, have better social skills, and graduate to go on to postsecondary education (Henderson & Mapp, 2002, p. 13). Given that parental influence plays such a significant role in children's educational achievements and career choices, some researchers have focused on increasing parental

STEM knowledge and behaviors. Tay, Salazar, and Lee (2018) designed a study to examine parental perceptions of the influence of a Saturday STEM enrichment program on pre-K and kindergarten students and to examine the children's attitudes toward STEM learning. Using qualitative survey data, the authors analyzed comments by parents about the benefits, drawbacks, and memorable moments they observed concerning their children's experiences during the program. The parents favorably evaluated the STEM classes their children attended and appreciated the opportunities provided for their children to engage in STEM learning. The parents also commented on their children's enthusiasm and motivation to learn, as well as on the benefits gained from the classes. From the parents' perspective, such an early introduction to STEM fields not only helped their children discover new interests and explore new topics, but also helped some of the young children to think about their future education and careers. Similarly, in another study, Klein-Gardner (2015) aimed at measuring the impact of a STEM summer institute (SSI) on students' understanding of what engineering is and assessed its impact on parents' engineering knowledge and attitudes. The analysis of the parents' data indicated a significant increase in parental knowledge of engineering (Klein-Gardner, 2015). Because their influence plays a significant role in their children's educational achievements and career choices, parents can provide a solution to the problem of a lack of STEM professionals (Heil, Hutzler, Cunningham, Jackson, & Chadde; 2012). Therefore, it is critical for parents to have knowledge and understanding of STEM fields, and specifically in the case of this study, of engineers and engineering. Parents who have accurate knowledge and a good understanding of engineers and engineering will be able to introduce their children to STEM fields early on and lead them to consider a STEM field as a good choice for their future career (Klein-Gardner, 2014).

4.2. Research Summary

The current study aimed to investigate parents' knowledge of and attitudes towards engineering, and their behaviors related to engaging their children in engineering related programs. Because it explored parents' knowledge, attitudes, and behaviors concerning engineering, this study is unique and has the potential to generate new questions in engineering education research.

4.3. Research Questions

The main research question (RQ) I asked in this study was: *What were the parents' knowledge of, and attitudes towards, engineering? What engineering-based experiences did parents engage in with their children?*

The following sub-questions (SRQ) helped answer the main research question.

SRQ1: *Were there any significant ($p < .05$) differences in the parents' knowledge and understanding of building automation, the Internet of Things, the engineering design process, and engineering careers before and after the summer camp?*

SRQ2: *Were there any significant ($p < .05$) differences in the participant students' knowledge and understanding of building automation, the Internet of Things, the engineering design process, and engineering careers before and after the summer camp from parents' perspectives?*

SRQ3: *What were the parents' knowledge of, attitudes towards and behaviors of engineering and what kind of differences, if any, existed in parents' knowledge of, attitudes towards and behaviors of engineering depending on their demographic characteristics?*

SRQ4: *What interactions, if any, existed among parents' knowledge of engineering, attitudes toward engineering, and behaviors they engaged in that support their children's understanding of engineering?*

4.4. Student Summer Camps

Several one-week summer camps for junior high school students, which were one component of a National Science Foundation (NSF)-funded project, took place at different locations in one of the southwest US state with the support of a Major Research 1university. The camps were aimed at increasing students' knowledge and understanding of STEM fields, specifically engineering concepts, and at improving the participants' attitudes toward the STEM fields. In addition, the summer camps helped students realize that engineering was a collaborative profession that required many disciplines working together to achieve a common goal. Engineering faculty and learning scientists prepared the camp curriculum and modified it as needed. The camps were scheduled for seven hours per day for the entire week. During the camps, students worked on a problem-based project. They were tasked with designing a smart home and developing a model that was energy-efficient and environmentally friendly, using connected devices and additive manufacturing. Through their work, students learned scientific concepts and confronted real-world engineering and technology challenges, using 3D printers (for additive manufacturing), Computer-Aided Design (CAD) tools, and the Internet of Things (IoT). Table 11 lists the summer camp activities.

Table 11

Camp Overview

DAY 1 – Introduction to Smart-Home principles
Introduction to the concept of a smart home and the engineering design process
Discussion of design requirements: building codes, lot characteristics, furniture, and budget
Students draw a floor plan, including material specs, measurements, pricing, etc.
Homework: Students ask their parents about the temperature profile at home, and they do research together
DAY 2 – Introduction to Programming
Discussion of homework results
Introduction to programming and sensors
Programming applied to smart homes
DAY 3 – IOT & 3D Printing
Illustration of IoT concept through the "city" (network)
Guided programming: give students pre-built code; students run it and tweak it.
Introduction to 3D printing and 3D design
Guest lecture regarding CAD/3D printing
Students customize their design for the 3D printer and print their design
DAY 4 – Build Out
Review of the judging criteria with students
Review of best practices for teamwork (strategies)
Construction of the smart homes (cutting, gluing, etc.) and programming
Finish the smart homes for the final competition
DAY 5 – Competition
Students finish constructing /programming and prepare their presentations
Students show their understanding of smart-home principles by presenting their design strategy
Question and answer session
Judges meet and evaluate groups
Announcement of winner, distribution of certificates

At the beginning of the summer camps, parents gave their consent for their children to participate in the activities. The parents were involved in camp activities at different points. For example, they brainstormed and conducted research with their children to complete the take-home assignments on engineering concepts and innovative technologies. They participated in the STEM Night, when the student groups presented their smart homes and their engineering designs. The STEM Night was held at the last day of the camp.

4.5. Methods

I employed a survey design to collect quantitative data from the students' parents about the week-long summer camps. The parents helped their children to complete the homework related to the camp activities, and they were invited to participate in the STEM Night towards the end of the week.

4.5.1. Participants

The study participants were the upper elementary and middle-school students who attended the summer camps, and their parents. While there was a small fee for camp participation, students who were in financial need were able to apply for a scholarship.

The study involved five one-week summer camps. Three of them, which took place in a town next to a university in the state, were completed in the summers of 2017, 2018 and 2019; the other two camps, which took place in a different town in the state, were completed in the summer of 2018. Forty-five parents and forty-three students participated in the camp activities. The demographic characteristics of the parent-participants are presented in Table 12.

Table 12

Parents' Demographic Information

Criteria	Categories	Total
Gender	Male	15
	Female	30
Ethnicity	Hispanic or Latino	21
	Non-Hispanic or Latino	24
Age	20-35	7
	36-49	28
	50+	10
Camp Location	Bryan, TX	30
	Mission, TX	15
Education Level	No-College Degree	16
	College Degree	29
Student Grade	Elementary	12
	Secondary	33

4.5.2. Instrumentation

I used two research instruments: the Parents' Engineering Awareness Survey (PEAS) (Yun, Cardella, Purzer, Hsu, & Chae, 2010) and an evaluation questionnaire.

The PEAS survey included three constructs: engineering knowledge, attitudes toward engineering, and engineering behavior (Yun et al., 2010). The PEAS was a five-point Likert-scale. The original version of the PEAS consisted of 47 items scored on a five-point Likert scale. For the current study, 25 items were selected from the PEAS (Yun et al., 2010). Eight items of the PEAS instrument focused on engineering knowledge. Ten items focused on attitudes toward engineering. Seven items focused on engineering behavior. Engineering behaviors items included questions about parents' activities that help support their children's understanding of engineering.

The evaluation questionnaire, which was developed by the project team, aimed at capturing the parents' knowledge and understanding of building automation, IoT, the engineering design process, and engineering careers. In addition, the evaluation questionnaire gathered information from parents regarding their children's knowledge and understanding related to building automation, IoT, the engineering design process and engineering careers. The demographic information was also collected. A copy of the questionnaire can be found in Appendix C.

4.5.3. Data Collection

The quantitative data were collected from the participating students' parents. The PEAS, which was developed by Yun et al. (2010), was administered to all consenting parents (one for each parent) after the summer camp was completed, to capture the parents' knowledge of engineering, their attitudes towards engineering, and their behaviors in regard to engineering.

A demographic questionnaire and an evaluation questionnaire were also administered to the parents upon completion of the summer camp. In the evaluation questionnaire, parents were asked to compare their before and after perceptions in the same questionnaire. The respondents were asked at post-PD time to recall their pre-PD status.

4.5.3.1. Missing Data

Missing data in this study were found within the dependent variables. To address this, I considered four options: (a) listwise deletion, (b) mean replacement, (c) maximum likelihood, and (d) multiple imputation. I ran Little's (1988) Missing Completely at Random (MCAR) test to evaluate the patterns of the missing data and determine whether the patterns of the missing data were completely random or not. The MCAR test indicated that the missing data showed a statistically significant pattern ($p = 0.03$) at a *p*-value 0.05. Because the missing data were not completely random, I decided to implement the multiple imputation method, which provides unbiased parameter estimates while addressing missing data (Graham, Olchowski, & Gilreath, 2007). To implement the method, I used the IBM Statistical Package for the Social Sciences (SPSS), version 26.

4.5.4. Data Analyses

The quantitative data were analyzed using descriptive and inferential statistics.

For the evaluation questionnaire, the descriptive statistics and paired samples *t*-

test were used to find the mean differences between the parents' responses to the evaluative feedback items before and after the camp. Significance was set at the $p < 0.05$ level. Cohen's *d* effect sizes were also computed and reported.

For the PEAS instrument, the Cronbach alpha values of the PEAS constructs were calculated to evaluate the internal consistency and reliability of the derived constructs. Then the parents' engineering knowledge, behavior, and attitudes scores were computed separately. For each of these three constructs, a sub-scale score was generated for each parent by summing the responses. For all the survey items, a five-point Likert scale was used, with alternatives ranging from 1 to 5 (i.e., 1 = strongly disagree, 2 = disagree, 3 = neutral, 4 = agree, and 5 = strongly agree). The mean scores for the parents' engineering knowledge, behavior, and attitude constructs were calculated.

To clarify the relations between the parents' knowledge, attitudes, and behaviors regarding engineering, a Pearson correlation test was run on three variables (i.e., parents' engineering knowledge, engineering attitude, and engineering behavior), and their results were interpreted according to Cohen's correlation criteria (Cohen, 1988).

I also examined differences in the parents' engineering knowledge, behavior, and attitude constructs that stemmed from their demographic characteristics. The independent variables included the following: (a) gender with two levels (i.e., female or male), (b) ethnicity with two levels (i.e., Latino/Hispanic or Non-Latino/Hispanic), (c) education with two levels (i.e., no college degree, college degree), and (d) age with three levels (i.e., 20-35, 36-49, 50 and above). The dependent variables were the parents' engineering knowledge, behavior, and attitude constructs. If a variable, such as gender, had two levels, I used an independent-samples *t*-test with a significance level of .05 to compare the two groups. If a variable had more than two levels, I used a one-way analysis of variance (ANOVA) with a significance level of .05. I examined the Levene's statistics (p =.05) to make sure the equal variance condition held before conducting the post-hoc tests. Tukey HSD post-hoc tests were conducted to evaluate statistically significant differences between groups. I chose this test because it is a robust and general post-hoc analysis, and it has the most reasonable balance of power and Type I error comparison among the conventional tests available (Newsom, 2006).

4.6. Results

4.6.1. Cronbach's Alpha Reliability Results

The quantitative data were analyzed using descriptive and inferential statistics. The PEAS instrument includes three dimensions, including (a) parents' engineering knowledge, (b) parents' engineering behavior, and (c) parents' engineering attitudes (Yun et al., 2010). The Cronbach alpha values of the PEAS constructs were calculated to evaluate the internal consistency and reliability of the derived constructs. The Cronbach's alpha scores are presented in Table 13. (I excluded one item from the analysis because, it did not fit well within its highest factor and lowered the reliability of its factor.)

Table 13

Cronbach's Alpha Values of the PEAS Scale

Factor	Number of items	Cronbach's Alpha value
Parents' Engineering Knowledge	8	.83
Parents' Engineering Behavior	7	.72
Parents' Engineering Attitudes	9	.67(one item dropped)

Research Question 1: Were there any significant ($p < .05$) differences in the parents' confidence in knowledge and understanding of building automation, the Internet of Things, the engineering design process, and engineering careers before and after the summer camp?

To answer this question, at the completion of the summer camp, feedback from the evaluative questionnaire was collected from the parents, regarding their confidence in their knowledge and understanding of building automation, the Internet of Things, the engineering design process, and engineering careers. The evaluative questionnaire asked the parents to report their confidence in their knowledge and understanding before and after the summer camp.

The parents' responses are summarized in Table 14. The mean differences between their responses to the evaluative questionnaire items before and after the camp increased at the end of the summer camp. The paired samples *t*-test results indicated that the parents showed a statistically significant positive increase ($p < .01$) in their responses to the evaluative questionnaire items after the summer camp.

Cohen's *d* effect size was computed; it ranged from 0.66 to 0.97, which showed a medium- to- large group mean difference.

Table 14

Descriptive Statistics and Paired-Sample t- *Test Results of Parents' Responses to Evaluative Questionnaire*

Evaluation Questions	*MD*	*SD*	*t*	*p*	*Cohen's d*
Your knowledge of building automation to maximize energy use	0.92	0.94	6.38	.001*	0.97
Your understanding of the engineering design process	0.77	1.12	4.66	.001*	0.69
Your awareness of engineering careers	0.60	0.98	3.86	.001*	0.61
Your understanding of the Internet of Things (IoT)	0.52	0.78	4.23	.001*	0.66

Note. *N* = 45. *MD* = Mean Differences, *SD* = Standard Deviation. *Statistically Significant at $p < 0.05$.

Research Question 2: Were there any significant ($p < .05$) differences in the participant students' confidence in knowledge and understanding of building automation, the Internet of Things, the engineering design process, and engineering careers before and after the summer camp, from parents' perspectives?

To answer the second research question, at the completion of the summer camp, data were gathered from the parents regarding their children's confidence in their knowledge and understanding of building automation, the Internet of Things, the engineering design process, and engineering careers. The parents were asked to score their children's confidence in their knowledge and understanding before and after the summer camp on a single, post-camp evaluative questionnaire. Their pre- and post-camp feedback responses are compared in Table 15. The mean differences between the parents' responses to the evaluative questionnaire items before and after the camp increased at the end of the summer camp. The paired samples *t*-test results indicated that there was a statistically significant positive increase ($p < .001$) between the parents' responses to the evaluative feedback items before and after the camp. Cohen's *d*- effect size was also computed; it ranged from 1.08 to 1.90, a large group mean difference for all of the items.

Table 15

Descriptive Statistics and Paired-Sample t-*Test Results of Parents' Responses to Evaluative Questionnaire (for their child)*

Evaluation Questions	*MD*	*SD*	*t*	*p*	*Cohen's d*
Your child's knowledge of building automation to maximize energy use	1.84	1.04	11.08	.001*	1.76
Your child's understanding of the engineering design process	1.76	0.93	11.87	.001*	1.90
Your child's awareness of engineering careers	1.56	1.14	8.55	.001*	1.40
Your child's understanding of the Internet of Things (IoT)	1.15	1.06	6.76	.001*	1.08

Note. $N = 45$. *MD* = Mean Differences, *SD* = Standard Deviation.
*Statistically Significant at $p < 0.05$.

Research Question 3: What were the parents' knowledge of, attitudes towards, and behaviors of engineering and what kind of differences, if any, existed in parents' knowledge of, attitudes towards, and behaviors of engineering depending on their demographic characteristics?

To answer the third research question, parents' engineering knowledge, behavior, and attitudes were computed separately. The mean score for the parents' engineering knowledge construct was 4.04, with a standard deviation of 0.63. On the other hand, the mean score for the parents' engineering behavior construct was 4.16, with a standard deviation of 0.59, and for the parents' engineering attitude construct, the average score was 4.46, with a standard deviation of 0.37. These numbers show that while the parents exhibited positive behaviors and attitudes toward engineering, their engineering knowledge was relatively low.

Table 16

Descriptive Results of the PEAS Constructs

Construct	*M*	*SD*
Parents' Engineering Knowledge	4.04	0.63
Parents' Engineering Behavior	4.16	0.59
Parents' Engineering Attitudes	4.46	0.37

Note: *M* = Mean, *SD* = Standard Deviation.

I further examined whether there were any significant differences in how the parents of different demographic groups rated the constructs. The independent-samples t-test with a significance level 0.05 was used to explore differences in the three constructs pertaining to gender (Group 1: male; Group 2: female), ethnicity (Group 1: Hispanic or Latino; Group 2: Non-Hispanic or Latino), student grade (Group 1: elementary; Group 2: secondary), location (Group 1: Bryan; Group 2: Mission) and education (Group 1: no college degree; Group 2: college degree) differences in the three constructs. The independent-samples t-test analysis indicated that there were no statistically significant differences among the scores of parents of different education levels with regards to their engineering knowledge (*MD* = 0.29, *t* (43) = 1.50, *p* =.58), engineering attitude (*MD* = 0.51, *t* (43) = 0.45, *p* = .65), and engineering behavior (*MD* = 0.11, *t* (43) = 0.60, *p* = .55). In addition, the independent-samples *t*-test analysis revealed that there were no statistically significant differences among the scores of parents of different ethnicities with regards to their engineering knowledge (*MD* = 0.18, *t* (43) = 0.91, *p* = .36), engineering attitude (*MD* = 0.02, *t* (43) = 0.19, *p* = .20), and engineering behavior (*MD* = 0.03, *t* (43) =0.15, *p* = .87). In addition, the independent-samples *t*-test analysis revealed that there were no statistically significant differences in scores of parents of different genders with regards to their engineering knowledge (*MD* = 0.14, *t* (43) = 0.69, *p* = .48), engineering attitude (*MD* = 0.03, *t* (43) = 0.02, *p* = .97), and engineering behavior (*MD* = 0.08, *t* (43) =0.04, *p* = .96). Furthermore, there were no statistically significant differences among scores of parents of children at different grade levels with regards to their engineering knowledge (*MD* = 0.14, *t* (43) = 0.62, *p* = .53), engineering attitude (*MD* = 0.01, *t* (43) = 0.15, *p* = .87), and engineering behavior (*MD* = 0.08, *t* (43) = 0.04, *p* = .96). Finally, there were no statistically significant differences among the scores of parents with children in different locations with regards to their engineering knowledge (*MD* = 0.15, *t* (43) = .74, *p* = .46), engineering attitude (*MD* = 0.01, *t* (43) = 0.16, *p* = .87), or engineering behavior (*MD* = 0.15, *t* (43) = 0.83, *p* = .40).

A one-way ANOVA was conducted to determine if the parents' knowledge, attitudes, and behaviors concerning engineering differed among age groups. The parents were divided into three groups (Group 1: 20-35 years; Group 2: 36-49 years; Group 3:

50 years and above). The data were normally distributed for each group, as assessed by a Shapiro-Wilk test ($p > .05$), and there was homogeneity of variances, as assessed by a Levene's test of homogeneity of variances ($p = .24$). The parents' scores for engineering behavior were statistically significantly different among the age groups. F (2, 42) = 6.881 $p < .003$ (see Table 17). The scores increased with age, from Group 1 (M = 3.52, SD = 0.41) to Group 2 (M = 4.28, SD = 0.46) and again to Group 3 (M = 4.59, SD = 0.47). A Tukey HSD post-hoc analysis indicated that the increase from the age group 20-35 (Group 1) to the age group 36-49 (Group 2) was statistically significant ($p = .002$), as was the increase from the age group 20-35 (Group 1) to the age group 50 and above (Group 3) ($p = .001$), but no other group differences were statistically significant. Furthermore, partial eta squared, the effect size, showed a small practical significance ($\eta p^2 = 0.27$).

Table 17

ANOVA Parents' Behavior of Engineering & Different Age Groups

	Groups	*df*	Sum of Squares	Mean of Squares	*F*	*p*	*Partial Eta Squared*
Parents' Behavior of Engineering							
	Between Groups	2	3.363	1.681	6.881	.003*	0.27
	Within Groups	42	8.796	0.244			
	Total	44	12.159				

*Statistically Significant at $p < .05$.

Research Question 4: What interactions, if any, existed among parents' knowledge of engineering, attitudes toward engineering, and behaviors they engaged in that support their children's understanding of engineering?

To be able to understand the relations among the variables of parents' knowledge of engineering, attitudes toward engineering, and engineering-related behaviors, a Pearson correlation test was run. As shown in Table 18, parents' engineering knowledge and parents' engineering behavior displayed a statistically significant and moderately positive correlation, ($r = .386$, $p < .476$). Similarly, parents' engineering attitude showed a statistically significant and moderately positive correlation with parents' engineering behavior, ($r = .361$, $p < .345$). There were no other significant correlations among the other variables observed.

Table 18

Correlations among PEAS Survey Constructs

Parents' Variables	1	2	3
1. Parents' Engineering Knowledge	1	.476**	.172
2. Parents' Engineering Behavior	.476**	1	.345*
3. Parents' Engineering Attitude	.172	.345*	1

Note. N=45
** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.01 level (2-tailed)

4.7. Conclusion

The parents involved in this study reported that participating in these programs helped them understand some innovative technologies and engineering concepts better. In particular, the results of the statistical analysis showed that the parents' and students' knowledge of building automation, their understanding of the engineering design process, awareness of engineering careers, and understanding of the Internet of Things (IoT) changed after the summer camp and STEM Night participation, to a statistically significant degree. In addition, the results indicated that even though parents' knowledge of engineering was relatively low, they had positive attitudes towards and behaviors in regard to engineering. I further examined whether there were any significant differences in how the parents of different demographic groups rated these constructs. While there were no statistically significant differences among the parents of different education level, ethnicity, and gender, or among parents whose children's grades differed or whose children attended school in different locations, the parents' engineering behavior scores increased with age, from Group 1 at 20-35 years (M = 3.52, SD = 0.41) to Group 2 at 36-49 years (M = 4.28, SD = 0.46), to Group 3 at 50 years and above (M = 4.59, SD = 0.47). In short, the older the parents, the higher the engineering behavior scores. Furthermore, partial eta squared, the effect size, suggested a small practical significance ($\eta p^2 = 0.27$).

It is worth mentioning that while the mean score for the participants' knowledge of engineering was the lowest among the constructs (M = 4.04), their mean score for attitudes was highest (M = 4.46). Specifically, their ratings for the item "I am aware of the engineering curriculum at my children's school" had the lowest mean (M = 3.47) among knowledge construct items. Similarly, their ratings for the item "I know how to help my child with his/her engineering ideas and skills" had the second-lowest mean score in the parents' engineering knowledge construct (M = 3.66). On the other hand, the item "I think engineering improves our society" had the highest mean score (M = 4.94) among the attitude construct items. This means that even if the participant-parents were not knowledgeable about engineering, they had a positive attitude towards it. These results are consistent with those in the literature (Yun et al., 2010). In addition, among the items relating to engineering behavior, the participants scored the highest for the item "I encourage my child to identify and solve problems."

In regard to the importance of engineering education for different genders, the participant-parents indicated that there should not be any difference between boys and girls when it comes to engineering education. Specifically, their ratings were very high for the item “I think it is equally important for both girls and boys to learn engineering” (*M* = 4.42). These results were supported by the ratings for two other items: “I think it is more important for boys to learn engineering than it is for girls to learn engineering” (*M* = 2.10)” and “I think it is more important for girls to learn engineering than it is for boys to learn engineering” (*M* = 2.67).

4.8. Implications

When parents increase their engineering knowledge and generate more positive behaviors and attitudes towards engineering topics and concepts, this will reflect on their children (Mahmoud, 2018). Because parents have a powerful impact on their children’s future career choices, helping them improve their engineering knowledge, behavior, and attitudes might be an effective solution to the STEM recruitment crisis (Heil, Hutzler, Cunningham, Jackson, & Chadde; 2012). Increasing parental participation in student STEM camps by creating an environment where parents can interact with their children, could be a good starting point. As students observe their parents’ interest and engagement in STEM camp activities, they will become more interested in STEM fields and view engineering activity from a more contextual perspective as something that is meaningful in their lives (Johnson, Ozturk,Valverde, Yalvac, & Peng, 2013; Ozturk et al., 2013; Peng, 2014).

4.9. Limitations

This research study should be viewed in light of certain limitations. First, the participant sample was relatively small. In addition, the population was self-selected and may not be representative. Moreover, families that would sign up and pay for a STEM-related summer camp are likely to be biased towards an interest in STEM fields, and even those that received scholarships might be active in seeking out STEM activities for their children.

Future work can attempt to overcome some of these limitations. A wider and larger population from a traditional school setting would enable these data to be compared to those of parents and students who are less proactive in searching for STEM-related activities.

4.10. References

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5. CONCLUSION

The overarching goal of this dissertation was to understand and improve teachers' and parents' conceptualization of engineers and engineering. The teacher participants attended a summer professional development (PD) program and completed engineering-focused activities. The parent participants attended a science, technology, engineering, and mathematics (STEM) Night, and engaged in STEM activities involving projects that their children were working on during a STEM-focused summer camp.

In the first study, I aimed at investigating the effectiveness of a two-week long engineering-focused summer PD for teachers. I focused on exploring the effects of the PD activities on the teacher participants' engineering knowledge and skills using a mixed-methods approach. The results showed that participating in the engineering-focused programs could effectively enable the teachers to understand advanced technologies and engineering concepts and improved their knowledge about how to teach those concepts.

In the second study, I aimed at understanding the characteristics of the mental images teachers had regarding engineers and engineering. Using qualitative research methods, I explored how the participant-teachers' perceptions, personal beliefs, and mental images of engineers and engineering had changed after a two-week-long PD. The findings indicated that teachers gained a better understanding of the skills needed for engineering, including programming and collaboration. They also increased their awareness of the activities engineers engage in, for example, computer coding and problem solving. In addition, the teachers increased their awareness of the tools engineers use, for example, electronics and hand tools, as opposed to lab equipment, which is associated more with science.

In the third study, I aimed at exploring parents' knowledge of and attitudes towards engineering, and their behaviors for engaging their children in engineering-related programs. Using quantitative research methods, the study focused on understanding the relations among the parents' knowledge, attitudes, and engineering-related behaviors, and on their perceptions of their children's summer camp learning experiences. The findings suggested that participating in the summer camp and family STEM Night programs helped the parents to better understand certain innovative technologies and engineering concepts. In particular, the statistical analysis results showed that after their participation in the summer camp and STEM Night, the parents' knowledge of building automation, their understanding of the engineering design process, their awareness of engineering careers, and their understanding of the Internet of Things (IoT) changed to a statistically significant degree. Additionally, the results indicated that even though the parents' knowledge of engineering was relatively low, they had a positive attitude towards engineering and engaged their children in engineering-related programs. I further examined whether there were any statistically significant differences in how parents in different demographic groups rated the three constructs of engineering knowledge and attitudes and engineering-related behavior. While there was no statistically significant difference on the three constructs among the parents of different education level, ethnicity, and gender, or among parents whose children's grade levels differed or whose children attended school in different locations, the scores for parents' behaviors for engaging their children in engineering-related programs differed to a statistically significant degree among parents of different age groups, with the older parents reporting higher scores. Furthermore, the parents' engineering knowledge and their behaviors for engaging their children in engineering-related programs displayed a statistically significant and moderately positive correlation. Similarly, parents' engineering attitude showed a statistically significant and moderately positive correlation with their behaviors for engaging their children in engineering-related programs. No significant correlations were observed among the other variables.

The overall finding from the three studies was that completing activities that were designed to integrate concepts of engineering and technology with the teaching of science and mathematics improved the participants' understanding of engineering, their attitude towards engineering, and their conceptualization of engineers. Attending the STEM engineering-focused PD benefited the teacher-participants by improving their understanding of engineers and engineering concepts, as well as their teaching skills. The participating teachers were able to learn about cutting-edge technologies and building automation, better understand the processes of engineering design and product development, acquire an awareness of engineering careers, acquaint themselves with the IoT, and strengthen their confidence in using a design challenge and industry experts in their teaching, as well as their confidence in ways to cultivate reflective decision making in students. The teachers showed an increased awareness of the activities in which engineers engage and the tools they use, and they gained a better understanding of the skills needed for engineering. Moreover, participation in the PD piqued their interest in concepts of engineering and technology, which might have led them to develop more positive conceptions related to STEM fields and assign more importance to STEM and STEM careers. The parents told us that the programs helped them improve their understanding of innovative technologies and engineering concepts, including building automation, the engineering design process, engineering careers, and the IoT.

The economic growth and global competitiveness of a nation are strongly impacted by innovations and advancements in STEM fields (National Science Board [NSB], 2020). In today's world, people who have STEM knowledge and expertise are essential to improving a nation's inventive capacity, due to their high skill levels, their creative ideas, and their ability to advance scientific knowledge. However, while the number of U.S. jobs that require STEM field knowledge is rising, the number of students choosing STEM majors is decreasing (National Research Council [NRC], 2011).

Considering that engineering has become crucial in the modern era, there is a need for a qualified and skilled engineering-literate workforce (International Technology and Engineering Educators Association [ITEEA], 2020; NRC, 2011). Many educators and members of various organizations and foundations express a concerted opinion that students need to be more literate about engineering (ITEEA, 2020; NGSS Lead States, 2013; NRC, 2011). Expanding learners' understanding of engineering tenets and concepts and developing their engineering literacy enables them to make informed decisions in their life and enjoy a higher quality of living. Today's society requires that education systems prepare as many people as possible to achieve advanced cognitive ways of thinking (Organization for Economic Co-operation and Development [OECD], 2014). Well-developed engineering literacy can help our students to develop problem-solving and critical-thinking skills and to become life-long learners.

Given that teachers and parents have a paramount influence on students' educational achievements and career choices, understanding and improving teachers' and parents' perceptions of engineering and STEM concepts can help remedy the scarcity of STEM professionals (National Science Foundation [NSF], 2019; Cevik et al., 2018; Mesutoglu, & Baran, 2020; Purzer, Moore, & Dringenberg, 2018). It is critical for teachers and parents to have knowledge and an understanding of all STEM disciplines, including engineering. Teachers and parents who have accurate knowledge and understanding of engineering and engineers will be able to influence students to choose a STEM field for their career (Cevik et al., 2018; Klein-Gardner, 2014).

In conclusion, the findings from the three studies call upon teachers and parents to improve their engineering knowledge and understanding of engineering concepts, so that they can better guide their students and children into the STEM pipeline.

5.1. Implications for Future Research

Future research in this area could follow a variety of paths. It could make efforts to understand the long-term impacts of engineering-focused PDs on teachers' understanding of engineers and engineering concepts. Teachers could be interviewed to determine what aspects of the PD activities are being used in their classes and to identify their rationales for maintaining, adjusting, or eliminating this content. Similarly, future research could investigate the impacts of engineering-focused PDs on students' understanding of engineers and engineering concepts. Also, interviewing students about changes in their conceptualization and understanding of engineers and engineering after teachers implement the PD project activities in their classrooms could shed light on the long-term impacts of the PD. In addition, the data collected from teachers and students could be compared to investigate the relationships between them. Due to the limitations of funding for this study, the data were collected from a limited number of teachers and parents; hence, the number of participants could be increased to capture a broader picture of teachers' and parents' understanding of engineers and engineering. The parents' data were collected through a questionnaire and survey instruments. To gain a more in-depth understanding of their engineering knowledge, attitudes, and behaviors for engaging their children in engineering-related activities, parents could also be interviewed. Documenting and studying parents' knowledge and awareness of engineering and engineering could be a direction for future research that supports efforts to improve the STEM pipeline in the U.S.

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APPENDIX A

TEACHER QUESTIONNAIRE

Please use the following scale to describe your pre-PD (before the professional development program) and post-PD (current) confidence in your understanding of the following topics.

Not at all confident 1	Not confident 2	Neither confident or not 3	Confident 4	Very Confident 5

Before		After
	Knowledge of building automation to maximize energy use	
	Understanding of the engineering design process	
	Understanding of the product development process	
	Confidence in using a design challenge with students/youth	
	Awareness of engineering careers	
	How to elicit reflective decision-making in students/youth	
	How to use industry experts	
	The Internet of Things	

This questionnaire was prepared by the Project Research Team.

APPENDIX B

INTERVIEW PROTOCOL

Teacher Interview Questions

These questions target the teachers' perceptions of the professional development program in terms of the content and skills they gained, the challenges and limitations they faced, and their suggestions for improvement.

1. What did you learn in the ITEST professional development program?
2. What skills did you develop in the ITEST professional development program?
3. What challenged you in this program? How would you use the things you learned in this program in the future?
4. What do you suggest for improving this professional development program?
5. How was your overall experience with ITEST professional development program?

APPENDIX C

PARENT QUESTIONNAIRE

Name______________________________

Child's Name____________________________

1. Please specify your sex:

☐ Female ☐ Male ☐ Prefer not to answer

2. Please state your age: _________

3. Education

☐ Some High School

☐ High school graduate - high school diploma or the equivalent (for example: GED)

☐ Some college credit, but less than 1 year

☐ 1 or more years of college, no degree

☐ Associate degree (for example: AA, AS)

☐ Bachelor's degree (for example: BA, AB, BS)

☐ Master's degree (for example: MA, MS, MEng, MEd, MSW, MBA)

☐ Professional degree (for example: MD, DDS, DVM, LLB, JD)

☐ Doctorate degree (for example: PhD, EdD)

4. Please identify the race/ethnicity that you most identify with; check all that apply.

☐ Hispanic or Latino

☐ American Indian or Alaska Native

☐ Asian

☐ Black or African American

☐ Native Hawaiian or Other Pacific Islander

☐ White

☐ Other

☐ Prefer not to answer

5. Please use the following scale to describe **your** pre- (before Family STEM Night) and post-(now) confidence in understanding the following topics.

Not at all confident 1	Not confident 2	Neither confident or not 3	Confident 4	Very Confident 5

Before		After
	Knowledge of building automation to maximize energy use	
	Understanding of the engineering design process	
	Awareness of engineering careers	
	The Internet of Things	

6. Please use the following scale to describe **your child's** pre- (before this design activity) and post-(now) confidence in understanding the following topics.

Not at all confident 1	Not confident 2	Neither confident or not 3	Confident 4	Very Confident 5

Before		After
	Knowledge of building automation to maximize energy use	
	Understanding of the engineering design process	
	Awareness of engineering careers	
	The Internet of Things	

7. How would you rate this Family STEM Night? Check one.

☐ Not a good use of my time

☐ Learned a few things

☐ I found it interesting

☐ Definitely worth attending

8. Comments or suggestions:

This questionnaire was prepared by the Project Research Team.