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Abstract

As the United States has introduced engineering to science through Next Generation Science Standards, in-service teacher professional development (TPD) becomes necessary because a majority of teachers did not encounter engineering and associated pedagogies in their pre-service programs. This study explored such in-service teachers' perspectives of engineering education for students and the efficacy of TPD programs in engineering. Responses from 302 K-8 teachers on an open-ended survey after a weeklong TPD were analyzed through an inductive analysis and a creative synthesis. While teachers were either intrinsically or extrinsically motivated, they preferred learning engineering through hands-on activities and liked the opportunities to interact with peer teachers, instructors, engineers, and students. They valued innovative ideas and teaching strategies that allowed them to directly integrate engineering into different subjects and wanted to learn more about different engineering fields, engineering pedagogical content knowledge and activities.

Introduction

With the adoption of the Next Generation Science Standards (NGSS) in the United States (US) (NGSS Lead States, 2013), engineering has been introduced to formal student education in many states. Bringing engineering into the classrooms as early as possible is desirable as it opens a window of opportunity to learn about engineering while reinforcing science, technology and mathematics learning (Katehi, Pearson, & Feder, 2009). Integrating engineering into formal education is particularly effective at reducing the loss of students' interest in STEM subjects during elementary school (Dyehouse, Yoon, Lucietto, & Diefes-Dux, 2012).

However, teachers know little about engineering due to a lack of preparation during their pre-service education in the US (Duncan, Diefes-Dux, & Gentry, 2011; Cunningham, 2009). A one way to solve this issue is through teacher professional development (TPD) because teachers can have an opportunity to fill the gap in their knowledge and instruction on the new contents (Darling-Hammond, 1996; Desimone, 2009). Therefore, TPD in engineering for in-service teachers becomes essential to enrich their STEM and pedagogical content knowledge (PCK) and to improve teacher practices, so they can be successful at teaching engineering (Sun & Strobel, 2013; Yoon, Diefes-Dux, & Strobel, 2013). Accordingly, research about the effects of TPD in engineering on in-service teachers becomes necessary to examine how they perceive and what they learn through TPD, under the circumstances of a lack of such research in the literature.

Teacher Professional Development in Engineering Integration

While the mathematics and science education literature shows abundant studies that assessed the effects of TPD on teachers (e.g., Bredeson, 2000; Garet et al., 2001; Kwakman, 2003; Mullens, Leighton, Laguarda, & O'Brien, 1996), limited studies existed in the engineering education literature. For example, Duncan, Oware, Cox, & Diefes-Dux (2007) assessed the impact of TPD in engineering upon teacher perceptions of engineering and investigated teacher attitudes toward integrating engineering into their curriculum that involved engineering activities, such as Mission to Mars (Hains-Allen & Beck, 2006), Milton is Missing, and Model-Eliciting Activities (MEAs) (Lesh & Doerr, 2003). As results of a weeklong TPD, teachers self-reported that they became more familiar with the engineering content and had a high level of interest in implementing engineering activities in their classrooms.

Bayles, Ross, Singer, Krikorian, and Sura (2011) evaluated a new TPD program in engineering by assessing teacher perspectives on the preparedness and attitudes toward seven pedagogical strategies: ―have students participate in hands-on activities," ―engage students in open-ended problem solving," ―engage students in inquiry based learning," ―make connections between science and engineering," ―work on solving real-world problems," ―do design exercises with constraints," and ―write reflections in a notebook or journal" (p. 7). In results, teachers perceived that all the seven strategies were important, especially for the ―write reflections in a notebook or journal" and ―do design exercise with constraints" strategies. Teachers also expressed that they were well prepared for the implementation of all these strategies in their classrooms, especially for ―make connections between science and engineering" and ―do design exercise with constraints."

Kendall and Wendell (2012) surveyed teachers' beliefs and perceptions toward implementing engineering-based classroom instructions with four different units (―properties of materials, sound, simple machines, and animal structure and behavior," p. 4), targeting third and fourth grade students. As a result, teachers showed high self-efficacy in science teaching beliefs and considered the TPD in engineering successful. Particularly, teachers ascribed the success of the TPD to ―the ‗hands-on' nature, LEGO™ materials, unit coherency, professional development, in-classroom support, and student journals" (p. 15).

Using a mixed-method approach, Hardré et al. (2013) investigated eleven secondary mathematics and science teachers' yearlong integration of engineering into the classroom. Through various measures, they found positive effects of the TPD on teachers' motivation, perceptions, learning, and practice over time. Although those studies focused on the evaluations of newly developed TPD programs in engineering from teacher perspectives, the study designs were limited to the small numbers of teacher participation and their responses were constrained by a few measures set forth by the researchers. Therefore, there is a need to evaluate and explore the effects of TPD in engineering on teachers from different aspects.

Significance in Evaluations of Teacher Perspectives on TPD

According to the TPD evaluation framework by Guskey (1998, 2003, 2005), there are five levels of evaluations in the hierarchically structured TPD model: (a) teachers' reactions, (b) teachers' learning, (c) organizational support and change, (d) teachers' use of new knowledge and skills, and (e) students' learning outcomes. As each of the five levels is scaffolded from a lower level to a higher level, an evaluation of the first level is a fundamental step to explore the effects of TPD on both teachers' learning, knowledge, and instructional skills, and students' learning outcomes. In other words, teachers' reactions, such as satisfaction with TPD experiences and perspectives on TPD, function as a mediator that influences the following four levels in sequence: teachers' learning (e.g., acquisition of new knowledge or instructional skills), support and advocacy of the school or district, teacher changes in the ways to use new knowledge and skills, and finally, students' learning outcomes, including their cognitive, affective, and behavioral changes in class.

In addition, evaluations of teacher perspectives on TPD are essential for various reasons. First, when applying reformed instructional practices in class, teachers' beliefs are part of cultural barriers to the successful implementation of TPD (Johnson, 2006). According to Johnson's (2006) three dimensions of teacher barriers, technical barriers include teachers' content knowledge, pedagogical knowledge, as well as teachers' ability to implement new instructional strategies constructively. Political barriers, which are hard for teachers to control, include the lack of local leadership and support. Cultural barriers, referring to teachers' beliefs concerning teaching and their preparation ethic (the feeling of obligation for transmitting content knowledge to prepare their students for the next level), were found to be the most difficult ones to overcome among the three dimensions. Therefore, evaluations of teacher prespectives on TPD are necessary to identify teacher barriers and provide appropriate support for them to overcome the challenges, so that they can be successful in their classrooms.

Second, as shown in the Guskey's (1998, 2003, 2005) hierarchical TPD evaluation model, the expected outcomes of TPD on teacher practice in class can be predicted by surveying teacher perspectives on prospective classroom instruction changes (Capobianco, Diefes-Dux, & Mena, 2011; Baker, Yasar, Kurpius, Krause, & Roberts 2005). While classroom observation is a direct and reliable way to evaluate teachers' classroom instructions, surveying teachers' planned classroom instructional changes can also provide an immediate estimate of the potential impact of TPD and highlights needs for additional improvement of TPD if the potential for change is slight.

Third, teachers' attitudes toward TPD can be captured in their perspectives of TPD. Since teachers with positive attitudes toward TPD tend to use "inquiry-based instruction" frequently in their classrooms (Wilkins 2008, p. 139), their positive attitudes toward TPD may increase the outcome of TPD implementation. Thus, evaluations of teacher perspectives on TPD can provide guidance to make future TPD more attractive to teachers, so teachers' attitudes toward TPD will be more likely to be positive.

Finally, some teachers' comments and suggestions are based on their expectations of TPD, so teachers' expectations of TPD can serve as a baseline in determining the effectiveness of TPD (Karabenick & Clemens Noda 2004), so the quality of TPD can be improved by considering teachers' comments and suggestions. Since both effective and ineffective aspects of TPD can be directly determined through evaluations of teacher perspectives on TPD, TPD can be modified efficiently with as few resources as possible (Bayles et al., 2011). Overall, teachers' feedback on TPD is vital for improving the effectiveness and quality of TPD. Thus, TPD designed based on evaluations of teacher perspectives can maximized benefits for teachers.

Theoretical Framework for TPD Evaluation

Reflecting upon Guskey's (2003, 2005) TPD evaluation framework and Newman's (2010) hierarchical interaction model, Yoon, Diefes-Dux, and Strobel (2013) proposed an interactive theoretical framework for TPD evaluation. While most components (teacher satisfaction, knowledge, practices, and student performance) are grounded in Guskey's (2003, 2005) TPD evaluation framework, this evaluation framework is distinct in that both teachers' and students' knowledge and perceptions of STEM can be considered within it. The framework also takes into account the influence of the characteristics of schools (e.g., administrators' support for teachers and Title I status), teachers (e.g., gender, teachers' education level, year of teaching experience), and students (e.g., gender, race/ethnicity, and SES). In Figure 1, each arrow presents the direction of the influence of one factor toward another. Here, the direct effectiveness of the TPD in integrated engineering education on teachers can be captured by an increase in their knowledge and changes in their perceptions regarding integrated engineering education. Accordingly, the indirect effectiveness of TPD on students can be captured by the increase in their knowledge and changes in their perceptions regarding STEM as their changes are mediated by teacher practice in the classroom. As a summative evaluation of TPD in engineering integration, the framework is designed to make explicit the associated relationships and changes among schools, teachers, and students.

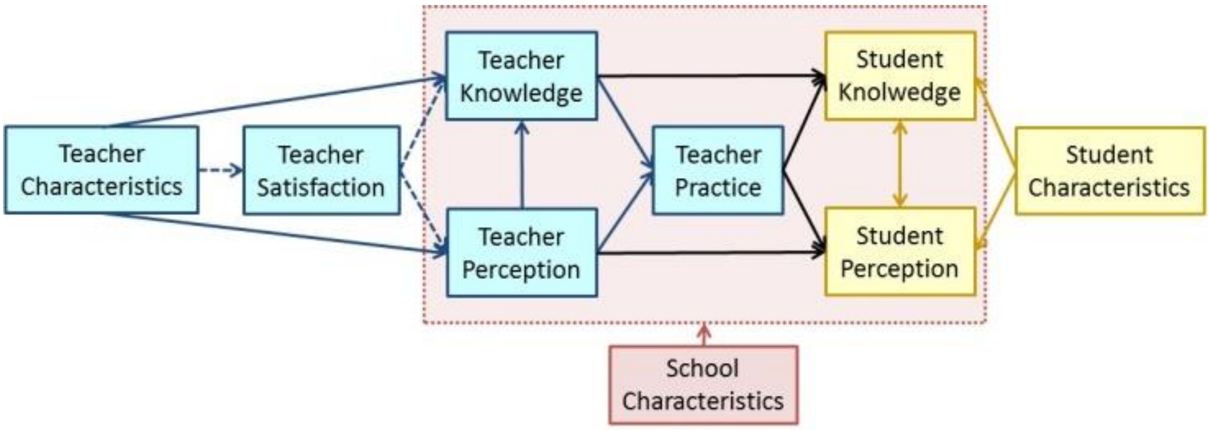

Figure 1. An interactive TPD evaluation framework grounded in Guskey's (1998) professional development evaluation framework and Newman's (2010) interaction model (Yoon, Diefes-Dux, & Strobel, 2013)

Purpose of the Study

An Institute at a Midwestern public university in the US offered one-week Summer Academies for K-8 teachers, who were new to engineering education and interested in incorporating engineering into their classrooms, from 2006 to 2011 including the first two years of pilots (Duncan et al., 2007). Following each TPD week, the Institute administered a survey to investigate the impact of the program on teachers. While several approaches including quantitative and/or qualitative methods were utilized to assess changes in teacher knowledge and student learning (Yoon, Diefes-Dux, & Strobel, 2013, Yoon, Dyehouse, Lucietto, Diefes-Dux, & Capobianco 2014; Douglas, Rynearson, Yoon, & Diefes-Dux, 2016), this study solely focused on evaluating the direct effects of the TPD in engineering on teacher perspectives of engineering integration based on the interactive

TPD evaluation framework shown in Figure 1 (Yoon, Diefes-Dux, & Strobel, 2013). Accordingly, addressed were the following research questions: (a) in what ways were teachers satisfied with the TPD in engineering?; (b) what were the most important things teachers learned from the TPD?; (c) which aspects of the TPD were meaningful for teachers?; (d) how were teachers motivated by the TPD?; (e) what were teachers' plans to integrate engineering into their instruction?; (f) what were teachers' suggestions for future topics of TPD in engineering?; and (g) what were teacher comments to improve the TPD in engineering in the future?

Method

Teacher Professional Development in Engineering Integration

During the initial two years of Summer Academies in 2006 and 2007, the Institute established infrastructure for the TPD in engineering and the TPD curriculum was developed by trial and error and refined for Summer Academies in the following years. From 2008 to 2011 , weeklong (~40 hours) Summer Academies were offered by the Institute on the university campus and at a particular school district site in southcentral US. The four stated goals for the TPD are to prepare teachers to (a) convey a broad perspective of the nature and practice of engineering; (b) articulate the differences and similarities between engineering and science thinking; (c) develop a level of comfort in discussing what engineers do and how engineers solve problems; and (d) use problem-solving processes, including scientific inquiry, mathematics model development, and the engineering design process (EDP), to engage P–6th grade students in complex open-ended problem solving. Through this TPD, teachers engaged in hands-on, standards-based activities (e.g., EDP and MEAs) as students and reflected on these activities (e.g., student learning potential and implementation logistics) as teachers. An interdisciplinary approach was taken to demonstrate how engineering can be related to existing and currently taught content areas (i.e., science, mathematics, and language arts) (Duncan et al., 2011).

Participants constructed working definitions of technology and engineering, learned about the EDP through a short engineering design activity, and engaged in two Engineering is Elementary (EiE) units (Cunningham 2004) and one or more MEAs. Participants maintained engineering notebooks in which they kept their work and reflections on the activities. Special events were provided during each academy. A Sunday night reception was held to get to know one another and lay a foundation for thinking about a broad definition of technology. A tour of engineering facilities (either university or manufacturing) was provided and a social event with engineering students and practicing engineers was hosted. At the end of the academy, the teachers created and implemented an engineering activity for local elementary students either attending a daycare camp or invited to attend an engineering day. Teachers participating in the on-school-site academy, as part of a NSF funded research project, were expected to deliver ―what is technology" and ―what is engineering" activities, an introduction to EDP, and the four EiE lessons contained in a single EiE unit during the school year. As the Summer Academies from 2008 and to 2011 were partially supported by the NSF fund for an experimental study, the curriculum and logistics of the TPD were stable across four years to explore the impact of the TPD on both teachers and students at a large scale at the end of the project.

Participants

Participants in this study were 319 teachers who were new to engineering education and attended the TPD in engineering for a first time (See Tables 1 and 2 for the number of participants each year and their demographics). Each year, two Summer Academies were held at the Midwestern university (National group) and at a large school district located in southcentral US (On-site group) from 2008 to 2011. The National Group teachers, who volunteered from a single school district in a western US or across the US, taught students in grades K to 8 (typical age of 5 to 13) at public or magnet schools.

Table 1. Numbers of TPD participants and survey respondents by year

Year	Participants	Respondents
2008	69	65
2009	78	76
2010	77	77
2011	95	84
Total	319	302

The On-site 2008-2010 attendees were volunteers from a single large school district and the On-site 2011 attendees from five elementary schools were required to attend the academy as part of participation in the NSF project. All On-site teachers in all years (2008-2011) taught or were instructional facilitators for grades 2 to 4, except two teachers who taught grade 5 in 2011. All participants applied in teams of four or more to ensure colleague support for engineering implementation post-academy. Among the 319 participants, 302 teachers (94.7%) responded to a survey at the end of the TPD.

Table 2. Characteristics of teachers

	Category	*N*	%
Gender	Female	291	91.2
	Male	28	8.8
Ethnicity	Asian	6	1.9
	Black	36	11.3
	Hispanic	41	12.9
	White	220	69.0
	Multiracial	8	2.5
	Non-respondent	8	2.5
Grade	K-2	82	25.7
	3-5	186	58.3
	6-8	6	1.9
	Facilitator	31	9.7
	Principal/Administrator	6	1.9
	Non-respondent	8	2.5
School	Public	292	91.5
	Magnet	21	6.6
	Not Applicable*	6	1.9
Total		319	100.0

Note. *Participants were either retired or worked at a learning center or a school district office.

Survey Design

The TPD evaluation survey was designed to explore teachers' overall satisfaction with the TPD, their perspectives on TPD in engineering, and potential application of their learning post-Academy. The survey consists of ten five-point Likert type items (rated as very poor, poor, fair, good, and excellent or strongly agree, agree, neutral, disagree, and strongly disagree) and seven open-ended items*. The ten Likert-type items named the Engineering TPD Evaluation Scale (ETES), ask about teachers' overall satisfaction with the TPD and their perceptions of the TPD effects on their instructional strategies. Seven open-ended items inquire about three important things teachers learned from the TPD in engineering, meaningful aspects of the TPD, how they were motivated by the TPD, teacher's plans for future classroom instruction, suggestions for future topics, and comments regarding the TPD, including one item asking for further clarification on prior responses.

Data Analyses

As the ETES was validated in Yoon, Kong, Diefes-Dux, and Strobel (2013), the major data analyses of this study was conducted for the seven open-ended items. The first two authors of this study coded the teachers' raw responses to the six items, which were supplemented by the responses to the one clarification item. An inductive analysis and a creative synthesis strategy were employed to analyze the responses (Patton 2002; Thomas 2006). First, the two researchers independently identified the themes that emerged in the data and coded the data based on their identified themes independently. Second, they held occasional meetings to reach a consensus on their independently identified themes. Third, they coded the data independently again based on the consensus themes, and then compared, discussed, and recoded until they reached a consensus on all of the coding. Finally, they labeled and described the themes and calculated the frequency of each theme appeared in teachers' raw responses. The frequency data were converted to the percentage of teachers who responded on each theme.

* The items in the survey were reordered to be aligned with the research questions.

Results

Overall Satisfaction with the TPD in Engineering

The results using the ten-Likert type questions showed that, overall, teachers were satisfied with the TPD. They rated the program *Good* (*n* = 302, *M* = 4.26, *SD* = 0.73) with indications of meaningful and motivating learning compared to other TPD programs. Regarding the effect on teachers' instructional strategies, teachers rated the program *Good* (*n* = 301, *M* = 4.34, *SD* = 0.94), meaning that the TPD contributed to their growth in using new instructional strategies with confidence.

Characteristics of Teacher Responses on the Open-ended Items

Teachers' response rates on the open-ended items varied as shown in Table 3. On average, 94.1% of participants (*n* = 284) responded to the four main open-ended questions, while response rates for the last two questions were relatively low (43.0% and 81.5%, respectively). Depending on the items, teachers provided a wide range of responses, so a varied number of themes appeared in each teacher's response. In some cases, teachers did not provide proper responses to the open-ended questions. For example, responding to the question about the three most important things that teacher learned from the TPD, teachers provided one to several ideas. Thus, the diversity in the number of themes in each teacher's response allowed for a sum of over 100% of respondents for each item.

Table 3. Response rates on the open-ended questions (n = 302)

Main Theme of the Question	Valid Responses		Missing Responses	
	n	%	*n*	%
Important learning	293	97.0	9	3.0
Meaningful aspects	276	91.4	26	8.9
Motivation	285	94.4	17	5.6
Plans for Instruction	282	93.4	20	6.6
Suggestions for future topics	130	43.0	172	57.0
Comments to the program	246	81.5	56	18.5

Important Things that Teachers Learned from the TPD in Engineering

Fourteen themes were induced from the responses to the item about the three most important things teachers learned from the TPD that they can use in their classroom. Figure 2 presents identified themes ranked by the percentage of teachers who responded its importance in learning (See Table 4 for the definition of the themes).

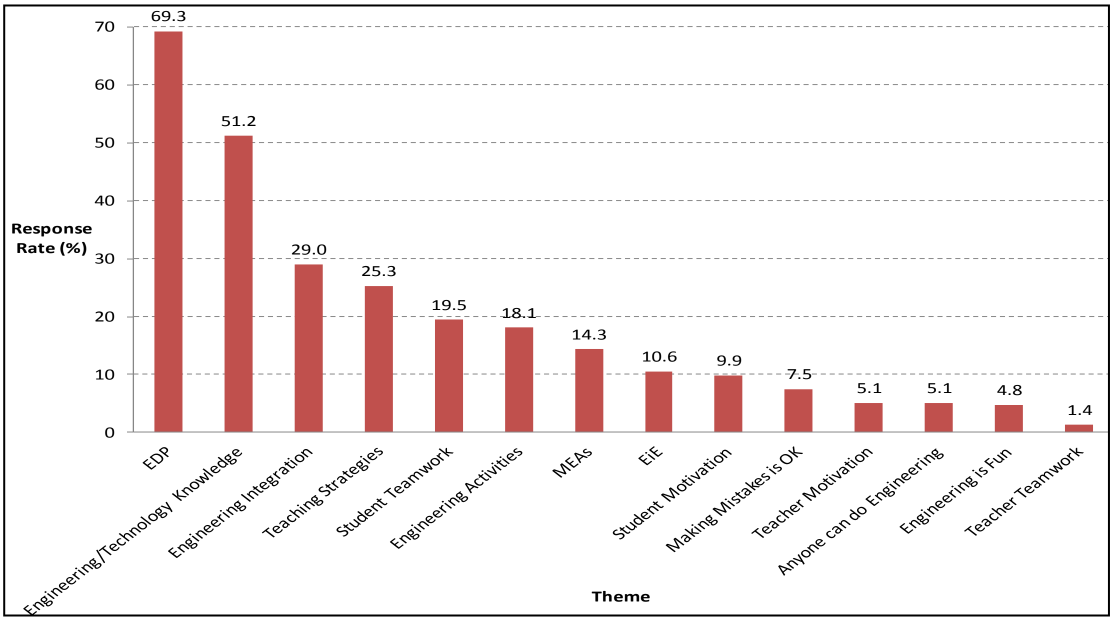

Figure 2. The most important things that teachers learned from the TPD in engineering (*n* = 293)

The top most important thing that teachers learned about was the EDP (69.3%), followed by knowledge about engineering and technology (51.2%). The third and fourth important things concerned integration of engineering (29.0%) and new teaching strategies (25.3%). The other themes, in order of the percentage of teachers from 25.3% to 1.4%, were Student Teamwork, Engineering Activities, MEAs, EiE, Student Motivation, Making Mistakes is OK, Teacher Motivation, Anyone can do Engineering, Engineering is Fun, and Teacher Teamwork.

Table 4. Themes of the important things that teachers learned from the TPD in engineering

Theme	Definition
Engineering Design Process (EDP)	The EDP encompasses iterative steps of ask, imagine, plan, create, test, and improve, which is distinct from scientific inquiry but incorporates it.
Engineering/ Technology Knowledge	Content knowledge about engineering and technology, including the nature of engineering and technology, introduction of different engineering fields, what engineers do, connections of engineering to the real world examples, and usage of engineering vocabulary.
Engineering Integration	Effective ways to integrate engineering into current curriculum, including language arts, social studies, mathematics, science, and art lessons.
Teaching Strategies	Teaching practices that include different ways to improve problem solving and critical thinking skills; questioning techniques to elicit student responses; writing techniques, such as expository, procedural, and reflective journal writing; and how to make learning more hands-on, etc.
Student Teamwork	Team building that fosters positive peer interaction and cooperative learning among students to solve problems and complete projects together.
Engineering Activities	Engineering activities, particularly hands-on activities practical to use in class.
Model-Eliciting Activities (MEAs)	Use of MEA lessons to bring real world mathematics into the classroom.
Engineering is Elementary (EiE)	Instructional application of EiE lessons.
Student Motivation	Teaching engineering in interesting and meaningful ways to increase students' interest in engineering and to encourage students to develop confidence in learning engineering and consider future careers as engineers.
Making Mistakes is OK	It is okay to fail at an engineering task because students can learn from their mistakes.
Teacher Motivation	An increase in teachers' interest and confidence in learning and teaching engineering.
Anyone can do Engineering	Anyone can do and all ages can learn from engineering.
Engineering is Fun	Engineering is fun for teachers and can be fun for their students.
Teacher Teamwork	Collaboration among teachers from the same grade or different grade levels to incorporate engineering into their classrooms.

Meaningful Aspects of the TPD in Engineering

Figure 3 presents thirteen themes emerged from the teachers' responses on the meaningful aspects of the TPD (See Table 5 for the definition of each theme). More than half of teachers (52.9%) indicated that hands-on approaches were the most meaningful aspects of the TPD. The second and the third most meaningful aspects of the TPD were the TPD instruction (29.7%) and application to classroom (26.4%). The other themes were Learning New Knowledge, Interaction with Peers, the EDP, Practice with Real Students, Teacher Motivation, Being a Student, Meeting with Real Engineers, Field Trip, MEAs, and EiE, with response rates ranging from 20.3% to 1.4%.

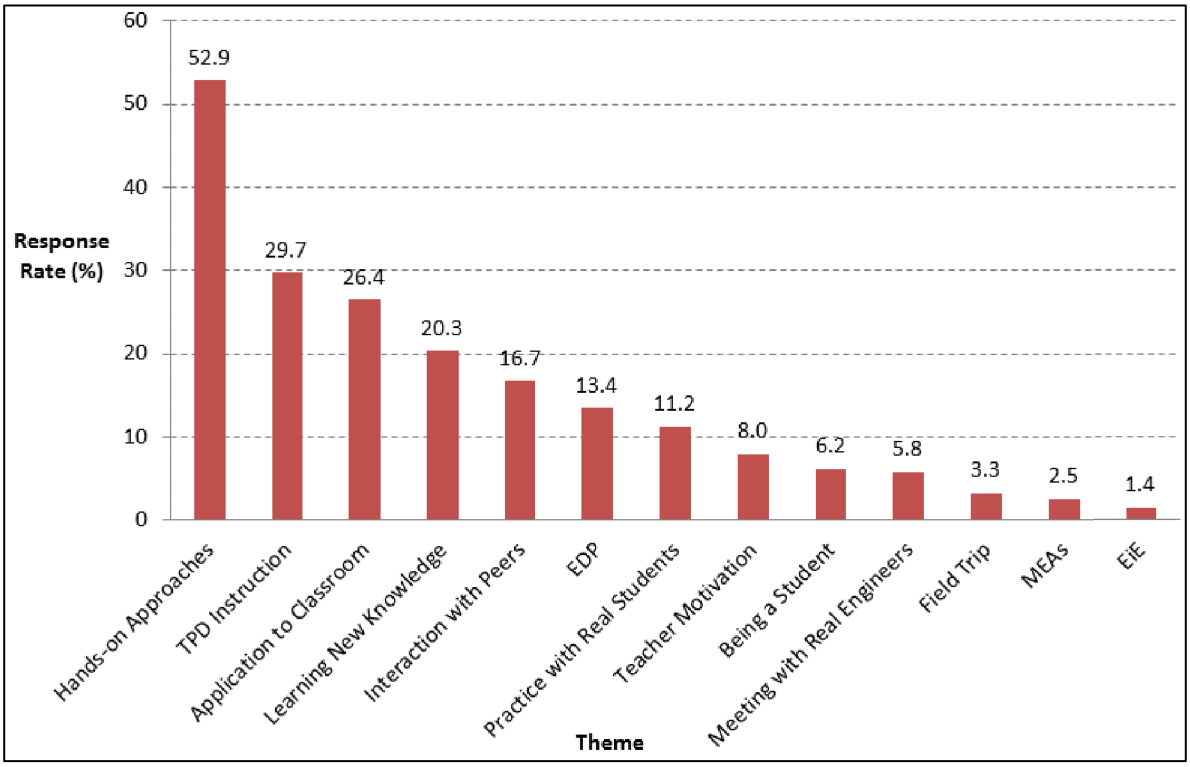

Figure 3. The meaningful aspects of the TPD in engineering (*n* = 276)

Table 5. Themes of the meaningful aspects of the TPD in engineering

Theme	Definition
Hands-on Approaches	Hands-on approaches help teachers learn engineering concepts and make the learning process fun.
TPD Instruction	Instructions/presentations were clear, helpful, and well balanced with activities, including sufficient practice, application, and reflection time. Instructors were friendly, knowledgeable, and encouraging.
Application to Classroom	What teachers learn from the TPD in engineering can be easily applied to classroom instruction. Teachers can integrate engineering in other subjects, such as mathematics and science, and adapt the materials and lesson plans from the TPD to their curriculum.
Learning New Knowledge	Teachers valued learning new content and ideas. They gained knowledge about what engineers do, what engineering and technology are, and how engineering and technology are related to real life.
Interaction with Peers	As teachers collaborated with peers and worked as a team, they were able to interact with the same and/or different grade-level teachers and discuss with other teachers who had implemented engineering.
Engineering Design Process (EDP)	Teachers valued learning of EDP and multiple opportunities to practice EDP-based activities.
Practice with Real Students	Teachers had an opportunity to teach engineering lessons designed by themselves to a small group of students.
Teacher Motivation	Teachers were engaged in learning engineering and developed confidence in teaching engineering.
Being a Student	Teachers took the role as learners like students during the TPD.
Meeting with Real Engineers	Teachers had a chance to interact with and learn from actual engineers.
Field Trip	A field trip to university facilities or manufacturing plants, such as pet carrier manufacturers, wetlands, and wind farms, brought real life aspects of engineering to teachers.
Model-Eliciting Activities (MEAs)	MEAs were useful as a new tool in teaching engineering.
Engineering is Elementary (EiE)	*EiE* can be adapted to teaching across curriculum.

Teacher Motivation

Corresponding to the teachers' responses on the motivating aspects of the TPD, types of teacher motivation were identified based on Ryan and Deci's (2000) definitions of intrinsic and extrinsic motivations (See Table 6 for the definitions). Including 20.7% of the teachers, both intrinsically and extrinsically motivated to participate in the TPD in engineering, more than half of the teachers (56.8%) demonstrated extrinsic motivation and a similar percentage of teachers (55.4%) showed intrinsic motivation. However, 8.4 % of teachers revealed that they were not motivated. Some of the reasons addressed in the responses were that the length of hours (8 am – 5 pm) in a day was too long and the program was intensive and lacked flexibility.

Table 6. Types of teacher motivation

Type	Definition
Intrinsic motivation	Teachers were interested in engineering and have a desire to learn new things about engineering and students' learning processes through engineering activities, the EiE units, MEAs, EDP, and field trips.
Extrinsic motivation	Teachers revealed external controls by others to learn from the TPD or showed their oriented goals not for their learning but for their students. For example, teachers were encouraged to learn from the TPD by peers or instructors and teachers wanted to learn to integrate engineering into their classroom because it will be beneficial for their students' learning.

Teachers' Plans for Classroom Instruction

Fourteen themes appeared in the teachers' responses on plans for classroom instruction, as described in Table 7. Less than half of teachers (43.3%) responded that they will introduce the EPD to their students, followed by 42.2% of teachers addressing application of teacher practice that they learned from the TPD (Figure 4). A small portion of the teachers (6.0%) planned to start or include engineering in class while 34.0% of teachers mentioned that they planned to integrate engineering into their curriculum or other subjects.

Table 7. Themes of the teachers' planned classroom instruction

Theme	Definition
Engineering Design Process	Incorporation of the EDP in class.
Teacher Practice	Applications of different questioning techniques, problem solving strategies, and hands-on approaches as well as writing and discussion techniques for their students to facilitate their learning in engineering.
Engineering Integration	Integration of engineering, such as engineering concepts, vocabulary, activities, the EDP, EiE, and MEAs, into current curriculum or subjects.
Engineering/ Technology Knowledge	Introduction of engineering/technology through instruction on engineering vocabulary, differences between engineering and technology, what engineers do, and examples of engineering in their everyday life in class.
Engineering Activities	Inclusion of engineering activities, which are more hands-on and/or use problem solving approaches.
Thinking Skills	Development of students' independent, creative, and critical thinking abilities and encouraging them to think like engineers.
Student Teamwork	Engaging students to work more as teams and learn through cooperative group projects.
Teacher Motivation	Teachers are inspired to teach engineering for their students. They revealed better understanding of engineering, gained confidence in teaching engineering, and excited to teach engineering.
Model-Eliciting Activities (MEAs)	Inclusion of MEAs in their instruction.
Inclusion of Engineering	Teachers will begin to teach engineering in their classroom or look for more opportunities to include engineering lessons in their teaching.
Student Motivation	Engineering instruction to get students engaged in the learning processes and promote their interests in engineering.
Multiple Solutions	Teachers will allow students to find the best solutions using multiple ways among numerous possibilities.
Engineering is Elementary (EiE)	Teaching of EiE lessons in their classroom.
Collaboration with Teachers	Collaborate with other teachers to infuse engineering into their curriculum.

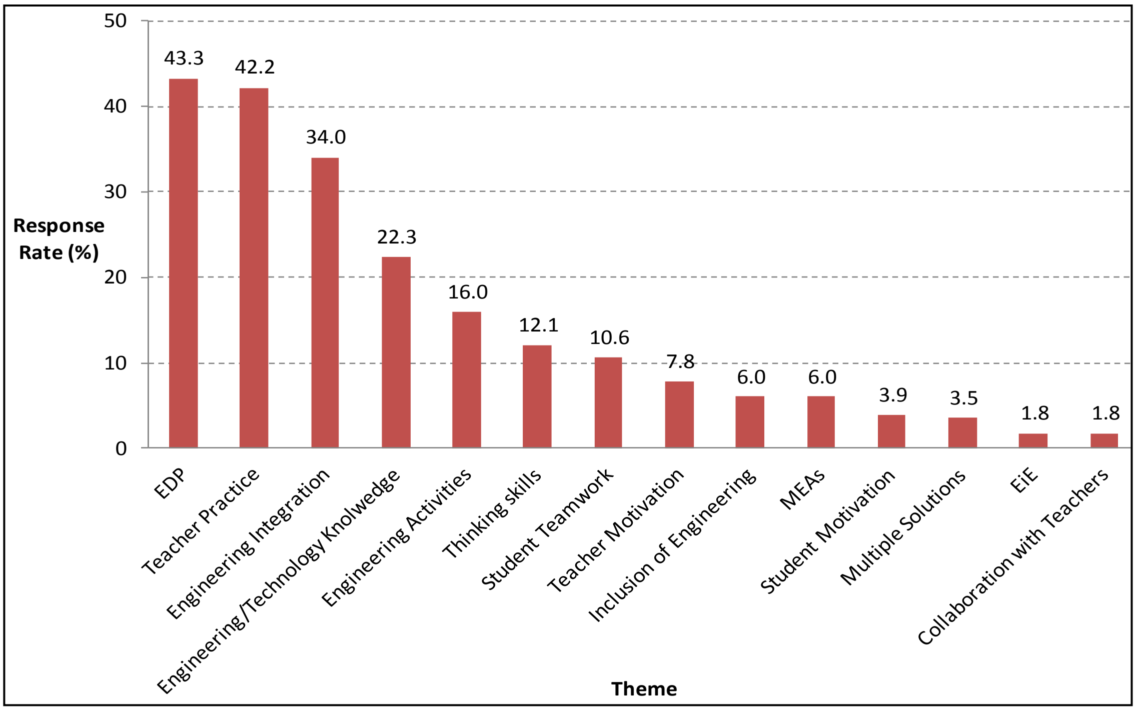

Figure 4. Teachers‘ plan for classroom instruction (*n* = 282)

Teachers' Suggestions for Future Topics

Less than half of teachers (*n* = 130, 43.0%) provided suggestions for future topics. Among them, 25.4% suggested topics or subjects to be integrated with engineering in class as future topics (Figure 5 and Table 6 for the definitions). Teachers wanted topics in arts, language arts, mathematics, and sciences for engineering integration. In detail, teachers suggested integration with fine arts, geometry, electricity and magnetism, space, plants, animals, habitat, water cycle, and the Earth's resources in science. New topics in engineering entailed such topics as aerospace, aeronautics, aquatic, architecture, and the ethical aspects of engineering. Teachers were also interested in resources; 21.5% of respondents would like to have more information about resources that can be practically utilized in class, such as specific and hands-on activities, PowerPoint slides, websites, and lessons. Teachers (12.3%) also suggested watching videos as examples from other teachers or engineers.

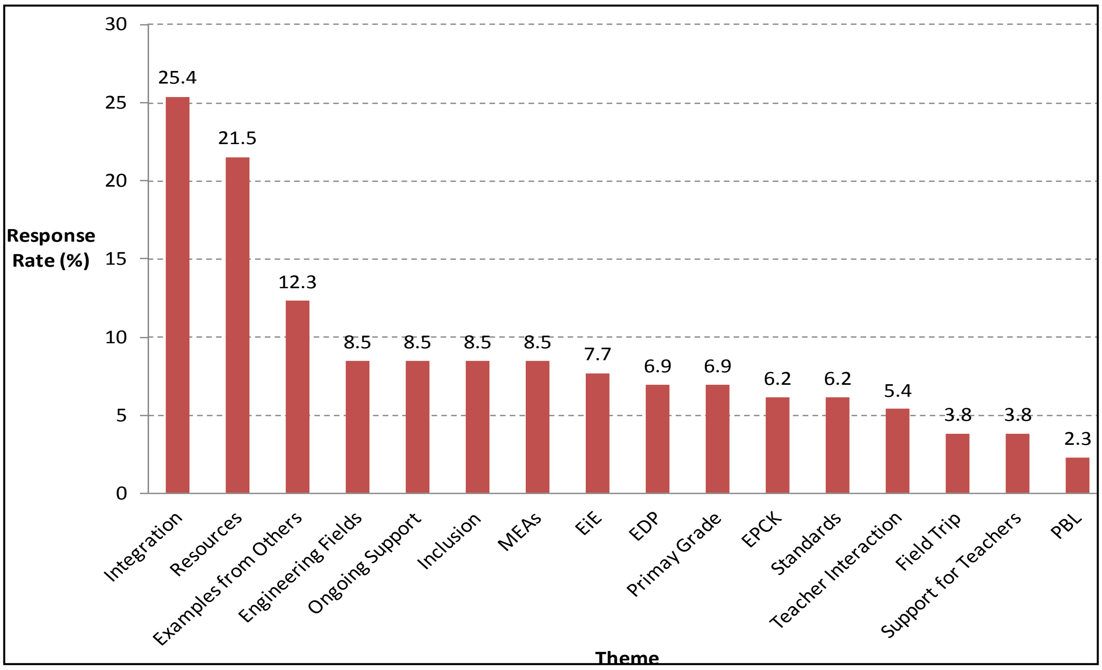

Figure 5. Teachers‘ suggestions for future topics (*n* = 130)

Table 8. Themes of teachers' suggestions for future TPD topics

Theme	Definition
Integration	Learning more about the ways to integrate arts, language arts, mathematics, science, and other subjects into EDP or engineering activities.
Resources	Need of more resources, such as hands-on engineering activities, lesson plans, PowerPoint slides, and websites.
Examples from Others	Having examples from other teachers who have taught engineering lessons in class.
Engineering Fields	Learning about other types of engineers and fields of engineering, which were not covered in the TPD.
Ongoing Support	Having follow-up TPD or ongoing support from the Institute.
Inclusion	How to find ways to motivate and support special education, female, minority, or low socioeconomic status students, as well as second language learners.
Model-Eliciting Activities (MEAs)	Need of more time to develop or learn to incorporate MEA lessons in class.
Engineering is Elementary (EiE)	Need of more time to develop or learn new EiE units.
Engineering Design Process (EDP)	Need of more explanation, examples, and application of the EDP.
Primary Grade	How to reach primary grades (K-1) using examples/lessons particularly developed for them.
Engineering Pedagogical Content Knowledge (PCK)	Learning more about effective teaching strategies to integrate engineering in class.
Standards	Learning more about how lessons are aligned with the National Core Standards or state standards of their teaching grade.
Teacher Interaction	Having more time to interact and collaborate with other teachers through discussion and small group activities.
Field Trip	Different types of field trips, such as a power-generating windmill tour and major industry companies.
Support for Teachers	Additional supports for teachers who teach gifted students, or who do not teach mathematics or science.
Project Based Learning (PBL)	Learning more about PBL and how it links to engineering activities.

Teacher Comments

While 81.5% (n = 246) of participants provided comments on the program, about half (42.3%) of respondents positively commented on the TPD, 27.2% addressed negative aspects, and 30.5% mentioned both positive and negative aspects of the program. Positive comments were usually general appreciation for instructors and staff. Teachers also appreciated the opportunity to get involved in the TPD. Most of negative comments were related to the program logistics (37.8%). For example, they wanted more breaks, longer lunch time, shorter days, and fewer days for the TPD. The second most frequent comments (22.8%) centered on the instructors and/or instruction. For example, participants wanted a slower pace and more planning and reflection time. Some teachers (4.1%) complained about other teachers because of their different work ethic, which made it uncomfortable to collaborate with each other. Few (2.4%) addressed that attendance was required.

Discussion

To address the effect of the TPD on teacher perspectives, this study utilized 302 teachers' data from a survey that accumulated from four years of weeklong Summer Academies. The results from the ten Likert-type items, which quantify teachers' perceptions regarding the TPD, show that overall teachers were satisfied with the TPD. Teachers perceived that the TPD in engineering was more meaningful and motivating than other TPD workshops and the TPD increased their confidence in teaching STEM. Such positive teacher responses might be partially due to the Hawthorn effect, which generates positive perceptions of participants due to their perceived involvement in intervention (Brown, 1992). Nonetheless, the high ratings indicate that the TPD had a positive influence on the teachers who participated and was worthy of their participation.

While the quantitative data presents a summary of the overall effects of the TPD, the qualitative data from the seven open-ended questions provided rich information about the TPD that encompassed a broad spectrum of teachers‘ opinions about their first TPD in engineering.

Important Things that Teachers Learned from the TPD in Engineering

As the Summer Academy was their first TPD in engineering, more than half of the teachers prioritized learning about the new subject-matter and pedagogical content knowledge, which were the EDP and knowledge about engineering and technology, respectively. Then, they valued application of their learning to instruction, which included effective ways to integrate engineering into other subjects and various strategies for effective teaching. As teamwork is one of the essential skills to do engineering (Mann, Mann, Strutz, Duncan, & Yoon, 2011c; Shuman, Besterfield-Sacre, & McGourty, 2005), teachers recognized that engaging in teamwork was important as students‘ personal and professional skill development for their successful learning of engineering. For example, one teacher stated:

> The MOST important thing I learned was how critical it is to teach kids to work as a team. Over the years of teaching and attending inservices and staff developments, I've heard over and over how important cooperative learning is for kids. It was good to here [HEAR] that, to SEE that, and to FEEL that as I worked in groups with my colleagues. We HAVE to have structured independent work time in our classroom, but we also need to provide time for the kids to practice being social and working through problems together.

Teachers also valued specific engineering activities and lesson plans, such as MEAs and EiE units that they can directly adopt in class. Even though less than 10% response rates might indicate small impact on teacher perspectives, appeared themes are worthy of attention to address because of the unique features in learning of engineering that are different from other subjects (i.e., mathematics and science). As engineering is new to both teachers and students, teachers considered that their change in perceptions of engineering is important. In detail, being motivated to teach engineering and motivating students to learn engineering are both important. Accordingly, they became more confident and familiar with engineering concepts, as they mentioned engineering is fun and for everyone. As such,

> ENGINEERING IS NOT AS COMPLICATED AS I THOUGHT

> I could have been an engineer. (I think that if I feel this way after this Academy, I will be able to INSPIRE my students to try new things, even if they think they will fail)

While the perception of ―Making mistakes is OK" originated from the test-retest step of the EDP, teachers took the concept further and perceived it as OK to fail as a learning process. Therefore, tolerating the feeling of failure during the EDP seemed to alleviate teachers‘ fear of teaching engineering.

> It's ok to fail. It's a part of the engineering design process. Create-Test-Improve!!!!!!

> Failure IS an option: I learned from my mistakes without being made to feel, well, stupid.

Meaningful Aspects of the TPD for Teachers

Garet et al. (2001) identified that providing opportunities for active learning is one distinct feature of effective TPD activities. The data from teachers‘ responses on the meaningful aspects of the TPD revealed that most of the themes relate to active learning experiences. For example, hands-on approaches were addressed by more than half of participated teachers (52.9%), as such,

> We were able to do the engineering activities, all hands-on. We didn't just sit and listen to the instructor. We were allowed to explore and solve problems within our groups.

As the second most meaningful aspect of the TPD, teachers (29.7%) mentioned how well instructors and staff of the TPD were prepared, encouraging, and interactive with teachers, as such:

> The people who taught the classes knew what they were talking about and was loved what they did, and it showed.
>
> Our instructor assisted us with the experiments, and made it very easy for us to understand the way we are supposed to perform them with our students.
>
> The instructors continued asking how was it going to look in our classroom.

As a practical aspect in teaching engineering in class, teachers (26.4%) valued being able to apply what they learned from the TPD to their classroom instruction as shown below.

> I can immediately take what I have learned back to my classroom and use it.

Teachers (20.3%) also stated that learning new knowledge, such as what engineering/technology is, what engineers do, and how engineering/technology are related to real life, is also meaningful. For other themes, teachers reported interactive learning environment, such as opportunities to interact with peer teachers, students, and actual engineers:

> [We] were able to bounce ideas off of each other for how to implement activities next year,
>
> Getting to work with students today allowed me to get immediate feedback about how these ideas would work with children without having to wait until school started.
>
> … interact and learn from actual engineers in a nonthreatening environment where I felt comfortable asking questions and taking learning risks.

Teachers also perceived that teacher-centered learning opportunities were meaningful. For example, being a student as a learner, meeting with actual engineers, and having a field trip to experience engineering fields appeared as meaningful aspects of the TPD.

Teacher Motivation

More than half of teachers were either intrinsically (54.8%) or extrinsically (56.80%) motivated because some (20.7%) were both intrinsically and extrinsically motivated. On the one hand, teachers expressed that they were interested in learning about engineering, enjoyed many hands-on activities, and learning was fun:

> I really enjoyed all the lessons and the meaningful discussions and insights during this Academy. The EIE and MEA's were very eye opening.

On the other hand, teachers were extrinsically motivated to attend the TPD with a specific goal that they wanted to improve their instruction or help students become learners that are more successful:

> I was motivated to learn because I want to take this information and implement it in my classroom.
>
> As an educator I am always looking to learn new techniques that can be incorporate into the curriculum. I know that engineering is a major component to helping the students build problem solving and team work skills.

Some teachers mentioned that peer teachers, instructors, or real engineers inspired them to learn engineering.

> I was more motivated in this academy because I was with my team mates during the training.
>
> Most instructors encouraged us to think like and explore like students.
>
> Meeting with the engineers made me more motivated to inspire my students and other children about the filed [field] of engineering

Teachers' Plans for Classroom Instruction

While majority of teachers (69.3%) indicated that learning about the EDP is one of the most important learning from the TPD, 43.3 % of teachers planned to teach the EPD in class. Similarly, many teachers wanted to employ various strategies to introduce engineering into the classroom: integrating engineering into different subjects (34.0 %), fundamental knowledge about engineering and technology (22.3%), and engineering activities (16.0%):

> I will definitely begin using engineering lessons in my classroom. I think that the engineering design process will be a great help to my students, and I am looking forward to teaching my students how to use their own creativity to come up with solutions to problems.
>
> I love the extension of science inquiry into the design process. Wow. That was a major revelation. I will be on the lookout for more and more design opportunities.

Interestingly, more teachers (6.0%) directly stated that they would like teach with MEAs than EiE units (1.8%).

> I really was impressed with the MEA activies [activities] because it really should [showed] me how to challenge my students to a higher level rather than try to spoon feed the information to them.

Further examination revealed that more National group teachers than On-site group teachers were interested in implementing EiE units, even though all On-site group teachers were expected to deliver an EiE unit in class. The difference in response rate might be because of On-site group teachers' obligation to deliver a whole EiE unit in the following year. An EiE unit has a broad coverage of contents, such as the EDP, knowledge about engineering and technology, and engineering activities. While National group teachers are free of selecting some of lessons, On-site group teachers might be overwhelmed in delivering the whole unit. As this TPD was their first exposure of engineering contents, teachers might feel more confident in planning smaller instructional lessons than the whole EiE unit.

Future Topics for the TPD in Engineering

While a relatively low response rate on the future topics of TPD might indicate a lack of idea due to limited knowledge of engineering, respondents offered various ideas for future TPD topics. Some teachers suggested specific topics in science and engineering to integrate into their curriculum. Others mentioned integration of engineering into other subjects, such as arts, language arts, and mathematics in general, but did not clearly address particular topics of interest. This implies even though teachers want application of those subjects, they may not be certain about topics and ways to integrate with engineering. The second and third most suggested topics were very practical and helpful for direct application in class, as they want more resources and examples from others.

> So I came away with more information, but I wish there were more things that I could immediately implement in the classroom that cover my core academics.

Teachers wanted to watch how others integrated engineering, solved design challenges, and managed classroom through videos or samples of student work or projects, as such:

> I would have liked to see evidence from implementation in the classroom from the teachers and hear about any frustrations or changes they had to make.

Teachers also mentioned that they would like to spend more time to learn about engineering knowledge and activities situated in an engineering field different from what they learned from the TPD. It might be because teachers were exposed to a few engineering fields through the TPD, teachers may feel a need for more knowledge about other engineering fields and activities. They also wanted to stay in touch with the Institute or continue to share their ideas and experiences, for example, through Facebook.

> It would be very beneficial for me to have some sort of follow-up at some point.
>
> [a teacher name] suggested having an [Institute] facebook page so we can all stay in touch and share our experiments. I think that is a fantastic idea!!!

Teachers also expressed concerns to support underrepresented students (such as female, minority, low socio-economic status, and English as second language learners) in learning engineering, as well as primary grade students.

> I think finding Hispanic role models, Spanish resources for Engineering, and contests that elementary level students can participate in would be helpful additions.
>
> it would be nice to develop units in other languages in order to cater to dual language programs. :)
>
> This will be my first year, but I would like to see how to develop additional units like EiE for first grade.
>
> More examples of K-1 lesson plans

While some teachers addressed concerns about the standards, the percentage of teachers was low. They more concerned about learning new knowledge and less concerned about assessment.

Comments to the TPD in Engineering

While more teachers were satisfied with their experiences than unsatisfied, both positive and negative comments were received. Sometimes the comments contradicted each other. For example,

> The entire week was very well run. The staff was there to help and guide us. I felt that they really loved what they were doing and through that excitement passed it on to us. I liked that meals were provided throughout the week. It kept us focused on the whole week running on schedule.
>
> Lack of Flexibility! Schedule was way too intense with no time to process before the next topic was intorduced [introduced]!

As the weeklong Summer Academy had an intensive schedule of 8am – 5pm that reached 40 hours in total, teachers wanted more flexibility in the logistics.

Limitations of the Study and Directions for Future Research

This study utilized the data with a large sample size (n = 302). Thus, the data of this study bring more power to generalize the results as compared to the data with a small sample size. However, the self-reporting nature of the survey has its limitations. First, a potential bias exists in the responses. For example, even though on average 83.5% of respondents answered the six open-ended questions, there might be a non-response bias because answers of non-respondents might differ from the ones of respondents (Gay, Mills, & Airasian, 2006).

Second, there is a possibility that the data may not fully represent opinions from the participated teachers because respondents might not sufficiently respond to the survey questions. Third, since the survey was anonymous, we could not identify factors that might relate to certain responses. Thus, future research is necessary to identify such factors through subgroup analyses, such as differences by gender and teaching grade level of teachers.

Fourth, even though we expected to see changes in teacher practice and curriculum as an effect of the TPD, what teachers responded to the survey does not guarantee what teachers do in the classroom. Thus, future studies including classroom observations are necessary to get a clear picture of connections between what teachers say and what teachers do in class (Ebert-May et al., 2011). Finally, as the literature suggests extended duration of TPD for its effectiveness (Loucks-Horsley, Stiles, Mundry, Love, & Hewson, 2009; Madigan, 2001), one-week TPD in engineering may not be sufficient to draw conclusions on the effectiveness of the TPD. Further research on TPD with different periods is recommended to examine the efficiency of TPD in engineering.

Conclusions

Overall, after TPD in engineering, teachers would like to teach engineering and technology and integrate engineering activities into their classroom instruction. Teachers' responses also indicated that they will motivate their students to learn about engineering and develop students' thinking skills and problem solving abilities through engineering activities. As Garet et al. (2001) identified the features of effective TPD, we could also recognize similar features in teachers' responses toward the TPD in engineering. Because the TPD provided active learning environment, teachers were engaged in learning engineering through various forms of hands-on engineering activities, and liked the opportunities to interact with instructors, peer teachers, real students, and actual engineers. They also appreciated what the TPD offered, such as innovative ideas and teaching strategies that they can directly adopt and use to integrate engineering into different subjects. They even wanted to learn more about engineering knowledge and activities that include the EDP, MEAs, and EiE and to receive an ongoing support from the Institute.

In addition, the results of this study demonstrated that the cultural barriers of TPD implementation (Anderson, 1996; Johnson, 2006) are not the factors that influenced the teachers. Most teachers were satisfied with the TPD and motivated to learn more about engineering. They were also eager to learn how to teach and implement engineering for their students. This implies that teachers' attitudes and beliefs toward the TPD were very positive and they became confident to teach engineering as an outcome of the TPD, as such:

> The academy has alleviated my reluctance to teach engineering.

In sum, through teachers' responses to their first TPD in engineering on the survey, we identified what teachers think are the most important to learn from the TPD, which aspects of the TPD were meaningful for teachers, how they were motivated to learn, how they plan to instruct engineering from teachers' viewpoint, and what they want more from the TPD.

Significance of the Study

This study systematically explored teacher perspectives on TPD in engineering by utilizing the survey data to evaluate the effects of the TPD on teachers from all aspects. Particularly, this approach is important to assess TPD in several ways. First, it discloses potential barriers that teachers might face when implementing engineering into their classrooms (Anderson, 1996; Mullens et al., 1996; Rossman, 1993). Second, it reveals the effect of the TPD on teachers directly from the teachers' viewpoint. Third, it provides guidance for TPD designers to improve the effectiveness of TPD in the future. While teachers' experiences with TPD in engineering were limited to the program offered by this institution, we expect the results of this study bridges the gap in the lack of research regarding the impact of TPD in engineering on teacher perspectives.

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