

Assessing the Effects of Authentic Experiential Learning Activities on Teacher Confidence with Engineering Concepts

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Abstract

There is a growing concern in the US about the lack of student interest and aptitude in science, technology, engineering and math (STEM) disciplines. Research indicates that engineering and technology integration in K-12 improve students' content understanding and skill development, understanding of interactions among the STEM disciplines, and interest in STEM careers [1-6]. Many in-service STEM teachers have limited experience and/or educational background in engineering and technology. These teachers have limited confidence to incorporate engineering and technology in their classroom.

At a professional development (PD) workshop, that is part of a National Science Foundation (NSF) funded engineering research project, teachers from different school districts were invited to learn building automation and additive manufacturing at a university campus in summer 2017. The overall goal of the project is to increase the number of students on the STEM pathway. This work reports the findings of a study that explored the effectiveness of a teacher PD workshop implemented in the first year of the project. In the PD workshop teachers engaged in authentic engineering design activities using 3D printers and the internet of things technologies. In this two-week program, teachers were trained to use computer-aided design tools, additive manufacturing processes, and how to integrate sensors into various devices. University faculty and students, who administered the workshop, illustrated how to effectively incorporate these technologies and engineering design principles into their classrooms.

The main question posed was: to what extent do the teachers' participation in the professional development activities affect their confidence and efficacy toward STEM and perception of engineering and teaching? To answer this question, authors employed a pre- and post-test survey research design was employed; data were collected from the participants before and after the PD workshop activities. The Design, Engineering and Technology (DET) Survey and Teacher Efficacy and Attitudes toward STEM Survey (T-STEM) were administered to participants. DET is a five-point Likert scale with 40 items. This instrument focuses on capturing the participants' views and familiarity with DET concepts. The T_STEM survey is a 5 point Likert scale with 36 items. The T_STEM survey measures participants' confidence and efficacy towards STEM fields, 21st century learning, and other constructs. Quantitative data and statistical analyses of pre and post workshop data are presented.

Introduction

There is a recognition that the United States does not produce enough students that have sufficient interest and aptitude Science, Technology, Engineering, and Math (STEM)[3]. The need to create this interest and understanding begins in the elementary and high school years. As more engineering and technical content is required in state [7] and national standards [8], there is a need for teachers to become well-versed in these areas. While many teachers may have studied math or science as undergraduates, they likely

have less experience with engineering and technology. This work examines the effects of a two week professional development (PD) workshop for junior high and high school teachers to introduce them to technology and engineering.

One way of promoting STEM is to demonstrate its relevance to the students [9]. In the case of the professional development workshop, this relevance was provided by using two interesting and often discussed technologies: the Internet of Things (IoT) and additive manufacturing (often called 3D printing). The goal of the workshop was to have the teachers create authentic experiential learning activities for their students that they would implement during the school year. Authentic problems are those which have a goal that is not directly related to the course or educational context [10]. Authentic activities are often open ended and the end results of the activities are not yet known by the teachers and the textbooks [11]. Students' personal experiences and interests guide the design and implementation of these activities instead of the standardized curriculum guides or documents. Experiential learning allows students to create knowledge "through the transformation of experience" [12]. In this case, the experience would be a design activity involving IoT and 3D printing.

This teacher workshop is part of a broader National Science Foundation Innovative Technology Experiences for Students and Teachers. These projects are funded with proceeds of the H1-B visa program and attempt to promote STEM interest. This paper details the professional development workshop instruction, the instruments used to evaluate the understanding and interest in STEM among the participating teachers, an additional survey, and the post workshop support that the teachers received to implement their activities.

Background

The National Research Council (2012) emphasizes the importance of exposing K-12 students to engineering-related activities in classrooms [13]. Research indicates that engineering practice and technology integration in K-12 improves students' content understanding and makes them more aware of what engineers do, skill development, understanding of interactions among the STEM disciplines, and interest in STEM careers [14]. One obstacle to the progress of the integration of engineering content into K-12 STEM education is lack of teachers prepared to teach science or engineering [15, 16]. Whenever the teachers are not prepared to teach STEM themes, they are not comfortable with teaching a topic, and they prefer not to teach the topic, or teach the subject in a superficial manner [17]. Since the teachers have a paramount impact on students' future career choices, the first step to enhance students' interest in STEM fields is to improve teachers' confidence and self-efficacy with engineering and STEM concepts. Once teachers have a chance to learn and implement engineering principles, they are comfortable sharing this knowledge with their students and can present the connections between math, science, and engineering and the real world [18]. In light of these issues, it's critical to develop professional development activities to expose teachers to authentic experiential learning activities and help teachers to improve their abilities and knowledge in these areas. Researchers have reported that professional development programs can be effectively used to expose teachers to engineering and STEM concepts [19, 20]. In

addition, these programs help teachers to improve their content knowledge in order to develop confidence and attitudes toward engineering [14, 21]. However, there have been limited engineering professional development programs for teachers [21].

Stevens and Schlossberg designed professional development activities related to STEM for teachers at Florida Atlantic University [22]. In Stevens and Schlossberg's study, they attempted to engage teachers with real world technological problems and enhance teamwork and creative thinking among participants and ultimately develop their skills [22]. A number of universities have developed professional development activities and workshops for teachers [18]. For example, the University of Florida developed a two-week summer program and invited K–12 teachers to engage in engineering activities and learn to implement these activities in their classrooms [23]. The Iowa State University College of Engineering designed a program for K–12 teachers that delivered technological literacy, and helped teachers to integrate engineering principles into their curriculum [24]. Dortmund College planned and implemented a summer short course to introduce high school educators to engineering problem solving [25]. It was noted that a short course was offered at first as a summer workshop for in-service teachers with future plans to offer courses to preservice teachers.

Teacher Summer Workshop

The workshop was a two week residential program that took place at Texas A&M University. A total of 12 teachers participated in the two-week program. The program began each day at 8:30AM and continued until 5:30 or 6:00 PM. There was a 30 to 45 minute break for lunch each day. The section below details the content of the workshop.

Building Automation

The concept behind this project was to use building automation as a concrete example of a STEM field to excite students about the possibility of STEM and engineering careers. Building automation was specifically chosen due to the impact it has on everyday lives, its ties to sustainable energy, and its ease of understanding for students in junior high and high school. To this end, teachers were introduced to the field of building automation (BA) through a two-pronged approach.

The workshop team enlisted the help of Schneider Electric, a well-known company in the BA industry and leveraged their “Energy University.” Energy University is a free, web-based education portal supported by Schneider that supports energy education. Each teacher in the workshop was required to take four separate online courses on building automation and sustainable energy prior to attending the workshop. In this manner, the cohort came in with a basic knowledge of vocabulary, concepts and tools used in the building automation industry. At the beginning of the workshop a short tutorial was presented to reinforce concepts from the online courses and help the teachers develop an appreciation for building automation as a platform for motivating STEM career paths in the classroom. The tutorial was broken down into several components:

- **Defining Building Automation:** The vocabulary and the concepts introduced in the online coursework were revisited and placed in the context of real building automation systems as found in public buildings such as schools.

- **Tying Building Automation to Sustainable Energy:** An area that resonates with today's youth is green and sustainable energy, especially as it pertains to solutions for climate change. The tutorial gave teachers facts, figures, and ideas on how to introduce building automation as a way to support sustainable and efficient energy usage.
- **Tour of a Building Automation System:** Another reason building automation was chosen as a focus area for this project was its ubiquity and ease of understanding for young minds. For example, the very schools they learn in often have a modern building automation system creating a true living-learning laboratory. The teachers were given a tour through a typical building automation system on the Texas A&M campus to help them be able to identify the components and software, and to give them ideas of how they might use their own school as an example in the classroom.
- **Introducing Teachers to Building Automation Tools:** Next, the tutorial introduced typical tools used by engineers in the building automation industry such as thermometers, light meters, hygrometers, and power meters. Specifically, the teachers were introduced to the tools they were being given such as their IoT platforms and power meters. More importantly, teachers were introduced to possible ways these tools could be used by students in the classroom.
- **Discussion of Possible Classroom Exercises:** Finally, teachers were asked to brainstorm possible exercises they could develop and use in their classroom to support their teaching that leverage building automation concepts and tools. This was done immediately after the tutorial while ideas and concepts were still fresh in their minds.

CAD Design

The teachers in the PD workshop were introduced to, and gained proficiency in, the engineering design process; which included the major steps of conceptualizing product designs, creating appropriate computer-aided design (CAD) models, fabricating them, and then going through design iterations to improve the product. The general process flow is shown below in Figure 1.

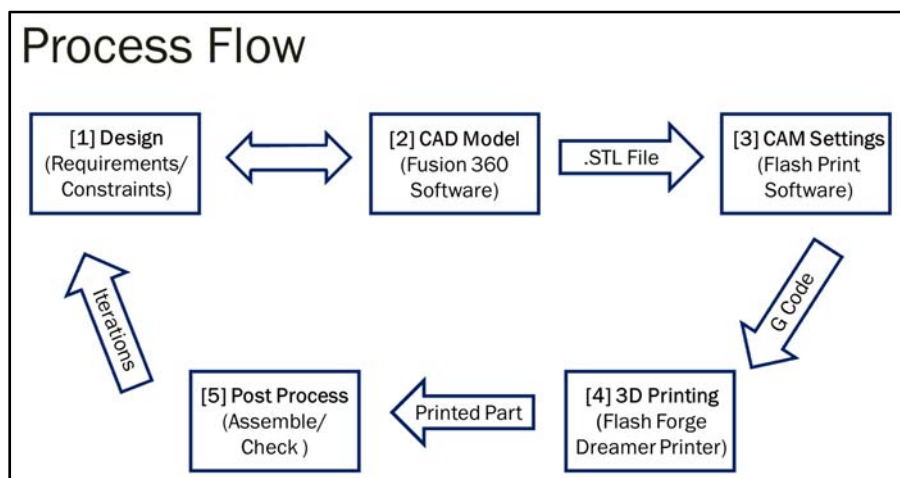


Figure 1. Major Steps Involved in the Engineering Design Process Flow for an On-demand Product.

During the first week of the PD workshop, the teachers were introduced to the engineering design process flow and its essential components, including the resources and model repositories available. To develop a relevant design example, the teachers were given the objective of designing and fabricating a functional enclosure for housing the IoT kit contents. As a first step, the teachers defined its requirements and constraints as:

- *should be able to secure a circuit board, battery and other IoT kit components,*
- *should be capable of assembly and disassembly,*
- *should be compact and durable,*
- *should be mountable on a vertical wall or surface,*
- *should have access to reset buttons, micro USB port, and other components.*

Based on the above list, the teachers brainstormed and came up with a number of potential product designs that included various lid types, battery placements, accesses, and other features. Following this, individual guided-practice was provided on systematically creating a CAD model of their finalized designs using Fusion 360 CAD software; which was provided to each participating teacher. The teachers were then provided guidance on exporting these files in a format readable by the CAM software, and in fabricating/post-processing the parts. Finally, the teachers were instructed to critically analyze their designs, and suggest design modifications for the next design iterations; thereby highlighting the need for continuous product improvement, and the iterative nature of the engineering design process.

Additive Manufacturing

Another essential component of the PD workshop included the teachers obtaining proficiency in additive manufacturing, and specifically, gaining knowledge and skills in 3D printing. This empowered them with the capabilities to fabricate custom components on demand, and served to build confidence in their ‘making’ abilities/mindset, while also complementing the engineering design process.

During the first week of the PD workshop, the teachers were first given a broad overview of additive manufacturing technologies, followed by information and resources specific to the type of 3D printing relevant to them, namely Fused Deposition Modeling (FDM) – this included details related to the specific 3D printer and materials, best practices, challenges, practical working tips, and knowledge/model repositories. Further, the teachers were given laboratory tours of state-of-the-art additive manufacturing equipment (Figure 2). Following this, the teachers were given and guided-practice on configuring/specifying 3D print settings for the computer-aided manufacturing (CAM) software FlashPrint; in operating the Flashforge Dreamer 3D printer, which was provided to each participating teacher at the conclusion of the workshop, and post-processing of the final printed parts (Figure 3a and 3b). Additionally, a short manual containing the details of how to work with the FlashPrint software (to specify print settings and export g code), printing/post-processing (using the Flashforge Dreamer printer), and troubleshooting tips was created and provided to the teachers – this enabled them to learn

the process, and create practice-parts, as well as the enclosure for housing the IoT kit contents.



Figure 2. Tour of AM Equipment

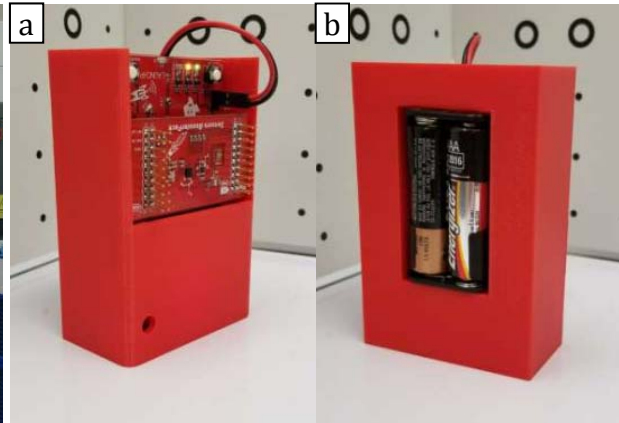


Figure 3. 3D Printed Enclosure for Housing IoT Kit

During the second week of the PD workshop, the teachers were given an assignment to print a number of test parts. This exercise served to test their proficiency in 3D printing, as well provided self-confidence via metacognition. Some of the teachers also printed modified IoT kit enclosures based on design iterations during this time. Finally, the teachers also 3D printed the designs that were created as part of their trial modules. They developed and tested these modules out by instructing middle schoolers.

Internet of Things

The Internet of Things (IoT) is a fast developing technology that will have an impact on all industry sectors. By 2020, experts estimate that there will be approximately 30 billion IoT objects that comprise a market value exceeding \$7 trillion [26]. Therefore, future STEM educational activities should and must include both an understanding and appreciation for this new, game-changing technology. During the PD workshop, IoT was used as the “glue” to interconnect 3D printing and design processes with concepts of building automation and energy management. Teachers began by learning about IoT infrastructure, embedded edge devices and dashboards to monitor and remotely control IoT systems.

The teachers underwent experiential learning activities that allowed them to understand and use an internet Broker for Publishing and Subscribing. They were able to accomplish a number of embedded sensor and actuator experiments by modifying/creating programs for the Texas Instrument’s CC3200 Launchpad coupled with BoostXL SensorPack. These capabilities were then integrated into a complete system using the Cayenne web-based Dashboard for display and decision making/control of their IoT systems. The work focused on the IoT kits that each teacher constructed during the workshop. As shown in the figure, the IoT Kit consisted of the following items:

- Battery pack
- Motion Sensor
- Relay/AC Outlet

- LaunchPad/BoostXL SensorPack
- 3D Printed Enclosure
- H-Bridge Driver
- DC Motor



Figure 4. Teachers using TI LaunchPad



Figure 5. Integrated System Driven by TI LaunchPad

Using these IoT resources, teachers were able to develop Energia software that linked the LaunchPad and its resources to the Cayenne Broker, Publish environmental data to the Broker and then Subscribe to the Broker to downlink control information for their Kits. During the first week, the PD workshop teachers built a complete IoT system that implemented building monitoring and energy management while integrating the engineering design process and 3D printing.

Post-Workshop Support

At the completion of the workshop, each teacher was given 2 Texas Instrument's CC3200 Launchpads along with BoostXL SensorPacks. They also received a Flashforge printer and several extra spools of material. Each teacher was assigned a contact person from the project team. They were also asked to send progress reports every six weeks which included a section regarding any challenges they were having. A group wiki on the pbworks.com platform was also created to allow the teachers to discuss any implementation of their activities and issues they were having with their hardware or software.

Methods

Teacher Recruitment and Selection Process

Various middle school and high school STEM teachers within a 200-mile radius from the university were sent information via email on the requirements and benefits of participating in the two-week summer PD workshop. Project personnel sent targeted emails to all middle school and high school STEM 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 that required general information, a letter of commitment from the teacher and his or her principal, and an essay that described (a) why the teacher wanted to participate in the program, (b) what the teacher hoped to gain from participating in the program, and (c) how the teacher planned to use the information gained in the two-week summer experience to improve student learning. A total of 129 teachers responded to the call for applications and 43 complete applications were received.

Project personnel designed a selection rubric that aided in the evaluation of the 43 applications. The rubric was designed to give preference to teachers who were clustered within a single campus and who were employed by the partnering district. The project team divided into groups of two and each dyad was assigned approximately 14 applications to evaluate. After the dyads had completed the evaluation process, the whole project team convened to select the final 12 teachers to invite to the summer program. Project personnel also selected 10 teachers for a waitlist in the event a selected teacher declined the invitation to the summer program.

Participants

The teachers participated in a two-week PD workshop at Texas A&M in 2017. In Table 1, demographic information of the teachers who participated is provided. The teachers were between the ages of 24 and 56. Participants' teaching experience ranged from 1.5 to 9 years. Five teachers were male and seven teachers were female. Eight of twelve teachers taught grades 9-12 and four taught 6-8 grades. Eight teachers had bachelor's degrees, three had Master's degrees, and one had a doctoral degree. Two teachers reported that they worked as engineers before starting their teaching careers.

Study Design

This study is a one-group pre-test post-test study. In this design, the participants complete the same research instruments before and after the intervention. Data were collected from the participants before and after the two-week workshop to see whether there was any difference between their pre-workshop and post-workshop instrument scores.

Study Instruments

The Design, Engineering and Technology (DET) Survey and Teacher Efficacy and Attitudes toward STEM Survey (T-STEM) were administered to the teachers before and after the workshop.

Table 1. Participant Demographic Information.

Criteria	Categories	Total
Gender	Male	5
	Female	7
Ethnicity	White	6
	Black	3
	Hispanic or Latino	2
	Asian	1
Age	20-29	4
	30-39	3
	40-49	2
	50+	3
Education	Bachelor's Degree	8
	Master's Degree	3
	Doctorate Degree	1
Teaching Experience (years)	1-5	8
	6-10	4
Teaching Grades	6-8	3
	9-12	9

The Design, Engineering and Technology (DET) Survey

The Design, Engineering, and Technology (DET) Survey [27] has been used by many researchers. The instrument was re-evaluated and re-analyzed, later [28]. DET is a five-point Likert scale survey with 40 items. This instrument focuses on capturing teachers' perceptions and familiarity with engineering. The survey consists of four constructs: which are importance of DET, familiarity with DET, stereotypical characteristics of engineers and barriers in integrating DET. The Design, Engineering and Technology (DET) Surveys were administrated to the all teachers before and after the PD workshop. In addition, the research team administrated a demographic questionnaire and the results of this are shown above in Table 1.

Teacher Efficacy and Attitudes toward STEM Survey (T-STEM)

The T-STEM survey is a 5-point Likert scale with 36 items. There are five different versions of the T-STEM survey [29]. One was developed for each teaching area of STEM (Science, Technology, Engineering, and Mathematics), and one for elementary teachers [29]. The T-STEM survey includes seven constructs: personal teaching efficacy and beliefs, teaching outcome expectancy beliefs, student technology use, STEM Instruction, 21st century learning attitudes, teacher leadership attitudes, and STEM career awareness.

First, the data were analyzed using descriptive statistics. Second, to answer the research question, Wilcoxon signed test for non-parametric test was chosen. Using this method the differences between means were analyzed.

Results

Descriptive Statistics

Table 2 shows a general overview of the teacher responses for each construct of the two survey instruments. All of the teachers answered both of the surveys. The mean differences between the teachers' pre- and post- survey results showed that the summer workshop had a positive effect on teachers' perception and knowledge of design, engineering, technology, STEM and several other areas.

Table 2. Descriptive Statistics for Teacher Instruments Pre- and Post-Workshop

Instrument	Construct	N	Pre-data		Post-data	
			M	St. Dev.	M	St. Dev.
DET Teacher Survey	Importance of DET	12	4.63	0.27	4.75	0.32
	Familiarity with DET	12	2.77	0.84	3.54	0.71
	Stereotypical Characteristics of Engineers	12	4.27	0.36	4.51	0.39
	Barriers in Integrating DET	12	2.72	0.56	2.88	0.78
T-STEM	Personal Teaching Efficacy and Beliefs	12	3.72	0.88	4.32	0.65
	Teaching Outcome Expectancy Beliefs	12	3.63	0.52	3.93	0.63
	Student Technology Use	12	3.06	0.9	3.38	0.85
	STEM Instruction	12	2.87	0.57	3.19	0.86
	21 st Century Learning Attitudes	12	4.68	0.34	4.81	0.22
	Teacher Leadership Attitudes	12	4.72	0.32	4.75	0.26
	STEM Career Awareness	12	3.72	0.82	4.31	0.64

In terms of inferential statistical analysis, non-parametric tests were used to explore the relations between the participating teachers and their DET and T-STEM Survey. It's critical to stress that the sample size for this study was fairly small.

Teachers' pre- post-PD workshop DET and T-STEM survey responses were compared as shown in Table 3. The non-parametric Wilcoxon signed-rank test indicated that the summer PD workshop generated statistically significant change in familiarity and importance of DET. The stereotypical characteristics of engineers of the DET also showed a statistically significant improvement. From the T-STEM instrument, teaching efficacy and beliefs, teaching outcome expectancy, 21th century learning attitudes, and STEM awareness also showed improvements. For the barriers in integrating DET, student technology use, STEM instruction, and teacher leadership attitudes constructs, no significant difference was detected between pre- and post-workshop responses.

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

Instrument	Construct	Wilcoxon Test	
		Z	p
DET Teacher Survey (Hong et al., 2011)	Importance of DET	-2.14	0.032
	Familiarity with DET	-2.71	0.007
	Stereotypical Characteristics of Engineers	-2.31	0.021
	Barriers in Integrating DET	-0.63	0.52
T-STEM	Personal Teaching Efficacy and Beliefs	-2.94	0.003
	Teaching Outcome Expectancy Beliefs	-2.27	0.023
	Student Technology Use	-1.84	0.065
	STEM Instruction	-1.80	0.071
	21 st Century Learning Attitudes	-2.09	0.036
	Teacher Leadership Attitudes	-0.51	0.600
	STEM Career Awareness	-2.10	0.035

The authors were not surprised that the barriers in integrating DET and the student technology use would not be significantly impacted by the PD workshop activities. There are many barriers school teachers face when they attempt to try a new teaching approach or an innovative technology in their instruction. Because these new approaches and technologies require extra time and effort, most teachers find their implementations challenging. The standardized curriculum does not allow teachers to be flexible in their use of time with their students. This is especially true for the authentic and experiential learning activities presented here; they require more time and effort from both teachers and students to effectively complete. “Cook book” type activities are less time consuming and easy to complete compared to authentic activities. Teachers who became more aware of the time and effort required to complete the PD workshop activities might have become more aware of the limited time and resources at their schools and therefore did not change their responses to the barriers in integrating DET sub-dimension’s items. Similarly, student technology use is something that could not be directly assessed in the PD workshop. Teachers might have recognized that student technology use is not something that they can necessarily control and improve, and therefore might have left their responses unchanged before and after the PD workshop.

The workshop activities were most influential in improving participating teachers’ familiarity with the DET and their personal teaching efficacy and beliefs. The time teachers spent in the workshop helped them improve their knowledge in DET quite effectively. This might have led to their improved teaching efficacy and beliefs. It is mostly expected that teachers who are familiar with the content knowledge often have high self-efficacy and positive beliefs in teaching that knowledge to their students. Opposite to this, teachers who are not familiar with the content often choose not to teach that content at all or develop very low teaching self-efficacy and become disinterested to teach.

Conclusion and Future Work

In a two-week professional development workshop, teachers engaged in real world engineering problems and learned to use innovative and exciting IoT and 3D printing

technologies. During the professional development workshop, teachers gained knowledge about authentic engineering activities and received support from engineering faculty to develop experiential learning activities. The faculty worked with the teachers to discuss how they could effectively incorporate these technologies and engineering design principles into their classrooms.

The overall purpose of this study is to help teachers improve their perception and knowledge of engineering and technology. These aspects were assessed using two validated instruments, the DET and the T-STEM. Overall results show the professional development workshop had a positive influence on the teachers' perception and understanding of these fields. While the number of participating teachers in this study was limited, several factors were shown to be improved when assessed using non-parametric statistical tests. However, given the small sample size, generalizability of the results is limited.

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