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Effects of Continuous Teacher Professional Development in Engineering on Elementary Teachers

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Effects of Continuous Teacher Professional Development in Engineering on Elementary Teachers

(Research-to-Practice)

Strand: Addressing the NGSS: Supporting K-12 Teachers in Engineering Pedagogy and Engineering-Science Connections

I. Introduction

As the Next Generation Science Standards (NGSS) embraces engineering as practices interacting with science, technology, and society, engineering becomes one of the key disciplines for K-12 education for future generations[1]. To prepare teachers to teach K-12 engineering, continuous support for teachers through teacher professional development (TPD) is necessary. In the past 20 years, many teachers have experienced TPD in engineering[2]. However, for most teachers, it has been a one-time opportunity because engineering is not a required subject to be taught in class in many states and lack of funding limited continuous support for teachers after their initial engineering TPD[2].

TPD is designed to change teachers' attitudes, beliefs, and perceptions, so such changes are expected to influence teachers' classroom practices and result in improved student learning[3,4]. However, one-time TPD is not enough to achieve desired teacher change because (a) changing practice requires prolonged engagement with a new practice, (b) it might be hard for teachers to make an immediate change after their TPD attendance, or (c) teachers may not want to continue different teaching approaches for various reasons[5]. Therefore, it is important to track teachers' perceptions and teaching practices after TPD, as well as guide teachers to apply their teaching practices in different ways after their first TPD. Additionally, there is a need to provide continuing support for teachers through follow-on TPD[4,6,7] as continuous professional development (CPD) is considered essential for furthering teachers' content knowledge, improving teacher practice, and making teachers successful in their teaching[8,9,10]. Providing prolonged professional development seems to be particularly true for engineering, which is a new content area for most teachers[11, 26].

A. Role of Continuing Professional Development (CPD)

Continuing professional development (CPD) is defined as "all types of professional learning undertaken by teachers beyond the initial point of training" (p. 6)[12]. CPD for teachers, on the one hand, helps teachers maintain their interest in and enthusiasm for teaching by refreshing and extending their content knowledge[7]. On the other hand, CPD brings about the sustained implementation of research-based practices and provides long-term support for teachers' implementation of new classroom practices for a successful TPD[6]. Since CPD ultimately increases the teachers' potential to benefit students' learning, it is considered to be an important way to fulfill social expectations of the teaching profession and meet students' needs, as well as a vital aspect of being a professional[13, 14].

Given the importance of CPD, there is a call for CPD in the literature. Guskey (2002)[4] stated that it is critical to provide continued support, encouragement, and subtle pressure to teachers, so that new practices and techniques from the TPD are used habitually. Loucks-Horsley et al. (1987)[5]

stated that successful TPD must be seen as a process instead of an event, because it is difficult to learn to be proficient at something new or find meaning in a new way of doing things, and it is likely to be slow and require extra work for individuals to increase their competence or for an organization to enhance its effectiveness[15]. Thus, it is imperative to make TPD a continuous and ongoing program[16]. Moreover, the National Staff Development Council (NSDC) Standards has CPD as one of its context standards: staff development, which improves the learning of all students and demands skillful school and district leaders to continuously guide the improvement of their instruction[17].

B. CPD Evaluations

CPD needs to be evaluated to justify decisions made by school management and funding agencies, to maximize teachers' benefit about the effects of CPD, and to improve the effectiveness of CPD[18]. Whitehouse (2011)[18] reported several outcomes of CPD that can be used to measure the effectiveness of CPD. These outcomes include teachers' content and pedagogical knowledge, teachers' self-efficacy, and the use of specific behaviors in their teaching, as well as students' learning outcomes. Many studies have evaluated CPD from different aspects in varied grade and subject areas[19, 20]. Some of the studies identified key factors that make CPD implementation successful.

For example, Neimeyer, Taylor, and Cox (2012)[20] evaluated the contribution of different CPD activities to ongoing professional competence and reported that CPD activities with self-directed learning, peer consultation, and formal continuing education significantly benefit ongoing professional competence. However, CPD activities, such as serving on professional boards, conducting client assessments, and taking graduate courses, provided minimum benefit. Armour and Makopoulou (2012)[19] evaluated CPD in England and found that positive factors of CPD were chances for interactive learning, cooperate participation, and localized implementation of CPD, which means that the provision of CPD is tailored to meet local needs. Although this reported CPD failed to extend teachers' learning in their interest area, it generated teacher enthusiasm for learning and was evaluated by participants as a successful program.

Some studies evaluated the outcome of CPD by examining teachers' teaching practices and beliefs. For example, Desimone, Porter, Garet, Yoon, and Birman (2002)[10] examined the effects of a longitudinal TPD on teachers' teaching practices in mathematics and science from 1996-1999. They found that the provision of active learning opportunities in TPD made teachers' use of new classroom practices increase. Fisher, Lapp, Flood, and Moore (2006)[21] described a CPD initiative that guided teachers' instruction by linking teaching and assessment. After this CPD, teachers improved their knowledge, skills, and dispositions, and they were able to apply what they learned from the CPD to improve their students' learning. Taitelbaum, Mamlok-Naaman, Carmeli, and Hofstein (2008)[22] reported that teachers became more reflective and aware of their teaching practices after they participated in a CPD program. de Vries, van de Grift, and Jansen (2012)[23] explored the link between teachers' beliefs about learning and teaching and their participation in CPD. They found that teachers with student-oriented beliefs wanted to participate more in CPD, while teachers with the subject-matter-oriented beliefs demonstrated no relationship with CPD.

While the importance of CPD is well documented in the literature and many studies have evaluated the impact of CPD on teachers and students in different subject areas, few studies have investigated the outcomes of CPD in K-12 engineering education. To fully evaluate the outcome of CPD in engineering on teachers, studies with the purpose of examining teachers' thinking, beliefs, perceptions, and teaching practices after they attend CPD need to be done.

C. Project Background

As part of a five-year longitudinal project funded by an National Science Foundation (NSF) grant from 2008 to 2012, the Institute for P-12 Engineering Research and Learning (INSPIRE) established at Purdue University offered a one-week introductory engineering TPD program each summer and a three-day follow-on TPD program the following year for grades two to four teachers in a large school district located in south-central United States**.** During their first one-week Summer Academy, teachers were exposed to engineering content by engaging in and reflecting on various engineering lessons. These lessons included developing working definitions of technology and engineering, an introduction to an engineering design process (EDP), two *Engineering is Elementary* (*EiE*) units[24], and one mathematical model development activity. Teachers had opportunities to engage with practicing engineers at the K-12 Engineering Education Dinner or Lunch and on an engineering facility tour. Teachers also practiced delivering an engineering lesson with elementary students invited to an engineering day. This first academy is described in detail by Yoon, Kong, Diefes-Dux, and Strobel[25] and an overall model of teacher adoption and expertise development is described in detail by Sun and Strobel[27].

In the following school year, teachers were requested to teach introductory lessons titled "What is Technology?" and "What is Engineering?" as well as an introductory engineering design challenge. After teaching introductory lessons, teachers engaged their students in an *EiE* unit composed of four individual lessons[24]. Each grade adopted a different *EiE* unit. During the school year, a local liaison was available to assist with any questions, provide in-class support, and support additional afterschool workshops as appropriate.

After their first year of integration of engineering in class, teachers were invited to attend a follow-on three-day Summer Academy. In the second TPD, teachers had time to debrief their implementation of the *EiE* units and their lessons, discuss concerns and lessons learned, and share with other teachers at the same grade level lesson materials prepared by themselves and student work on engineering activities. The second academy also included activities to bolster teachers' understanding of the field of engineering depicted in their grade level adopted *EiE* unit. The opportunities for exploring math and science concepts through these activities were also highlighted. Assessment strategies were discussed in association with each of these activities.

In small grade-level groups, teachers used internet resources to assemble content for a poster or handout about their particular *EiE* field of engineering focusing on the actions of that particular kind of engineer, the resources that engineer uses, and the people that interact with that engineer. Teachers also had a chance to again interact with practicing engineers attending the K-12 Engineering Education Lunch.

D. Purpose of the Study

Since the follow-on TPD is one kind of CPD, we examined changes in teachers' beliefs and attitudes to understand how CPD with engineering impacts elementary teachers differently from their first to their second participation. The research questions were as follows: (a) how did the most important things that teachers learned from the engineering TPD change from their first to second TPD experience?; (b) how did the meaningful aspects of the engineering TPD for teachers change from their first to second experience?; and (c) how did teachers' motivation to attend the engineering TPD change from their first to second experience?

II. Methods

A. Participants

Participants in this study are elementary teachers from a single large school district participating in a NSF funded research program. During the project period, from 2008 to 2012, teachers attended their first Summer Academy in one year and then returned to attend their second Summer Academy in the following year. While teachers from 2008 to 2010 were volunteers who applied in teams of four or more to ensure colleague support for engineering implementation post-academy, teachers who participated in the first Summer Academy in 2011 were required to attend the academy as part of their school's participation in the NSF project. All 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. Classroom teachers were assigned a classroom of between 14 to 23 students in the following school year.

From 2008 to 2011, 157 elementary teachers received engineering TPD for the first time. Among them, 145 teachers (92.4%) responded to a survey at the end of their first Summer Academy TPD program and 97 teachers (61.8% of 157) returned the following year after teaching engineering in their classrooms. Among the returnees, 92 teachers (94.8% of 97) answered the same survey at the end of their second Summer Academy. Table 1 shows the number of participants and respondents on the survey according to their year and times of attendance, and Table 2 shows demographic information for the 157 teachers.

Table 1. Number of Participants of TPD in Engineering by Year

First Summer Academy			Second Summer Academy		
Year	Participants	Respondents	Year	Participants	Respondents
2008	32	29	2009	23	23
2009	36	36	2010	24	20
2010	30	30	2011	23	23
2011	59	50	2012	27	26
Total	157	145	Total	97	92

Table 2. Characteristics of Teachers

	Category	*N*
Gender	Female	144
	Male	13
Ethnicity	Asian	0
	Black	9
	Hispanic	24
	White	115
	Multiracial	6
	Non-respondent	3
Grade	2	41
	3	40
	4	60
	5	2
	Facilitator	14
Total		157

B. Instrument

After each engineering TPD, INSPIRE administered a Summer Academy evaluation survey to teachers with the purpose of evaluating the impact of the engineering TPD program on teachers[25]. The survey consists of ten five-point Likert type questions (rated as very poor, poor, fair, good, and excellent or strongly agree, agree, neutral, disagree, and strongly disagree) and eight open-ended questions. For the purpose of this study, we only examined the open-ended questions from the survey as they pertained to our research questions. Among the eight open-ended questions, seven questions inquire about three important things teachers learned from the engineering TPD, meaningful aspects of the engineering TPD, how they were motivated by the TPD, teacher's plans for future classroom instruction, suggestions for future topics, and comments regarding the Summer Academy, including one question to clarify responses on the prior questions if needed. The last question requested comments about the instructors. This study utilized elementary teachers' responses on the first three open-ended questions to assess teachers' beliefs and attitudes about the engineering TPD.

C. Data Analysis

To investigate the impact of the engineering CPD on teachers, we examined changes in teachers' responses to the survey from their first to second time engineering TPD participation. To do this, we adopted the coding schemes developed by Yoon et al. (2013)[25] that employed an inductive analysis and creative synthesis strategy[28, 29]. In their study, 302 teachers in grades K-8, who participated in the engineering TPD offered by INSPIRE, responded to the same survey and the data were analyzed to examine teachers' satisfaction, beliefs, and attitudes toward their first time engineering TPD. The first survey responses from 157 participants of this study were a part of the data coded by Yoon et al. (2013)[25]. Teachers' responses on the survey from the follow-on engineering TPD participation were coded in the same manner based on the same coding schemes and the common themes emerged from the coding schemes. Please refer to the study by Yoon et al. (2013)[25] for the description of the themes that appeared in the responses to each open-ended question. Descriptive statistics were applied to compare teachers' first to second TPD experience: the frequency with which each theme appeared in teachers' raw responses was calculated.

III. Results and Discussion

A. Characteristics of Teacher Responses on the Open-ended Question

Table 3 shows teachers' response rates varied by the open-ended questions. On average, 92% (n = 133) and 85% (n = 79) of participants responded to the three open-ended questions in the first and second survey, respectively. The response rates on the questions in the second survey were lower than on the first survey. Similar to the study by Yoon et al. (2013)[25] about first time engineering experiences, teachers provided a wide range of responses on both the first and second survey, and a number of different themes appeared in each teacher's response. In some cases, teachers did not provide the requested number of responses to the open-ended questions. For example, when asked about the three most important things learned from the engineering TPD, teachers provided one to several things.

Table 3. Response Rates on the Two Open-ended Questions

Main Theme of the Question	First TPD (N = 145)				Second TPD (N = 92)			
	Valid Responses		Missing Responses		Valid Responses		Missing Responses	
	n	%	n	%	N	%	n	%
Important learning	138	95.2	7	4.8	85	92.4	7	7.6
Meaningful aspects	128	88.3	17	11.7	77	83.7	15	16.3
Motivation	133	91.7	12	8.3	74	80.4	18	19.6

B. Important Things that Teachers Learned from the Engineering TPD

For the teachers' responses concerning the most important things learned from the engineering TPD, fourteen themes emerged (Table 4). Figure 1 shows the frequency distribution of the fourteen themes following teachers' first and second engineering TPD. After their first engineering TPD, the top three most important things that teachers learned were the engineering design process (EDP) (72.5%) followed by knowledge about engineering and technology (47.1%) and new teaching strategies (31.9%). However, after their second engineering TPD, teachers equally mentioned learning about new teaching strategies and engineering activities (36.5% each) as the most important, followed by knowledge about engineering and technology (34.1%) and the engineering design process (32.9%). The big drop in the percentage on the EDP indicates that more teachers became familiar with the EDP during their first engineering TPD. The priority on learning about teaching strategies after the second TPD implies that teachers considered practical strategies of teaching engineering more important than learning content (e.g., the knowledge about engineering and technology and the EDP) after their first implementation of engineering in their classrooms. The frequency of the theme, "Making mistakes is OK," changed from 9.4 to 0%. This indicates that failure as part of an engineering design is not a new concept for teachers during their second TPD.

Table 4. Themes of the Important Things that Teachers Learned from the Engineering TPD[25]

Theme	Description
Engineering Design Process (EDP)	The EDP that encompasses iterative steps of ask, imagine, plan, create, test, and improve; and that is distinct from scientific inquiry but incorporates it as a step.
Engineering/ Technology Knowledge	Pedagogical 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, such as 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 in general, which are hands-on and practical to use in the classroom.
Model-Eliciting Activities (MEAs)	Use of MEA lessons to bring real world mathematics into the classroom.
Engineering is Elementary (*EiE*)	Instructional modeling 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 O.K.	It is O.K. to fail at an engineering task because students can learn from their mistakes.
Teacher Motivation	An increase of teachers' interest and confidence in learning and teaching engineering.
Anyone can do Engineering	Anyone can do and all ages can learn 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.

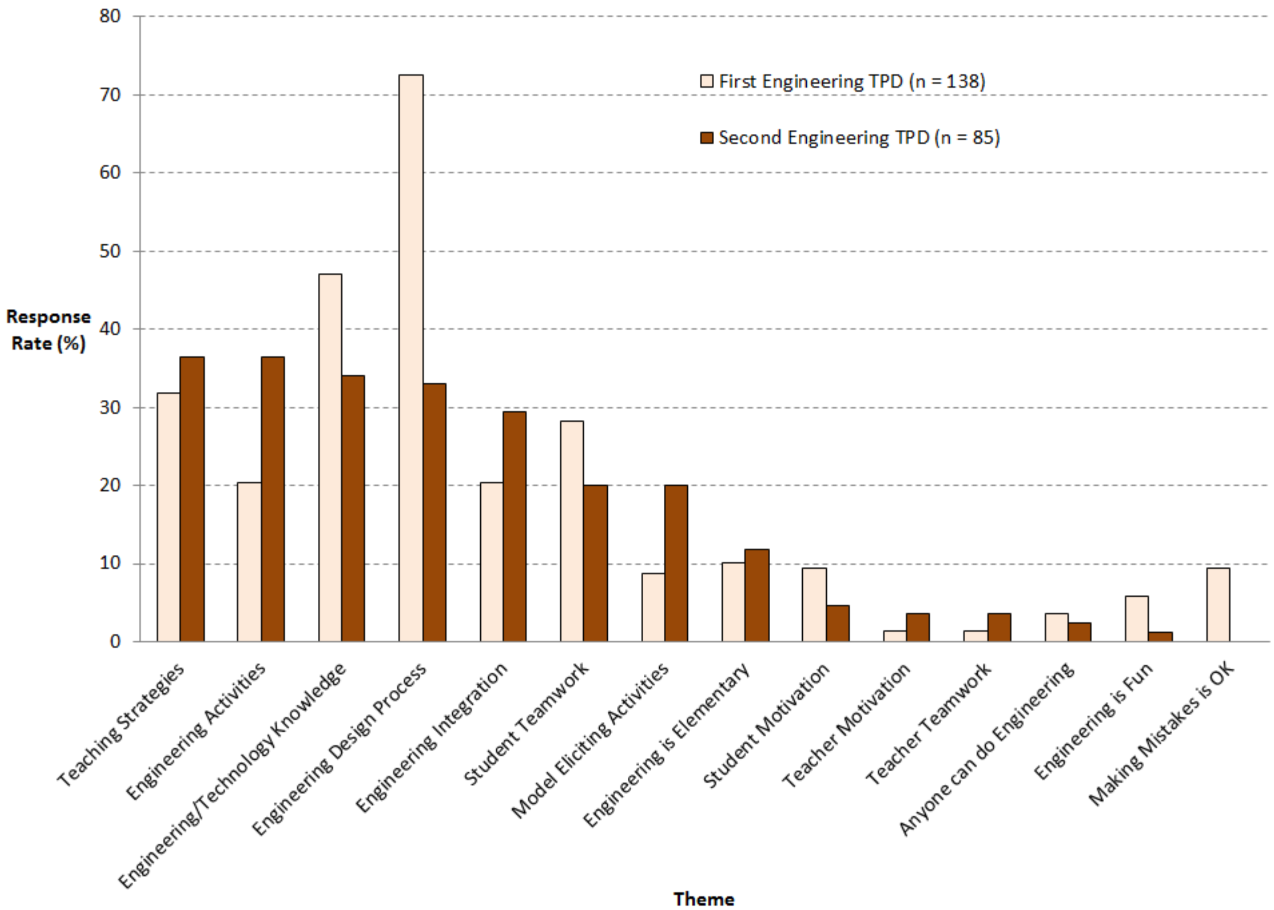

Figure 1. Most important things that teachers learned from the engineering TPD

C. Meaningful Aspects of the Engineering TPD for Teachers

While thirteen themes (Table 5) emerged from the teachers' responses on the meaningful aspects of the engineering TPD after their first engineering TPD, only eleven themes appeared in the teachers' responses after second engineering TPD (Figure 2). The two activities that were dropped (i.e. practicing with real students and field trip) were not included in the second engineering TPD. Similar to the first engineering TPD, teachers indicated that hands-on approaches were the most meaningful (50.8% in the first and 29.9% in the second survey) followed by application to classroom (28.1% in the first and 28.6% in the second survey). Interestingly, more teachers (26.6%) perceived that interaction with peers was meaningful in the second than the first engineering TPD (14.8%). During the CPD, teachers were able to interact with same and/or different grade-level teachers and discuss teaching strategies with teachers who had implemented their engineering lessons in different ways. This implies that after their implementation of engineering in class, more teachers valued collaboration with peers and working as a team to improve their engineering knowledge and teaching practice through CPD.

While after the first engineering TPD, teachers barely mentioned *EiE* (0.8%) and Model-Eliciting Activities (MEAs) (1.6%) were meaningful aspects of engineering TPD, more teachers mentioned that *EiE* (9.1%) and MEAs (5.2%) were meaningful after the second engineering TPD. As these activities are more learning and coordination intensive than the introductory engineering activities, teachers may have been overwhelmed by them during their first TPD. With a year of teaching experience behind the teachers, they may have been more ready to find meaning in these activities.

Table 5. Themes of the Meaningful Aspects of the Engineering TPD[25]

Theme	Description
Hands-on Approaches	Hands-on approaches help teachers learn engineering concepts better with more fun in the learning process.
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 learned from the engineering TPD can be easily applied to classroom instruction. Teachers can integrate engineering in their subject areas, such as mathematics and science, and adopt the materials and lesson plans from the Summer Academy to their curriculum.
Learning New Knowledge	Teachers valued learning new knowledge and ideas. They gained knowledge about what engineers do, what engineering/technology is, and how engineering/technology is related to real life.
Interaction with Peers	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 had a lot of opportunities to go through the EDP.
Practicing with Real Students	Teachers had an opportunity to teach engineering lessons designed by themselves to a small group of real 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 engineering TPD.
Meeting with Real Engineers	Teachers had a chance to interact with and learn from actual engineers.
Field Trip	Teachers had a field trip to university facilities or manufacturing plants, such as Driscoll, Doskocil, wetlands, and wind farms which 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.

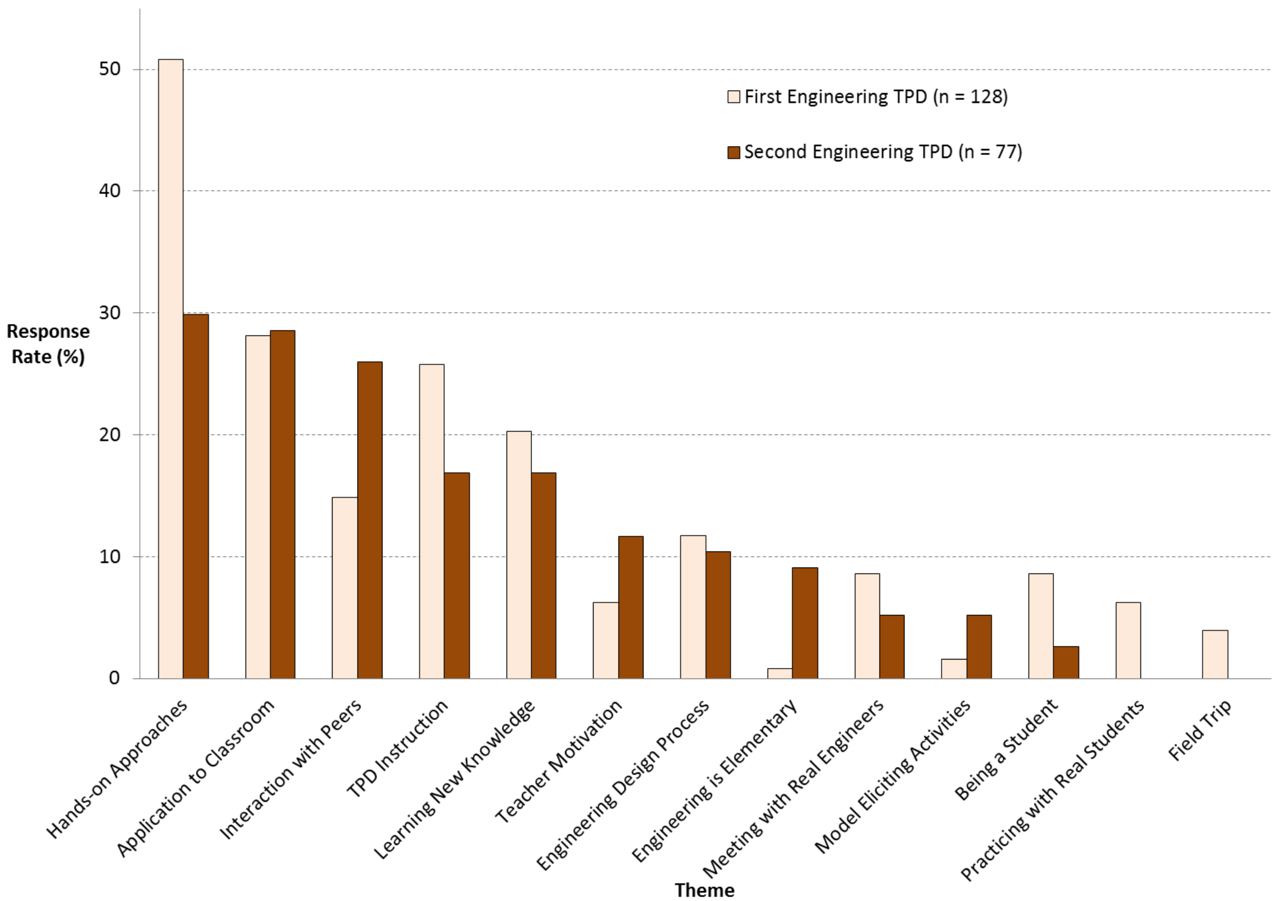

Figure 2. Meaningful aspects of the engineering TPD

D. Teacher Motivation

Corresponding to the teachers' responses on the motivating aspects of the Summer Academy, we identified the types of teacher motivation based on Ryan and Deci's (2000) definitions of intrinsic and extrinsic motivations. Table 6 shows description of the types of teacher motivation identified in teachers' responses. In the first TPD, more than half of the teachers (56.4%) demonstrated intrinsic motivation and a bit lower percentage of the teachers (51.9%) showed extrinsic motivation (Figure 3). Among those teachers, 21.8 % were both intrinsically and extrinsically motivated to participate in the engineering TPD. About 13% of teachers revealed that they were not motivated. Some of the reasons addressed in the responses were the length of the academy days (8 am – 5 pm) and the intensity and lack of flexibility in the program. Teachers' motivation during the second TPD was somewhat different from the first TPD; the majority of teachers (70.3%) felt that they were extrinsically motivated and about half of the teachers (48.6%) were intrinsically motivated. Among those teachers, 25.7% were both intrinsically and extrinsically motivated. Few teachers (2.7%) reported that they were not motivated.

Table 6. Types of Teacher Motivation[25]

Type	Description
Intrinsic motivation	Teachers are interested in engineering and have the desire to learn new knowledge through various forms of engineering learning processes, including engineering activities, the *EiE* units, MEAs, EDP, and a field trip.
Extrinsic motivation	Teachers are motivated by their oriented goals and/or external controls to learn from the engineering TPD. For example, teachers were encouraged to learn by peers or instructors; teachers wanted to learn to integrate engineering into their classroom because it will be beneficial for their students' learning.

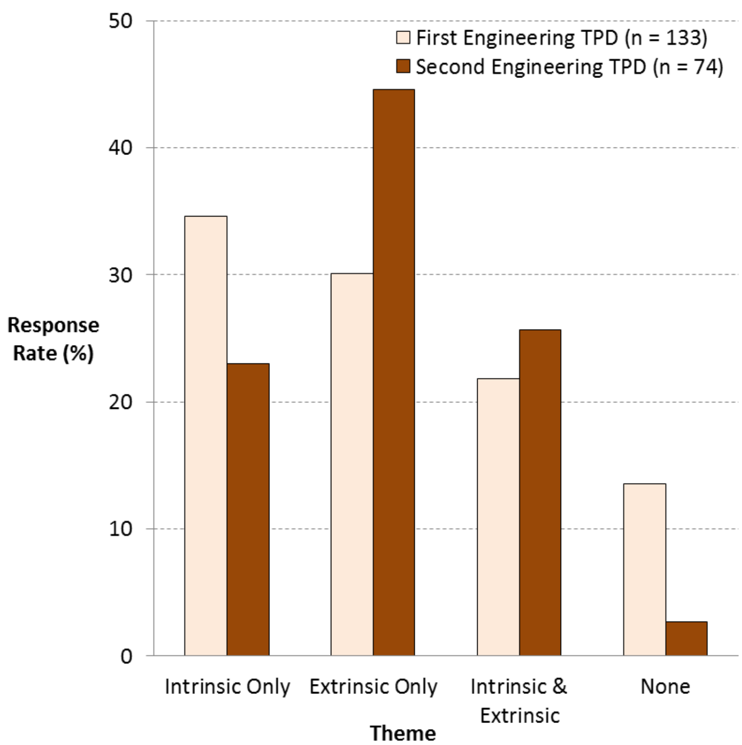

Figure 3. Types of teacher motivation during engineering TPD participation

IV. Conclusion

The results reveal apparent shifts in teachers' perceptions of engineering TPD between their first and second engineering TPD. While teachers perceived the most important learning from their first TPD related to new content knowledge, they considered practical aspects of teaching engineering and integrating engineering into their curriculum as more important after their second TPD. In addition, teachers valued peer interactions as a meaningful aspect of engineering TPD more in their second TPD than in their first TPD. Even though teachers in the second TPD were more extrinsically motivated, through the evaluation of CPD in this study, we could observe themes with weights different from the first TPD, indicating teachers' changes of beliefs and attitudes in positive ways as an effect of the CPD. This suggests the important role of CPD for teachers learning engineering through continuous follow-up and feedback.

Even though the literature provides research evidence about the importance of CPD in different subject areas, there has been little research concerning engineering CPD through empirical studies. This study has provided research evidence about the effects of engineering CPD. As the importance of CPD is evident in K-12 engineering education, we suggest consideration of CPD as a component when planning engineering TPD. While these teachers' engineering experience was limited to the program offered by INSPIRE, the results revealed the positive impacts of the engineering CPD on teachers from the teachers' point of view.

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