Professional Development Activities for Secondary STEM Teachers and Students' Engineering Content Knowledge and Attitudes

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Abstract
To promote an integrated Science, Mathematics, Engineering, and Technology (STEM) education in K-12 school levels and cultivate STEM literacy in the society, there is a growing interest in including engineering content in K-12 curricula. A review of literature suggests that teachers' knowledge and attitudes towards the STEM fields are positively correlated with their students' knowledge and attitudes towards the STEM fields. Hence, it is central to explore and document the characteristics and qualifications of the teachers in teaching engineering content.

This paper describes a two-week-long residential professional development (PD) activity designed for STEM teachers to improve their engineering content and attitudes and reports the findings from the descriptive and inferential quantitative analyses of the data collected at the PD workshops. Presented are the meaningful correlations among the teachers' perceptions of and familiarity with design, engineering, and technology (DET) and their students' STEM attitudes.

A group of faculty and researchers developed the engineering-focused PD workshops to instruct the teachers about the cutting-edge technologies related to the Internet of things (IoT) and additive manufacturing. The overarching goals of the project was to introduce underrepresented students to the authentic engineering activities and varied career opportunities in the STEM fields and improve students' attitudes toward STEM through preparing their teachers to be effective in teaching these concepts in the classroom.

The two-week PD workshops were held at a Research I University campus in Summer 2017 and Summer 2018. Participating teachers learned about the basics of the engineering design principles, IoT technologies, computer-aided design tools, and additive manufacturing processes. The teachers also received training on how to develop lesson plans that incorporate the engineering content into the existing school curricula.

The research questions in this study were 1) to what extent did the teachers' participation in the PD workshops affect their perceptions of engineering and their familiarity with teaching DET; and 2) What are the relations among teachers' perceptions of engineering, familiarities with teaching the DET, and their students' attitudes towards the STEM fields? The design of the study was a pre- and post-test survey. A DET survey was administered to the participating teachers before and after the PD workshop activities. The DET survey is a five-point Likert-scale that consists of 40 items. The instrument focused on measuring the participants' perceptions and familiarity with the DET concepts. A S-STEM survey was also administrated to the teachers' students at the beginning and the end of the school year. The S_STEM survey is a five-point Likert-scale with 37 items. The S_STEM survey captured the students' attitudes towards the STEM fields and the 21st-century skills. In the paper we will describe the research conducted and discuss the implications for cultivating STEM literacy and integrated STEM education. Both pre- and post-comparison results and correlation results are presented.

Introduction

STEM fields play a crucial role in generating technological advancements, creating new methods, ideas, and skills for the improvement of society and human kind [1]. Although there has been growing interest in teaching engineering in schools and implementing engineering-related activities in K-12 settings, there is a shortage of interest among students who are willing to build a career path in STEM areas [2, 3]. In this sense, it is critical to establish environments in K-12 settings to be able enhance students' attitudes towards STEM fields. Research indicates that teachers' knowledge and attitudes towards the STEM fields are positively correlated with their students' knowledge and attitudes towards the STEM fields [4, 5]. Due to teachers' huge impact on students' future career choices, the most important step to boost students' interest in STEM fields is to increase teachers' perceptions and self-efficacy with engineering and STEM concepts [6]. While most teachers have the necessary educational background in math and science, their knowledge and experience related to engineers, engineering and technology are very limited [7]. This causes a lack of widespread engineering education at the K-12 level. Previous research reveals that teacher professional development programs have a positive impact on the students' achievement [8, 9] as well as providing benefits to the teachers. With this in mind, STEM focused teacher professional development programs that provide opportunities to the teachers to engage in authentic STEM and specifically engineering and technology activities can be utilized to enhance teachers' perceptions, content and pedagogical knowledge related to STEM areas [6]. When teachers gain necessary skills, knowledge, and background information related to those areas, this will be transferred to the students and they will have a chance to develop a STEM literacy through those experiences.

Yoon, et al. [10] designed a one-week long engineering-focused teacher professional development program and found that the program was effective at developing the participating teachers' engineering design process knowledge and changing their perceptions of engineering. Similarly, Hsu, et al. [11] established a study to assess teachers' knowledge of the engineering design process. The workshop was a week-long program and researchers focused on teaching the "Engineering is Elementary" engineering design process model. Their findings demonstrated that the engineering- focused workshop elevated teacher engineering design content knowledge. In addition, Tank, et al. [12] developed a short course for prospective teachers about several fundamental aspects of engineering, Their main purpose was to assist teachers to understand engineering design process, what engineering is, and what engineers do. After the course, participating teachers reported that they felt more motivated and confident to incorporate design, engineering and technology into their instruction. In addition, they presented an improvement in their ability to describe an engineering problem, develop solutions, and articulate what engineers do [12]. These results were echoed by many researchers [6, 13-17].

Teacher Summer Workshop

The teacher workshop took place at Texas A&M University in summers of 2017 and 2018. This teacher workshop was one component of a three-year NSF-funded project. The aim of the project is to foster junior high and high school student interest, skills, knowledge, and career aspirations in engineering through authentic engineering design activities related to building automation and IOT technologies. With this in mind, participating teachers were invited to an engineering-focused summer workshop that was designed to use the transformational and exciting technologies 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.

Twenty-four teachers participated in the program. The participating teachers attended a two week training and piloting session at Texas A&M University. During the training part of the workshop, middle school, junior high and high school teachers from different school districts worked with Texas A&M faculty to learn about the basics of the engineering design principles, the IoT technologies, computer-aided design tools, and additive manufacturing processes. The teachers also received training on how to develop lesson plans that incorporate the engineering content into the existing school curricula. In addition to learning about the numerous aspects of the STEM topics necessary to implement the program, participating teachers also had a chance to pilot their teaching with volunteer students.

Figure 1. Teachers Working with Students

Figure 2. Teachers Teaching Students to use 3D Printer

While the training portion of the activities took place during the first week, the piloting took place during the second week. At the end of the summer workshop, participating teachers were provided with the necessary software, hardware, and extra spools of 3D printing material to implement these activities in their classrooms. After the workshop, several faculty members from the project team were matched with the participating teachers to give more support. Furthermore, teachers prepared and sent progress reports every six weeks to the project team and received feedback from the project faculty members. Moreover, there were online meetings where teachers discussed their experiences and challenges during the implementation phase.

Figure 3. Teachers' Lesson Plan Presentation Day

Methods

Participants

Participant teacher demographics are presented in Table 1. There were twenty-four teacher participants in this study. While fifty-eight percent of the teachers were female, forty-two percent of the teachers were male. Nine of twenty-four teachers taught grades 9-12 and fifteen of them taught 6-8 grades. Teachers' age ranged from 20 to 58. 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. Sixteen teachers had bachelor's degrees, six had Master's degrees, and two had doctoral degrees.

Study Design

This study was a one-group pre-test post-test design. In this design, the participant teachers were tested before and after the two-week summer workshop to see whether there was any difference between their pre-workshop and post-workshop results. Participating teachers' students were also tested at the beginning of the school year as well as at the end of the school year. In addition to correlation analysis, the collected quantitative data were analyzed using inferential statistics.

Study Instruments
While we administrated the Design, Engineering and Technology (DET) Survey [18, 19] to the teachers, we administered Student Efficacy and Attitudes toward STEM Survey (S-STEM) [20, 21] to the students. A demographic questionnaire was also administrated to the all participants.

Table 1. Teacher Demographic Information.

Criteria	**Categories**	**Total**
Gender	Male	10
	Female	14
Ethnicity	White	10
	Black	6
	Hispanic or Latino	4
	Asian	3
	Two or more races	1
Age	20-35	10
	36-49	8
	50+	6
Education	Bachelor's Degree	16
	Master's Degree	6
	Doctorate Degree	2
Teaching Experience (years)	1-5	12
	6-10	7
	11-19	2
	20 and up	3
Teaching Grades	6-8	15
	9-12	9

The S-STEM survey is a 5-point Likert scale with 37 items. It was developed to measure students' attitudes toward science, technology, engineering, and mathematics subjects, 21st century skills, postsecondary pathways, and career interests. In this study, the survey questions that capture students' attitudes toward science, math, engineering/ technology and 21st century skills concepts were analyzed. The Design, Engineering, and Technology (DET) Survey is a five-point Likert scale survey with 40 items. This instrument was designed to capture teachers' perceptions and familiarity with engineering. The survey consists of several constructs including: importance of DET, familiarity with DET, stereotypical characteristics of engineers and barriers in integrating DET.

Results
Table 2 shows a general description of the teacher responses for each construct of the DET instrument. Total number of teachers who participated in these summer professional

development workshops were twenty-four. All of the teachers answered all of the DET survey questions. Teachers' perceptions regarding importance of DET, familiarity with DET, stereotypical characteristics of engineers and, barriers in integrating DET were calculated, independently. For each construct, a sub-scale score was produced for a teacher by adding up each of these items under that construct, individually. In all 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). While the mean score of the teachers' importance of DET construct was 4.46 with a standard deviation of 0.32 prior to the summer workshop, the mean score of teachers' importance of DET construct was 4.61 with a standard deviation of 0.40 after the summer workshop. Similarly, while the mean score of the teachers' familiarity with DET construct was 4.42 with a standard deviation of 0.44 prior to the summer workshop, the mean score of teachers' familiarity with DET construct was 4.61 with a standard deviation of 0.47 after the summer workshop. In addition, the mean score of the stereotypical characteristics of engineers construct was 4.43 with a standard deviation of 0.38 prior to the summer work shop, the mean score of stereotypical characteristics of engineers construct was 4.65 with a standard deviation of 0.44 after the summer workshop. Finally, the mean score of the barriers in integrating DET construct was 2.47 with a standard deviation of 0.31 prior to the summer work shop, the mean score of stereotypical characteristics of engineers construct was 2.51 with a standard deviation of 0.55 after the summer workshop. The mean difference between teachers' pre- and post- survey results indicated that the summer workshop made a positive effect on teachers' perceptions regarding the importance of DET, perceptions of engineers and teachers' perceived barriers in teaching DET.

Table 2. Descriptive Statistics for DET(Design, Engineering, Technology) Instrument Constructs for Pre- and Post- Summer Workshop

			Pre-data		Post-data	
Instrument	**Construct**	**N**	**M**	**St. Dev.**	**M**	**St. Dev.**
DET Teacher Survey [18]	Importance of DET	24	4.463	.322	4.610	.404
	Familiarity with DET	24	4.421	.449	4.612	.478
	Stereotypical Characteristics of Engineers	24	4.434	.385	4.654	.443
	Barriers in Integrating DET	24	2.475	.314	2.510	.559

The data collected were non-normally distributed and so, we considered using nonparametric tests as being most appropriate for the inferential statistical analyses. A Wilcoxon signed-rank test was conducted to determine whether there was a significant difference between teachers' pre- and post-summer workshop DET survey results. The non-parametric Wilcoxon signed-rank test indicated that the summer workshop produced statistically significant change in familiarity of DET ($Z = -3.204$, $p = 0.001$) and stereotypical characteristics of engineers ($Z = -2.411$, $p = 0.016$) constructs. However, there were not any significant differences for the barriers in integrating DET and importance of DET constructs between pre- and post-summer workshop results. Wilcoxon test results can be seen in Table 3.

Table 3. Statistical Comparison of Teacher Pre- and Post-Workshop Data

Instrument	**Construct**	**Wilcoxon Test**	
		Z	***p***
DET Teacher Survey (Hong et al., 2011)	Importance of DET	-1.247	.212
	Familiarity with DET	-3.204	0.001**
	Stereotypical Characteristics of Engineers	-2.411	0.016**
	Barriers in Integrating DET	-.486	.627

Table 4. Correlations Between S-STEM Post-Student Data and DET Post-Teacher Data

	1	2	3	4	5	6	7	8
1. StudentPostMath_Atti		0.180**	0.180**	0.317**	-0.026	-0.007	-0.050	0.055
2. StudentPostScience_Atti			0.99**	0.213**	-0.006	0.051	-0.058	-0.077
3. StudentPostEngTech_Atti				0.213**	-0.006	0.051	-0.058	-0.077
4. StudentPost 21^{st} Century Learning Attitudes					-0.052	0.009	-0.112*	-0.061
5. Post-Importance of DET						0.935**	0.907**	0.173**
6. Post-Familiarity with DET							0.731**	-0.025
7. Post-Stereotypical Characteristics of Engineers in DET								0.286**
8. Post-Barriers in Integrating DET								

* Correlation is significant at the 0.05 level (2-tailed).
** Correlation is significant at the 0.01 level (2-tailed).

We ran a Pearson correlation test to understand relationship between teachers' post workshop perceptions regarding importance of DET, familiarity with DET, stereotypical characteristics of engineers, barriers in integrating DET and students' end of year (post) attitudes toward science, math, engineering/ technology and 21st century skills by using SPSS software. All of the results were interpreted based on Cohen's correlation criteria [22].

As shown in Table 4, students' post math attitude and students' post science attitude displayed a statistically significant and slightly positive correlation, $r = .180$, $p <0 .01$. Similarly, students' post math attitude was positively correlated with students' post engineering/technology attitudes, $r = .180$, $p <0 .01$. Likewise, students' post math attitudes showed a statistically significant and moderately positive correlation with the students' post 21^{st} century learning attitude, $r= .317$, $p <0 .01$. Students' post science attitudes showed a statistically significant and slightly positive correlation with the students' post 21^{st} century learning attitude, $r= .213$, $p <0.01$ and strongly positive correlation with the students' post engineering/technology attitudes, $r= .99$, $p<0.01$. Furthermore, the students' post 21^{st} century learning attitude and teachers' post-stereotypical characteristics of engineers displayed a statistically significant and slightly negative correlation

$r=-.112$, $p<0.05$. In addition, there was a statistically significant and strong correlation between the teachers' post importance of DET and their post familiarity with DET, $r=0.935$, $p<0.01$. Similarly, the teachers' post importance of DET showed a statistically significant and strong correlation with the teachers' post-stereotypical characteristics of engineers, $r=0.907$, $p<0.01$. Furthermore, teachers' post familiarity with DET displayed a statistically significant and strong correlation with post-stereotypical characteristics of engineers, $r=0.731$, $p<0.01$. Finally, there was a statistically significant and a slightly positive correlation between the teachers' post-stereotypical characteristics of engineers and the teachers' post barriers in integrating DET, $r=0.286$, $p<0.01$. There were not any other significant correlations among the other variables observed.

Conclusion

In this study, we analyzed quantitative data to find out whether there were meaningful differences in teachers' perceptions of engineering and their familiarity with teaching DET before and after the summer workshop as well as to understand relations among teachers' perceptions of engineering, familiarities with teaching the DET, and their students' attitudes towards the STEM fields and 21st century learning attitudes. In regards to the impact of this teacher summer workshop on the teachers' perceptions of engineering and their familiarity with teaching DET, results revealed that teachers' familiarity with DET and their understanding regarding the stereotypical characteristics of engineers improved significantly after the teacher summer workshop. However, there were not any statistically significant differences between pre and post-summer workshop with regards to importance of DET and barriers in integrating DET.

Regarding the correlations among eight different variables, we found statistically significant correlations among students' post attitudes toward STEM subjects and 21st century learning attitudes. Likewise, there were meaningful correlations among teachers' perceptions and familiarity with DET constructs. However, the cross relationship between students' and teachers' constructs was very limited. In this sense, results revealed that there was a slight, but statistically significant negative correlation between students' post 21st century learning attitudes and teachers' post-stereotypical characteristics of engineers. However, the statistical validity of these stereotype questions has been questioned [19].

Implications and Future Work

Since the sample size of the study is not large, it is very hard to make generalizations based on the results. However, findings of the study revealed that teachers' familiarity with DET and their understanding related to the stereotypical characteristics of engineers were enhanced significantly. These results can be used to validate that the engineering professional development experience strengthen the participants' ability to develop a better understanding of fundamental aspects of engineering.

In the past few years, there has been a rising interest in incorporating engineering into K-12 education [23]. To meet these demands, it is paramount to better prepare teachers to teach engineering in all grade levels. Designing and implementing engineering-focused interventions can be very effective solutions to improve teachers' knowledge and experience related to engineers and teaching engineering.

Since the small sample size of this study limits the generalizability of the results, increasing the number of participants can be used to overcome this limitation. Finally, the conclusions of this study reflect the results of the quantitative data analyses. In the future, collecting the qualitative data as well as collecting the quantitative data might provide a richer and more in-depth understanding of the topic that is under investigation.

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