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Improving In-Service Science and Mathematics Teachers' Engineering and Technology Content and Pedagogical Knowledge (Evaluation)

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Abstract

Teachers play a crucial role in developing the nation's STEM workforce and boosting the student interest towards the STEM fields. However, there are limited opportunities available for in-service teachers to improve their engineering and technology content knowledge and implement that knowledge effectively in designing integrated STEM learning environments. To increase students' interest in STEM fields and improve the quality of integrated STEM education, we developed a series of integrated engineering and technology focused teacher professional development (PD) activities.

In this paper, we discuss the effectiveness of a two-week long PD which was a part of a National Science Foundation (NSF) funded Innovative Technology Experiences for Students and Teachers (ITEST) project. This workshop was implemented at a Research 1 University campus in Summer 2019. The project goals were to enhance in-service teachers' engineering and cutting edge technology content knowledge to help them build confidence to teach engineering concepts using technology, remedy engineering misconceptions, and improve their attitudes toward engineering. Twelve math and science teachers participated and learned the fundamental principles of the engineering design, gained knowledge about the cutting-edge technologies including Internet of things (IoT), additive manufacturing, and computer-aided design (CAD) tools. In addition to improving their engineering and technology content knowledge, the teachers also received training on how to incorporate the engineering and technology content into the existing mathematics and science school curricula. The overarching goal was to encourage teachers to design and offer integrated STEM learning environments.

In order to evaluate the effectiveness of the PD activities, we asked: "After participating in the engineering and technology focused PD activities, what were the participating mathematics and science in-service teachers' perceptions of the content and skills they gained, the challenges and/or limitations they faced, and recommendations for improvement?"

We designed a teacher questionnaire and administered it after the PD activities. In the questionnaire, participants were asked to compare their before and after perceptions. Our research team conducted observations and took field notes. We designed a semi-structured post-interview protocol and conducted interviews with the teachers at the end of the two-week PD sessions. The recorded interviews were transcribed verbatim. All teachers (N=12) responded to the pre and post questionnaire and all (N=12) participated in the semi-structured one-one-one interviews. In our analyses we ran descriptive statistics and non-parametric tests for the quantitative data. For the qualitative data, we employed constant comparative method and iteratively searched for the main themes and categories emerged from the analyses. In this paper, we report the study findings and discuss the successful and unsuccessful aspects of the two-week PD session from the perspectives of the participating teachers.

Introduction

Science, technology, engineering, and mathematics (STEM) have been the foundation for innovation and technological improvement throughout US history [1]. While the number of the US jobs required in the STEM fields has increased nearly 34% over the past decade [2], the number of students choosing STEM positions as their career goals is decreasing [3]. Teachers have a paramount influence on students' future career choices. An effective way to increase students' interest in STEM fields is to improve teachers' conceptions and self-efficacy of engineering and STEM concepts [4]. Specifically, a teacher's understanding of engineering plays a critical role in increasing a student's interest in STEM areas [2, 5, 6].

Previous research demonstrated that teachers who participated in engineering and technology focused PD programs showed improvement in their knowledge and understanding of engineers, engineering disciplines, and their relations with the society and how engineering processes work [7-11]. 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 improving their perceptions of engineering [4, 11-16]. Some other studies stated that PD programs provided the necessary knowledge and motivation to the teachers to implement engineering concepts and practices into their curricula [9, 17, 18].

In the present study, the research team has designed, planned, and implemented a two-week summer PD program for middle school science and mathematics teachers. The program had ten periods each lasted eight hours. Through this engineering focused PD endeavor, teachers were trained to understand and use the cutting-edge technologies of connected devices, also known as the Internet of Things (IoT) as well as building automation and additive manufacturing technologies. In addition to gaining content knowledge, teachers had an opportunity to gain pedagogical knowledge to develop lesson plans that were aligned with science and mathematics curricula. Pedagogical knowledge is defined as the ability and knowledge to teach effectively. Content knowledge is the understanding of the subject matter. Shulman defined a pedagogical content knowledge, as the knowledge teachers should possess to teach the subject matter effectively to their students [19]. In this paper, we present the teachers' experiences related to the engineering and technology focused summer PD program.

Study Context: Teacher Summer Workshop

The teacher workshop took place at the university campus in Summer 2019. We invited teachers to attend the summer workshop that lasted two weeks. During the first part of the workshop, teachers from different school districts worked with the university faculty to learn about the engineering design principles, IoT technology, computer-aided design tools, and additive manufacturing processes (e.g., Figure 1). In the second part of the workshop, the teachers were provided training on how to develop lesson plans that were suitable to incorporate the engineering content into the existing school curricula. In addition, participating teachers practiced teaching their lesson plans with volunteer students (e.g., Figure 2). In these teaching sessions, participating teachers had an opportunity to spend one-on-one time with the volunteer students (e.g., Figure 3).

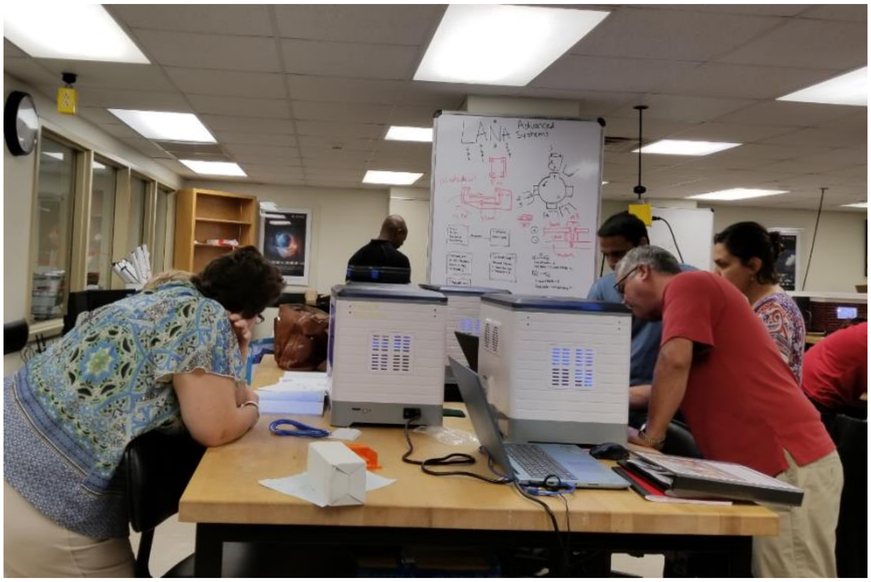

Figure 1. Teachers Learning to use 3D Printer

Figure 2. Teachers Working with Students

The teachers were provided with the necessary hardware and software resources to implement the activities in their own classrooms. The research team met with the teachers online in several occasions throughout the year to provide support and continuous guidance.

Figure 3. Teachers Teaching 3D Printer to Volunteer Students

Methods

We conducted a mixed methods study to explore the effectiveness of the PD activities. Quantitative data were collected using a questionnaire. The research team conducted observations during the PD activities and interviewed the participants about their lived experiences at the end of the project activities. The participating mathematics and science in-service teachers' perceptions of the content and skills they gained from the PD activities and the difficulties they faced during both the PD activities and the implementation of their planned lessons were explored and documented. Walther, et al. [20] argued that research reports should follow a systematic process and provide actual knowledge claims. In our data collection and analyses, we used both qualitative and quantitative paradigms systematically and we attempted to provide knowledge claims that portray the participants' lived experiences in the PD activities.

Participants

The study participants were twelve in-service science and mathematics teachers. One of the teachers participated in the PD program both in 2018 and in 2019. 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 doctorate degree. While sixty-six percent had a bachelor's degree, twenty-five percent had a master's degree. One teacher had earned a Ph.D. degree. The gender distribution of the participants was 58.3 % (N = 7) female and 36.6% (N = 5) male. All demographic and background information of participants are reported in Table 1.

Table 1. Teachers' Demographic Information

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%)
	Doctorate Degree	1 (8.3%)
Teaching Experience (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%)

Data Collection

This study included both qualitative and quantitative data collection and analyses. To collect quantitative data, an evaluation questionnaire was administered to the teachers after the summer workshop. The teachers answered the questions retrospectively. In this sense, we asked the respondents to recall pre-intervention status at post-test time. The evaluation questionnaire items were developed to capture the participants' knowledge and understanding of building automation, IoT, the engineering design process, and engineering careers. A copy of the questionnaire is represented in Appendix A.

We developed a semi-structured interview protocol in order to explore participating teachers' perceptions of the content and skills they gained, the challenges and/or limitations they faced, and their recommendations for improvement to teaching. The interview questions were prepared open ended for the purpose to collect a vast variety of responses from the participants [21]. Because the interview protocol was semi-structured, we posed emerging questions during the conversations that were not listed in the protocol. A copy of the interview protocol is represented in Appendix B. We conducted individual interviews with the participating teachers using the semi-structured interview protocol at the end of the summer workshop. Each interview lasted around 30 to 45 minutes and all of the conversations were audio recorded.

Data Analyses

The mean scores of the teachers' responses to the evaluative questionnaire were computed and reported. We ran non-parametric Wilcoxon signed-rank test to compare the participants' responses to the questionnaire items [22]. Since the data collected were non-normally distributed, we decided using nonparametric tests as being most appropriate for the analyses. The level of significance was set at 0.01. The interview recordings were transcribed verbatim by Verbal Ink. The use of a professional external transcription service can contribute to process reliability in the research [20]. One of the learning scientists analyzed the interview transcriptions using the constant comparative method [23]. The transcriptions were read several times and categories and subcategories were created [21]. We employed open coding, selective coding, and axial coding strategies to analyze the transcriptions. Commonalities and differences among the participants' descriptions of their experiences were reported.

Findings

At the completion of the summer workshop, we collected evaluative feedback from the participating teachers about their confidence in and understanding of building automation, IoT, engineering design process, product development process and engineering careers. We used the questionnaire we had developed. The questionnaire was a five-point Likert scale instrument with eight evaluative questions. While the questionnaire was administered at the completion of the workshop, teachers responded to some questions in retrospect. Teachers' perceptions of their knowledge, understanding, awareness, and self-confidence before and after the PD activities were posed to them to answer. Self-reported responses from the teachers are listed in Table 2. The non-parametric Wilcoxon signed-rank test indicated that the mean difference between the teachers' answers to most of the items before and after the workshop were statistically significant at the $p<0.001$ level.

Table 2. Statistical Comparison of Pre- and Post-Teacher Responses

		Self-assessed knowledge prior to program		**Self-assessed knowledge after the program**		Wilcoxon Test	
Evaluation Questions	***N***	***M***	***St. Dev.***	***M***	***St. Dev.***	***Z***	***p***
Your knowledge of building automation to maximize energy use	12	2.50	1.13	3.90	1.07	-4.22	< 0.001**
Your understanding of engineering design process	12	2.65	1.20	3.75	1.09	-3.695	< 0.001**
Your awareness of engineering careers	12	3.46	1.22	4.27	0.91	-3.246	0.001**
Your understanding of Internet of Things	12	3.35	1.23	3.99	1.23	-3.340	0.003**
Understanding of product development process	12	3.31	1.21	3.97	1.25	-3.341	0.003**
Confidence in using a design challenge	12	3.31	1.19	3.97	1.03	-3.140	0.003**
How to use industry experts	12	3.41	1.24	4.35	0.92	-3.246	0.001**
How to elicit reflective decision-making in students	12	2.61	1.07	3.68	0.85	-3.586	< 0.001**

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

In our interview conversations, teachers expressed positive experiences with the PD activities. Teachers' feedback suggested that the PD activities were very rewarding experiences for them. They reported that the activities they engaged in were excellent

opportunities to learn about the cutting edge technologies including the Internet of things (IoT), additive manufacturing, and computer-aided design (CAD) through thought-provoking and unique learning materials. The knowledge they learned was unique.
One participant told us that:

"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".

Another participant reported:

"I had attended a number of workshops but not an engineering workshop 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 workshops before and most of the workshops I went I used to know most of the things because of attending similar ones over and over again. So this was something totally new for me."

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

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

After the workshop, teachers became more inclined to exchange ideas and working in groups instead of working by themselves at their own pace. One participant responded in the interviews:

"I really like to be part of this program. And then having the workshop 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."

The majority of the participating teachers also indicated that in addition to learning theoretical knowledge in this workshop, they had an opportunity to teach these newly-gained knowledge to volunteer students. This teaching practice experience allowed them to get immediate feedback from the students. This feedback was valuable because it guided teachers to think about how to teach this novel content to their students in the classroom. During the interviews one participant noted that:

"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."

The participating teachers were also very appreciative of the resources of the program as well as the immediate collaboration opportunities that the workshop had to offer. One participant told us that:

"We have found a bunch of resources together here and we glued it together through this engineering perspective."

Another one indicated that:

"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. What do you need? 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."

On the other hand, some of the participating teachers stressed out that the workshop was very heavy in content. One participant indicated that:

"So I think this program should be two separate things, still two weeks long because I think we need all of that time to play with the 3D printing because 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 didn't do any of that the first four days of this program."

The interview results also revealed that some of the teachers preferred having more time to spend on lesson planning and curriculum implementation. One participated stated that:

"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."

Similarly, some of the participants also reported that during the workshop they had a difficulty staying focused on the topic because the workshop required them to study for a very long period of time during the day.

One participant told us that:

"If I look at something 45 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, and 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 breakout sessions for really."

Conclusion

The study results showed that the teachers found the summer workshop very original, informative, and thought-provoking experience. Participating in the program assisted them to understand some advanced technologies and engineering concepts. They also improved their pedagogical knowledge about how to teach those concepts. The majority of the participants agreed this program was exceptional in a sense that it provided very strong theoretical and practical knowledge related to engineering and engineering concepts. It was a real challenge, however, to implement those concepts into the existing curricula. Hence, the teachers were appreciative for incorporation of structured lesson planning and curriculum development sessions into the summer camp curriculum as well as for having vast variety of resources and collaboration opportunities.

On the other hand, some of the teachers' feedback indicated that despite their overall experience being quite positive related to workshop, it was very challenging for them to study and work on these novel concepts for an extended period of time during the workshop. In future implementations of the program, the team might plan to include more frequent and extended breaks to increase the productivity and the motivation of the participants. In addition, lesson planning and curriculum development sessions started during the second week of the summer camp. Some of the teachers indicated their preference to start lesson planning and curriculum implementation sessions earlier in the program. Those "how to teach" sessions might be incorporated in the workshop during the first week of the workshop as well. Because teachers have a paramount impact on students' future career choices, assisting them to improve their experience related to engineering and engineering concepts will translate into more positive student interest in STEM careers. PD activities similar to the one we described in this paper can be an operational solution to the STEM recruitment shortage in the US. Technology is advancing rapidly. STEM careers demand a sound understanding of the cutting edge technologies. In-service teachers are often left behind when it comes to learning about the new technologies and their role in current and future STEM careers. PD activities similar to the one portrayed in this paper can improve teachers' knowledge about these cutting edge technologies and help them design and implement integrated STEM learning environments in middle and high school levels. Students who engage in engineering practices involving cutting edge technologies may be more prompt to select engineering or related STEM fields as their future career options.

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Appendix A- Questionnaire

Please use the following scale to describe your pre- (before the professional development 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 engineering design process	
	Understanding of 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	
	Internet of Things	

Appendix B- Interview Protocol

Teacher Interview Questions

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

1. What did you learn in the ITEST professional development program?
2. What skills have you developed 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 to improve this professional development?
5. How was your overall experience with this ITEST professional development program?