AC 2012-3127: EEE (ELEMENTARY ENGINEERING EDUCATION) ADOPTION AND EXPERTISE DEVELOPMENT MODEL: CONCEPTUALIZING, ASSESSING, AND TRACKING ELEMENTARY TEACHERS' EEE ADOPTION AND EEE EXPERTISE DEVELOPMENT

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EEE (Elementary Engineering Education) Adoption and Expertise Development Model: Conceptualizing, Assessing, and Tracking Elementary Teachers' EEE Adoption and EEE Expertise Development

Abstract

EEE (Elementary Engineering Education) is an educational innovation. The purpose of this study was to construct an evidence-based EEE adoption and expertise development model to describe the staged development process of EEE adoption and EEE expertise development and to capture individual elementary teachers' differences in this process. Informed by Rogers's diffusion of innovation model, the Concerned Based Adoption Model (CBAM), and Dreyfus skill acquisition model, the present study investigated elementary teachers' EEE adoption and EEE expertise development. Data of this study were collected through face-to-face interviews (in 2008, 2009, and 2010) and open-ended online surveys (in 2009 and 2010) conducted among 73 elementary teachers who received one-week EEE training from an EEE professional development program. An analytic induction approach was adopted in the data analyses. Based on the data analysis results of this study an EEE adoption and expertise development model was constructed. This model is two-dimensional including the EEE adoption dimension and the EEE expertise development dimension. There are four classificatory categories in the EEE adoption dimension and three classificatory categories in the EEE expertise development dimension. The staged descriptive characterizations falling under each of the classificatory categories delineate respectively what the four EEE adoption stages and the five EEE expertise development stages are like. The EEE adoption and expertise development model is helpful for EEE professional development providers to conceptualize, assess, and track their elementary teacher learners' synchronic differences and diachronic progression in EEE adoption and EEE expertise development, and thus to provide their learners with effective and in-time support.

Introduction

Integrating engineering into elementary classrooms is an innovative practice in the educational system that promotes technological literacy [17] and addresses the national concern about the shrinking Science, Technology, Engineering, and Mathematics (STEM) workforce [35]. However, engineering is not a discipline traditionally taught at the elementary level, and elementary teachers, in comparison to middle and high school teachers, are the least prepared for and least interested in teaching design, engineering, and technology (DET) [46]. There is an urgent need to prepare elementary teachers to teach engineering. This need is even more pressing given that a significantly large number of states (currently 41) contain explicit engineering components in their existing standards for science, math, vocational, and technological education [44], and that the new national science education framework contains for the first time engineering as explicit content [13]. An ever-increasing number of professional development programs, in the form of weekend workshops, summer institutes, or afterschool seminars, are currently offering in-service elementary teachers opportunities to increase their engineering content knowledge and to improve their engineering teaching skills [12, 15, 45].

Research has been conducted among elementary teachers who participated in professional development for elementary engineering education (EEE) [9, 10, 16, 29]. Findings from previous research revealed elementary teachers' misconceptions about engineering and technology [17]; their varying degrees of unfamiliarity with Design, Engineering and Technology (DET) [30]; and their perceived barriers to integrating engineering into elementary classrooms [31]. These misconceptions, unfamiliarity with DET, and perceived barriers contributed to elementary teachers' fear of teaching engineering and skepticism about integrating engineering into their classrooms [15]. Research on the effects of professional development yielded findings showing the positive impact of professional development on both elementary teachers' engineering content knowledge and their teaching practices [16, 29]. Despite these positive impacts, research revealed that, although professional development training paved way for the development of engineering pedagogical content knowledge (PCK), elementary teachers developed their PCK only slowly and gradually by experiencing how engineering teaching interacted with students and specific classroom and school contexts [45].

Individually, each of these research studies contributed from its particular perspective to our understanding about preparing elementary teachers for integrating engineering into elementary classrooms. Collectively, these studies made it clear that, given the innovative nature of EEE and elementary teachers' unpreparedness for engineering teaching, both elementary teachers' EEE adoption and EEE expertise development is a process over time. However, a comprehensive and systematic investigation of this process is missing in the research literature of elementary engineering education. The present study was intended to fill up the gap by investigating elementary teachers' EEE adoption and EEE expertise development and by constructing an EEE adoption and expertise development model.

Adopting theoretical perspectives furnished by (1) Rogers's [40] diffusion of innovation model, (2) the Concerns-Based Adoption Model (CBAM) [24, 26, 28], and (3) Dreyfus and Dreyfus's skill acquisition model [18, 19], the researchers of this study constructed an EEE adoption and expertise development model. The construction of the model was based on analyses of interview and survey data collected from 2nd–4th grade elementary teachers who participated in the elementary engineering education summer academies offered by INSPIRE (Institute for P-12 Engineering Research and Leaning at Purdue University).

Purpose and Research Questions

The purpose of this study was to construct an EEE adoption and expertise development model by investigating elementary teachers' adoption and implementation of engineering teaching. This model is intended to diachronically capture the developmental process of EEE adoption and EEE expertise development by elementary teachers, and to synchronically reflect individual differences and personal experiences during the process. The construction of this model was oriented by two research questions: 1) What are stages of EEE adoption and what are the descriptive characterizations associated with each stage? 2) What are the stages of EEE expertise development and what are the descriptive characterizations associated with each stage?

The EEE adoption and expertise development model construction in this study includes two diagnostic dimensions: the EEE adoption dimension and the EEE expertise development dimension. This model would provide professional development programs with a useful tool to construct individual profiles of where their elementary-teacher learners are in the developmental process of EEE adoption and EEE expertise development. These profiles would facilitate the identification and design of appropriate individualized support and teaching strategies to address elementary teachers' the needs of at different EEE adoption and expertise development stages.

Literature Review

Preparing Elementary Teachers for Teaching Engineering

Integrating engineering into elementary classrooms is innovative both in the sense that it requires modifications of existing teaching practice to include engineering [15] and that engineering is a discipline not taught or learned in the majority of schools in the United States [17]. This level of innovation entails great challenges in preparing elementary teachers because "the education of the vast majority of elementary school teachers (like the bulk of our population) did not include engineering or technology activities or information" [17] (p.1). The challenge of preparing elementary teachers for engineering teaching also lies in the fact that elementary teachers are generally disinterested in and intimidated by science content [8] and by DET [46]. Professional development, as a conventional and promising intervention to improve teacher quality is assuming the challenge of preparing elementary teachers to teach engineering.

Research-based data collected from elementary teachers participating in EEE professional development has laid bare elementary teachers' unpreparedness for teaching engineering. Specifically, elementary teachers have misconceptions and overly broad ideas about engineering and technology [17] and low self-reported familiarity with DET [30]. The concerns reported, such as meeting state standards, and barriers perceived, such as lack of time, resources, and administrative support [30, 45], reflect elementary teachers' hesitance to teach engineering. There is research-based evidence that professional development has increased elementary teachers' knowledge of the engineering design process [29]. It is also reported that professional development has improved elementary teachers' understanding of engineering and technology and has resulted in the integration of engineering concepts, examples, and design processes into the teaching of STEM subjects to elementary students [16].

Despite the above mentioned positive impact of professional development, previous research also revealed that the development of engineering PCK is a dynamic and evolving process involving interactions among students, the content of engineering, and classroom and school contexts [45]. In their engineering teaching practice, elementary teachers demonstrated individual differences in terms of comfort levels with teaching engineering and decisions about implementing engineering teaching: not only did the amount of engineering teaching implemented vary from teacher to teacher, elementary teachers' decisions about future implementation varied greatly. Some indicated that they would include more engineering into their classrooms, some expressed their inclination not to do so, and some were not sure about their decision for want of enough information and knowledge about engineering [10]. Individual elementary teachers, as revealed in another study, also differed in their perceptions of the importance of DET; these differences were reported to be related to previous full-time teaching experience in general and science teaching experience in particular [30].

Two overarching themes that can be identified from previous research are: 1) it will be a time-consuming process for elementary teachers to become prepared for teaching engineering; 2) there exist individual differences among elementary teachers in their perceptions and attitudes toward, and their capabilities in, teaching engineering. These two overarching themes highlight the importance for professional development programs to develop both a diachronic and a synchronic view of integrating engineering into elementary classrooms. While a diachronic view will enable professional development programs to understand strategically the changes elementary teachers have to go through to ensure the sustainable integration of elementary engineering, a synchronic view will allow professional development programs to make tactical planning aimed at helping individual elementary teachers make progress in adopting and implementing engineering teaching. Such a diachronic and a synchronic view would be made available through the EEE adoption and expertise development model constructed in this study.

Reviewing previous literature, the researchers of this study found Rogers's innovation diffusion theory, the CBAM, and the Dreyfus skill acquisition model relevant and enlightening for the construction of the EEE adoption and expertise development model. Therefore, these models are now discussed.

Diffusion of Innovation Models (Rogers's and CBAM)

Rogers's diffusion of innovations model. Rogers's diffusion of innovations model describes how, why, and at what rate innovations become diffused into widespread practice among members of a social system. Rogers [40] defines innovation as "an idea, practice, or object that is perceived as new by an individual or other unit of adoption" (p.12) and diffusion as "the process in which an innovation is communicated through certain channels over time among the members of a social system" (p.5).

In his diffusion of innovation model, Rogers [40] described the innovation-decision process as "an information-seeking and information-processing activity, where an individual is motivated to reduce uncertainty about the advantages and disadvantages of an innovation" (p. 172). According to Rogers [40], the innovation-decision process involves the following five stages:

The knowledge stage	An individual learns about the existence of an innovation and seeks information about it.
The persuasion stage	The individual develops a positive or negative attitude toward the innovation.
The decision stage	The individual makes a decision to adopt or reject the innovation.
The implementation stage	The individual puts the innovation into practice and reinvention of the

	innovation may take place.
The confirmation stage	The individual stays away from "conflicting messages about the innovation" (p. 189), seeking confirmatory information supporting his/her decision, but discontinuance may still occur

Rogers [40] pointed out that while the knowledge stage is more cognitive or knowing-centered, the persuasion stage is more affective or feeling-centered. And although an individual may reject the innovation early in the decision stage, he/she may also reverse an initially positive decision at the confirmation stage and discontinue the adoption of the innovation.

Rogers [40] recognized individual differences in innovativeness—"the degree to which an individual or other unit of adoption is relatively earlier in adopting new ideas than other members of a system" (p. 22). Based on their innovativeness, individuals can be classified into five adopter categories: *innovators* (2.5%), who are risk-takers willing to try new things and prepared for associated uncertainty; *early adopters* (13.5%), who are role models assuming leadership in furthering the adoption of the innovation; *early majority* (34%), who are individuals deliberately adopting an innovation before the other half of their peers; *late majority* (34%), who are suspicious of innovations and wait until it is perceived as safe to adopt them; and *laggards* (16%), who are more suspicious of innovations than the late majority and adopt innovations last.

Rogers's diffusion of innovation model provides us with both a diachronic view and a synchronic view of the process of innovation adoption and diffusion. Diachronically, the model allows us to visualize the stages an individual will go through in making decisions about innovation adoption. Synchronically, the model demonstrates the complexity at a given time in the diffusion process in terms of individual differences in perceptions, attitudes, and decisions about an innovation, and in terms of the influences of external factors (e.g. innovation characteristics, communication channels, and innovation decision types) on individual decisions and on overall adoption rate. Based on a wide application of this model in a variety of academic disciplines (e.g., geography, political science, anthropology, marketing, and public health), Rogers [41] argued that "diffusion was a general process, not bound by the type of innovations studied, by who the adopters were, or by place or culture" (p. 16) and concluded: "the diffusion process displays consistent patterns and regularities, across a range of conditions, innovations, and cultures" (p. 19). This "generalizability of the diffusion model" (p. 18), as discussed by Rogers, lends great support to the researchers' belief that Rogers's innovation diffusion model will help shed light on the investigation of the adoption of elementary engineering education by elementary teachers.

The Concern-Based Adoption Model (CBAM). Although Rogers's diffusion of innovation model provides a solid theoretical framework for diachronic and synchronic exploration of EEE adoption in this study, the diffusion and adoption of educational innovations by school teachers have their own idiosyncratic features associated with the teaching profession and school contexts. These idiosyncratic features are hard to capture with a general diffusion model alone. One idiosyncratic feature of teaching profession is related to the fact that teachers, unlike many other types of innovation adopters, "work for organizations," and organizations are involved in innovation-decisions and have control over teacher innovativeness [39] (p. 63). Moreover, teaching is a situated practice involving knowledge of content, pedagogy, and learners [42], and teachers work in education accountability systems where they are held accountable for their teaching performance and teaching outcomes, both of which contribute to the uniqueness of the diffusion and adoption of educational innovations. To better understand elementary teachers' subjective experiences in adopting and implementing EEE, the researchers used Rogers's diffusion of innovation model to provide guidance at the macro-level and added the Concern-Based Adoption Model (CBAM) into the theoretical framework of this study as a source of guidance at the micro-level.

Unlike Rogers, who argued for and was committed to the development of a general diffusion model across various disciplines [41], the CBAM team rooted the development of CBAM in college and school contexts and specifically focused on describing and explaining the process of attitudinal and behavioral changes experienced by teachers when adopting educational innovations and the effects of interventions from external change agents on adoption. CBAM has been widely adopted by educational researchers as a useful framework for understanding the experiences of teachers adopting and implementing educational changes and the facilitation of such changes.

CBAM [24] consists of three diagnostic frameworks for conceptualizing and measuring individual teachers' engagement with and implementation of proposed educational innovations: *stages of concern*, *levels of use*, and *innovation configuration*. This research study only utilizes the first two (1) *stages of concern*, and (2) *levels of use* due to the fact that our model is not based on classroom observation—a requirement for the third framework.

The *stages of concern* framework [24] identifies the following seven developmental stages of concern that teachers go through in adopting and implementing an educational innovation:

Stage	**Concern**
Stage 0: Awareness	Little interest in or concern with the innovation.
Stage 1: Informational	Interest in learning more about the innovation (without worry about self in relation to the innovation).
Stage 2: Personal	Uncertainty about the demands of the innovation, personal ability to implement it, and personal costs of getting involved.
Stage 3: Management	Focus on implementation issues of efficiency, organization, management, scheduling, and time demands related to the innovation.
Stage 4: Consequence	Focus on the impact of the innovation on students and the possibility of modifying the innovation to improve learning outcomes.
Stage 5: Collaboration	Interest in coordinating and cooperating with other teachers regarding the innovation.
Stage 6: Refocusing	Focus on exploring more benefits of the innovation, including the possibility of making changes in it or replacing it with an alternative innovation.

While the stages of concern framework presents the affective dimension of change experienced by teachers in the adoption and implementation process of an educational innovation, the *levels of use* framework [24] focuses on teachers' behavioral patterns as they prepare to use, begin to use, and gain experience in implementing an educational innovation. An individual teacher's behavior in the change process can be identified as belonging to one of the following seven levels (which include both non-users and users of the new program), with seven corresponding decision points at which a positive decision signals a subsequent increase in the teacher's commitment to and utilization of the innovation [24]:

Level of Use	**Description of levels and decision points**
Nonuser	
Level 0: Nonuse/Unaware	The teacher has no knowledge of the new program and no involvement in it, and is doing nothing to get involved.
Level 1: Orientation	The teacher has acquired or is acquiring information about the new program and is exploring its value orientation. ***Decision point A:*** *The teacher decides to take action to seek more detailed information about the new program.*
Level 2: Preparation	The teacher is preparing for first use of the innovation. ***Decision point B:*** *The teacher decides to use the innovation.*
	User
Level 3: Mechanical Use	The teacher begins to implement the innovation but is struggling with following the stepwise procedures required of the innovation implementation with little time for reflection. ***Decision point C:*** *Decisions about changes (if any) and use (e.g., making the innovation more manageable and easy to implement) are teacher-centered rather than student-centered.*
Level 4a: Routine Use	The teacher establishes a routine pattern of innovation use. ***Decision point D1:*** *The teacher makes a few attempts to improve the innovation practice or its consequences.*
Level 4b: Refinement	The teacher assesses the impact of the innovation on his/her students and initiates corresponding changes in innovation use to improve student outcomes. ***Decision point D2:*** *The teacher makes changes in the use of the innovation to improve student outcomes.*
Level 5: Integration	The teacher collaborates with other teachers to extend the impact of the innovation beyond his/her individual classroom. ***Decision point E:*** *The teacher makes changes based on input of peer teachers and in coordination with what they are doing.*
Level 6: Renewal	The teacher re-evaluates the quality of innovation implementation and seeks to make major modifications in the innovation and/or explore alternative innovations. ***Decision point F:*** *The teacher begins making major modifications to the innovation and/or exploring alternative, better innovations.*

The *stages of concern* framework and the *levels of use* framework each present a possible, not a necessary, developmental progression of teacher attitudinal and behavioral changes toward an educational innovation [1]. This means that not all teachers go beyond the early stages of concern to the later stages of consequence, collaboration, and refocusing, and some teachers find an innovation acceptable but have difficulty implementing it and sustaining its implementation. Similarly, individual teachers' progression along the *levels-of-use* continuum may not necessarily include each level [25]. Some teachers may choose not to implement the innovation after the *orientation level*, some may abandon the implementation at the *mechanical level of use*, or they may stay in the *routine level of use* without going further.

CBAM makes it explicit that the adoption and implementation of educational innovations is a process that is developmental in nature and a highly personal experience for each teacher, involving developmental growth in feeling and skills [1, 27]. The CBAM framework furnished researchers of this study with new lenses to approach the adoption and implementation of EEE by elementary teachers. The CBAM *stages of concern* and *levels of use* frameworks allow the researchers to use teacher concerns as an "indicator" to understand, evaluate, and chart individual elementary teachers' personal experience and progress in the EEE adoption and implementation process. Equally important is that the CBAM concept of IC offers the researchers useful insights into the importance of viewing the implementation of EEE as a series of operational practices shaped by specific contexts and individual dispositions.

Dreyfus Skill Acquisition Model

Studies of change in adopting and implementing an innovation should focus on individuals—their change first in attitudes and then in knowledge and skills [11]. Both Rogers' diffusion of innovation model and CBAM center around individual experiences and differences to capture how innovation adopters' attitudes, perceptions, and adoption and implementation decisions evolve over the course of the change process. However, the development of skills or expertise in using innovations is not specifically addressed in either of these two theoretical models. This absence, as the researchers of this study see it, may be attributed largely to the fact that it would be hard to generalize the development of innovation-use skills or expertise given the diversity and multitude of innovations in general or even of innovations in educational settings more particularly. Focusing specifically on only one educational innovation—integrating engineering into elementary classrooms, the researchers saw both the necessity and the possibility of developing an expertise development model capturing elementary teachers' development of EEE expertise. And the researchers found the Dreyfus skill acquisition model [18, 19] instrumental in guiding their construction of the EEE expertise development model.

Based on studies of chess players, air force pilots, and army tank drivers, Stuart Dreyfus and Hubert Dreyfus developed the Dreyfus skill acquisition, consisting of five stages of skill acquisition [18]: stage 1, *novice*; stage 2, *advanced beginner*; stage 3, *competence*; stage 4, *proficiency*; and stage 5, *expert*. In stage 1, a novice learner has no previous experience in the task he/she is learning, and is therefore dependent on context-free rules and invariably follows these rules without heeding specific external circumstances. After experiencing a sufficient number of examples of the task, a novice learner becomes an advanced beginner and begins to develop context-specific knowledge about the task. But according to Dreyfus [18], "Still, at this stage, learning can be carried on in a detached, analytic frame of mind, as the student follows instructions and is given examples" (p. 177).

At the stage of "competence," a learner may become overwhelmed by the increasing number of relevant elements and procedures that need to be recognized and followed. Consequently, on the one hand "performance becomes nerve-wracking and exhausting" and the learner may wonder "how anybody ever masters the skill" (p. 178). On the other hand, the learner is learning to deal with the overload by developing a plan or choosing a perspective that helps him/her to focus on a few of the vast body of possible relevant elements and aspects, and as a result, "understanding and decision making becomes easier" (p. 178). Characteristic of this stage is that the detached stance of the novice and the advanced beginner (competent stage) is replaced by the learner's emotional involvement in the chosen actions and in responsibility for the outcomes, successful or unsuccessful, of his/her choices.

A learner enters the stage of "proficiency" as he/she assimilates experience into the ability to discriminate important aspects from unimportant aspects among a variety of situations and the ability to act accordingly. But a proficient learner, lacking "enough experience with the outcomes of the wide variety of possible responses to each of the situations" (p.179), still has to consciously make decisions about the best course of action in a specific situation. With enough experience in a wide variety of situations, a proficient leaner gradually develops the ability to make more subtle and refined discriminations and enters the stage of "expertise." In this stage, the individual possesses the expertise that allows him/her to make intuitive decisions about the best action without calculating or comparing alternatives.

The Dreyfus skill acquisition model is developmental, based on situated performance and experiential learning [2]. It has been adopted by researchers to study expertise development in areas like nursing [2, 3] and teaching [5, 6, 14]. Berliner's studies [4, 5, 6] in teaching-expertise development were based on comparative analyses of the teaching performance of both expert and novice teachers. Berliner [5, 6] pointed out that teachers at various levels of experience and expertise differed in their ability to interpret classroom phenomena, discern the importance of events, use routines, predict classroom phenomena, judge typical and atypical events, and evaluate teaching performance. Empirical data in Berliner's studies revealed that "developmental differences are real" among teachers in teaching-expertise development and that these differences "have important implications for the policies we adopt for the education of teachers" [5] (p.33). Findings from Berliner's studies help justify the appropriateness of adopting the Dreyfus skill acquisition model as a theoretical framework for studying teaching expertise. In the context of elementary engineering education, elementary teachers more often need to develop their engineering teaching expertise from scratch. The novice-to-expertise continuum of the Dreyfus skill acquisition model provided the researchers with insightful guidance in understanding elementary teachers' engineering teaching expertise development.

Theoretical and Methodological Framework

The researchers of this study used Rogers's innovation diffusion model, the CBAM, and Dreyfus's skill acquisition model as the theoretical frameworks for the construction of the EEE adoption and expertise development model. Four presumptions about the EEE adoption and expertise development model were derived from these theoretical frameworks: 1) The adoption and implementation of EEE as an innovation is a process; 2) During the process, there exist different EEE adoption stages along a continuum, with identifiable traits and qualities associated with each stage; 3) During the process, there exist different EEE expertise development stages along a continuum, with identifiable traits and qualities associated with each stage; 4) Synchronically, individual elementary teachers stand in different EEE adoption and EEE expertise development stages, and diachronically, individual elementary teachers progress along the stages. To construct the EEE adoption and expertise development model, researchers of this study adopted an analytic induction approach which is first deductive and then inductive (Patton, 2002). Specifically, the researchers began examining the data of the study in terms of the theory-derived presumptions and then looked at the data afresh for "undiscovered patters and emergent understandings" [36] (p.454).

The four theory-derived presumptions served as guidance for the construction of a prototype model as well as being sensitizing concepts [7] which provided the researchers "a general sense of reference" and "directions along which to look" (p. 148) when examining the data in the deductive phase to verify the assumptions and refine the prototype model. In the inductive phase, the researchers identified themes and patterns through inductive analysis and put these themes and patterns into categories. The researchers developed terms to describe these inductively generated categories [36], and then used them to create analyst-constructed typologies [32, 36]. The typologies are explanatory in nature, assuming both the classificatory and descriptive roles [20]. The classificatory role functions to divide elementary teachers' EEE adoption and expertise development into "parts along a continuum" [36] (p.457), while the descriptive role functions to provide a description of these parts based on an inductive analysis of the patterns that emerged from the data.

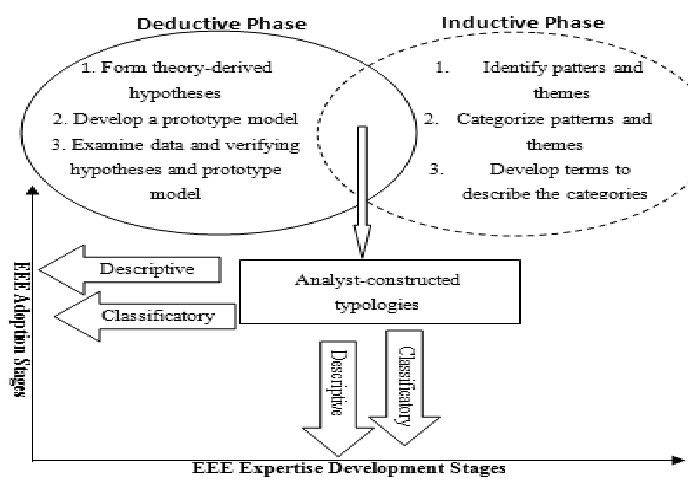

Figure 1: Theoretical and Methodological Framework

Research Design

Data for this study were collected from the participating teachers of INSPIRE Arlington local summer academies using face-to-face interviews and online open-ended surveys. Transcriptions of the interviews were analyzed together with the answers to the online open-ended survey questions for the purpose of constructing the EEE Adoption and Expertise Development Model.

INSPIRE Arlington Local summer academies (Project Context)

INSPIRE was established in 2006 and is dedicated to the integration of engineering into K–12 education and the improvement of engineering education in K–12 school settings. The mission of INSPIRE is to "study engineering thought and learning at the P-12 level and to inspire diverse students to pursue engineering and science for the benefit of humanity and the advancement of society." INSPIRE provides elementary teachers with professional development in engineering education through national summer academies at the university where INSPIRE is located, local summer academies at the locations of partnering schools, and online professional development programs. The summer academy is a week-long, face-to-face workshop for elementary teachers interested in integrating engineering into their classrooms. Since 2006, INSPIRE has organized four national summer academies for over 120 elementary teachers from 16 states, and local summer academies in Arlington, Texas under an NSF DR K–12 grant.

Participants

The INSPIRE Arlington summer academies were held among elementary teachers from 13 elementary schools in a school district in Arlington, Texas. The project called for volunteer and target-recruited teachers working in diverse classrooms and schools across the participating school district. The 73 participating teachers interviewed were recruited by a mix of convenience sampling and purposeful sampling. These teachers taught grades 2 through 4, mostly in self-contained classrooms. A total number of 101 interviews were conducted among them, including 75 individual interviews and 26 group interviews. The demographic information of these teachers is given in *Figure 3*.

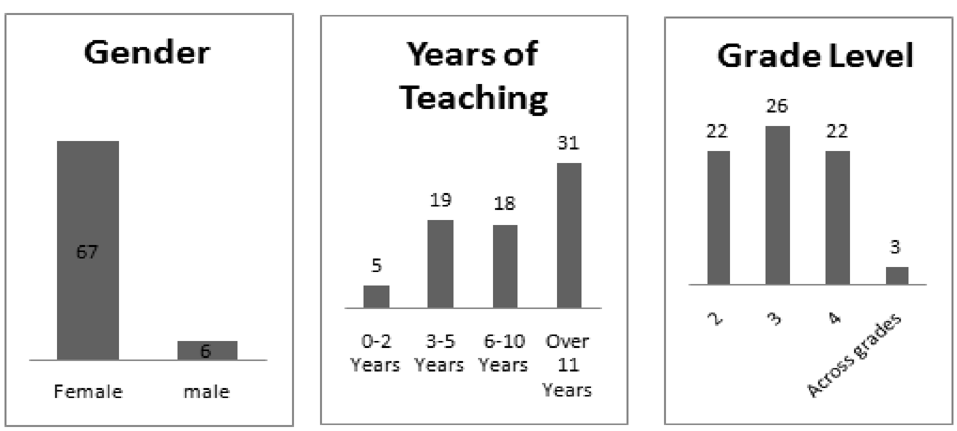

Figure 2. Demographic information of teacher participants

Approximately half of the elementary teachers interviewed hold B.A. degree in fields such as

English, Early Childhood Education, Interdisciplinary Studies, and Government (see *Figure 4*). Twenty-eight out of 29 B.S. degrees held by the teachers are in non-STEM fields like Education, Advertising, and Photography. Nine teachers have Masters Degrees, three of which are in STEM-related fields. One of the teachers holds an Ed.D. in Curriculum and Instruction with a focus on math education.

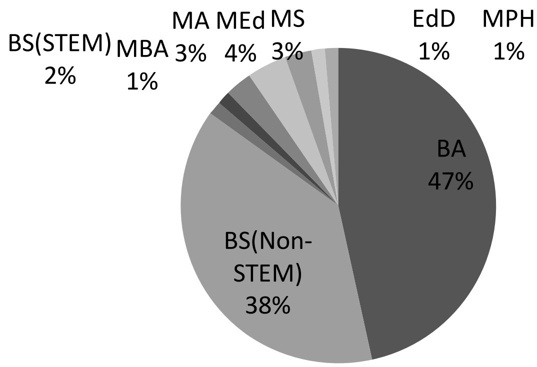

Figure 3. Educational background of teacher participants

Two open-ended online surveys were conducted among the participating elementary teachers of the INSPIRE Arlington local summer academy. Sixty-eight elementary teachers responded to the survey, answering questions about their beliefs, motivations, concerns, and plans for incorporating engineering into their classrooms.

Data Collection

The face-to-face group interviews were conducted in June 2008, December 2008, and December 2009. In the group interviews, the elementary teachers were selected into groups of three to six based on their individual schedules and each group was interviewed by a member of the research team. Fifty-eight teachers were included in group interviews. Two rounds of individual interviews with 62 different elementary teachers took place in May 2009 and May 2010. All interviews were audio-taped and then transcribed. The two open-ended surveys were posted online in July 2009 and July 2010 and survey data were collected in September 2009 and September 2010 respectively. The data were sorted in an Excel file after collection and prepared for analysis.

Data Analysis

Three sets of data sources were included in this study: the individual interviews, the group interviews, and the answers to the online open-ended survey questions. For the first round of data analysis, the individual interviews were arranged into 4 groups according to the elementary teachers' years of teaching experience: the "0-2 years" group, the"3-5 years" group, the "6-10 years" group, and the "over 11 years" group. There were in total eight groups of individual interviews and two individual interviews were randomly selected from each of the eight groups. The 16 individual interviews were put together with 12 randomly selected group interviews (four from June 2008, four from December 2008, and four from December 2009) and the answers to the open-ended survey questions.

The researchers of this study read through these interviews carefully first for verification of the four presumptions and for the development of the prototype model of EEE adoption and expertise development. Then the researchers read through these data for the second time on a line-by-line basis, independently taking analytical memos of the themes and patterns either supporting or challenging the stages of EEE adoption and expertise development in the prototype model. The prototype model was modified and refined based on the comparisons and discussions of the analytical memos to ensure reliability and validity. The modified and refined model was then tested against new randomly selected interview data. Each time, five new interviews were selected and the researchers read though the data, independently taking analytical memos of newly emerged themes and patterns. Whenever finishing five newly selected interviews, the researchers joined together to compare and discus their analytical memos and made revisions of the model to reflect the newly emerged themes and patterns. The testing continued until no new themes and patterns emerged, agreement was reached, and the themes and patterns became saturated. All themes and patterns thus yielded were collected and compared to be classified into different stages and different categories in each of the stages. Analyzing the themes and patterns at each stage, the researchers developed terms to name each of the stages.

As the final check for the reliability and validity of the EEE adoption and expertise development model, three rounds of model check were conducted. In each round, two individual interviews were randomly selected and were read by two of the researchers, and the two researchers rated the two interviewed teachers into specific stages and specific categories of the stages while taking notes of evidence explaining their ratings. At the end of each round, the two researchers compared their ratings and discussed the differences in their ratings with reference to their notes. Researchers modified or clarified particular themes and patterns in the model. In the first round model check, the two researchers reached 57% agreement (4 categories out of 7), in the second round, the researchers reached 71% agreement (5 categories out of 7), and in the last round, the researchers reached 100% agreement (7 categories out of 7).

For the second round of data analysis, the researchers analyzed the individual interviews of those elementary teachers who were interviewed both in May 2009 and May 2010. There were in total 13 elementary teachers who were interviewed individually in both these two years, but only 12 teachers' interviews (24 interviews in total) were analyzed, because one elementary teacher acted as engineering teaching facilitator for the other 12 teachers and did not actually implement engineering in her classroom. Each of the researchers first independently read the 24 individual interviews and rated the 12 teachers' 2009 and 2010 standings in the EEE adoption and expertise development stages. While reading and doing the rating, the researchers took notes of evidence supporting their ratings and of the differences the teachers demonstrated between the two years. Then the researchers met to compare their ratings and resolve the differences by referring to their notes and the original interviews. A final list of the 12 teachers' 2009 and 2010 standings in the EEE adoption and expertise development stages were agreed upon by the researchers and this list showed the elementary teachers' progress over the two years of 2009 and 2010.

Findings and Discussion

Data analysis results of this study verified the four theory-derived presumptions. The final EEE adoption and expertise development model includes the dimension of EEE adoption and the dimension of EEE expertise development. We present the two dimensions in this section, specifying the classificatory categories included in each dimension and expatiating upon the descriptive characterizations of each classificatory category that distinguish the elementary teachers into different EEE adoption and EEE expertise development stages.

The EEE Adoption Dimension

Findings from this study indicated that one important characteristic of EEE adoption among the elementary teachers was synchronic differences, that is, synchronically, individual elementary teachers stood at different EEE adoption stages. Four themes emerged from the data analyses as factors that influenced elementary teachers' EEE adoption process: 1) perception of practicality and sustainability of EEE; 2) comfort level with engineering teaching; 3) perception of EEE benefits to elementary students; 4) degree of engineering integration. These four themes are the overarching classificatory categories, and the specific data-derived patterns falling under these four categories serve as descriptive characterizations that classify the elementary teachers into the four stages of EEE adoption: *attempter, adopter, ameliorator, and advocator*. The following table (*Table 1*) lists the four different EEE adoption stages and the descriptive characterizations of each stage.

Stages of EEE Adoption	Perception of Practicality and Sustainability of EEE		Comfort Level with Engineering Teaching		Perceptions of EEE benefits to elementary Students		Degree of engineering integration	
Stage I: Attempter	I-1: Overwhelmed by the perceived barriers to EEE and regarding EEE as impractical and unsustainable because of the perceived barriers	**Teacher-centered**	I-2: Feeling unconfident in one's engineering knowledge and uncomfortable with teaching engineering	**Unconfident, Uncomfortable**	I-3: An "engineering as anti-illiteracy" view about EEE benefits	**Simple, Limited**	I-4: Treating engineering teaching as isolated and as an add-on and teaching engineering discontinuously and sporadically	**Passive, Isolated, Sporadic**
Stage II: Adopter	II-1: Fully aware of the perceived barriers of EEE but viewing engineering as practical in elementary classrooms		II-2: Feeling somewhat confident in one's engineering knowledge and comfortable with teaching engineering		II-3: An "engineering as an extension" view about EEE benefits		II-4: Making attempts of integrating engineering teaching and learning into the teaching and learning of other disciplines with shortened time gaps between engineering teaching	
Stage III: Ameliorator	III-1: Proving EEE practicality though engineering teaching practice and becoming conscious of how to make EEE sustainable		III-2: Feeling confident in one's engineering knowledge and comfortable with teaching engineering		III-3: An "engineering as application and enrichment" view about EEE benefits		III-4: Practicing engineering teaching on regular basis and making widespread connections between engineering and other disciplines	
Stage IV: Advocator	IV-1: Convinced of EEE practicality based on successful personal experience and making efforts to make EEE sustainable	**Student-centered**	IV-2: Feeling fully confident in one's engineering knowledge and fully comfortable with teaching engineering	**Confident, Comfortable**	IV-3: An "engineering as empowerment" view about EEE benefits	**Comprehensive, Broad**	IV-4: Making engineering teaching an integral part of teaching practice and making systematic connections between engineering and other disciplines	**Active, Connected, Regular**

Table 1: Stages of EEE Adoption

Attempter. Typical of the elementary teachers in the *attempter* stage was that their perception of the practicality and sustainability of EEE was teacher-oriented rather than student-oriented. Barriers related to time issues, administrative support, and accountability issues like high-stakes tests drew most of their attention. These elementary teachers became rather overwhelmed by these barriers and regarded EEE as impractical and unsustainable. For some *attempters*, these barriers all came back to time, but when asked what they planned to do to move past the issue of time, the answer was always "I don't know" or "It's really a tough question."

For the elementary teachers in the *attempter* stage, engineering teaching was treated as an isolated activity or an add-on to what they had been teaching. With the notion that engineering teaching and learning was isolated from the teaching and learning of other disciplines, elementary teachers at the *attempter* stage demonstrated limited degrees of integrating engineering with the rest of the curriculum. Treating engineering as an add-on, these elementary teachers taught it only when they could squeeze time out of their required teaching tasks for engineering. There were also some *attempters* who postponed engineering teaching until the end of the year and had to rush through it. The adoption of EEE by the elementary teachers at this stage is characterized by passivity in integrating engineering, sporadicity, and discontinuity.

Elementary teachers at the *attempter* stage felt unprepared for engineering teaching or not comfortable with it. They demonstrated low levels of understanding of the benefits of EEE to elementary students. For these elementary teachers, engineering learning for elementary students was "having fun" or allowing them to know "what the word 'engineering' means and be familiar with some terms." These understandings were based on an "engineering-as-anti-illiteracy" view towards EEE. With such limited understandings of the benefits for elementary students of learning engineering, it was not surprising to see a limited degree of engineering integration at the attempter stage.

Adopter. Like those in the *attempter* stage, the elementary teachers in the *adopter* stage were fully aware of numerous barriers to EEE. But the *adopters* saw EEE as practical despite these barriers and they became conscious of their students in their perception of EEE practicality. In addition, the *adopters* began to realize that the practicality of EEE lies in the fact that engineering is not just something to be done for its own sake and in isolation, but rather something "can be built in a lot through the classroom." Another change that came to the elementary teachers at the *adopter* stage is that they devoted more time to EEE. Not only did the *adopters* allow more time for engineering teaching and learning and cover more engineering content, they allowed their students to go back and forth with various engineering concepts to enable a deeper understanding of these concepts. According to the *adopters*, there was no need to rush through the engineering content or activities because they felt quite comfortable with teaching engineering to their students and allowing their students to pose questions and to argue with each other in engineering class.

For the elementary teachers at the *adopter* stage, the benefits of learning engineering lay in its serving as "a review or an extension" of what their students had learned, such as helping them review a lot of math or supporting some of their existing skills or vocabulary. The "engineering-as-an-extension" view enabled the elementary teachers at the *adopter* stage to find some opportunities to link engineering with the teaching and learning of other disciplines. Although such connections were limited in terms of depth and width, certain amount of initiative, absent among the *attempters*, could be indentified among those at the *adopter* stage in finding ways to integrate engineering into their classrooms. Being able to link engineering with those disciplines they had "been teaching for many years" also made these elementary teachers feel more comfortable with and confident in teaching engineering.

Ameliorator. Compared with the elementary teachers in the *adopter* stage, those in the *ameliorator* stage began to practice engineering teaching on a regular basis. Some of them chose to do engineering on every Friday, and named the day "Engineering Friday" or "Freaky Friday." The main reason why the elementary teachers at the *ameliorator* stage practiced engineering teaching on a regular basis is their considerably broadened views about the benefits of EEE to their elementary students. For these elementary teachers, learning engineering "opened the students' minds to other things," enhanced their hands-on skills and abilities that would "help in all areas," and enabled them to see that engineering was "not something that they have learned but something people use in the real world." The comment made by one of the *ameliorators* that "the benefits outweigh the time it takes" gives a good summary of the reason why *ameliorators* made engineering teaching a regular practice.

At the *ameliorator* stage, the elementary teachers went beyond the "engineering-as-an-extension" view to embrace engineering learning as "an application and an enrichment." As indicated by the interview data, this "engineering as application and enrichment" view drove the *ameliorators* to learn more about engineering and to expand more on their engineering teaching. They explored more resources to help their students "see that engineering goes into many, many, many different areas and components and parts of the world" and they intertwined engineering more closely with the teaching and learning of other disciplines. Being more active and taking more initiative in integrating engineering into elementary classrooms became a landmark separating the *ameliorators* from those in the two previous EEE adoption stages.

Another important characteristic of the elementary teachers in the *ameliorator* stage is that they began to think about how to make EEE sustainable. This characteristic reflects that the elementary teachers in the *ameliorator* stage have moved out of the confinement of their immediate classroom environments to think about how to ameliorate the larger educational environment to make EEE more widely accepted and sustainable. It is not difficult to see that those amelioratory ideas about making EEE sustainable these elementary teachers talked about in the interviews were born out of their regular engineering teaching practice, their broadened views about the benefits of EEE to elementary students, and the confidence in teaching engineering they had gained through engineering teaching practice.

Advocator. Elementary teachers in the *advocator* stage expressed their intention of becoming an advocator of EEE. But this is only one identifying characteristic of the *advocator* stage. Another important characteristic is that the elementary teachers at the *advocator* stage became aware of the persuasive power of their successful practice-based engineering teaching experience in winning sustainable integration of engineering into elementary classrooms. Compared with those in the *ameliorator* stage, the elementary teachers in the advocator stage, rather than having only general ideas, came up with specific plans of how to win support for EEE and how to make it sustainable. Although several elementary teachers had their specific plans, interview data from the study showed that only one of them actually put the plans into practice. What this elementary teacher did was take pictures of her students doing engineering activities and make them first image to be seen on the school webpage.

The elementary teachers at the *advocator* stage had practice-based success in engineering teaching and they wanted to make their success known to others to ensure sustainable integration of engineering into elementary classrooms. This was the evidence of their conviction of the practicality of EEE. For these *advocators*, engineering permeated their teaching and learning of other disciplines and became an integral part of their teaching practice. The researchers of this study fully realized the powerful effects of advocating EEE by using personal teaching success stories and evidence-based demonstrations of EEE benefits to elementary students. So, despite the fact that only one of the elementary teachers had carried out EEE advocacy plan by the time of second round interviews, the researchers included carrying out EEE advocacy plans as an indispensible characteristic of the *advocator* stage.

The *advocators* were able to understand the benefits of EEE to elementary students from broader and more comprehensive perspectives than teachers at earlier stages. They viewed EEE not only as something about making real-life connections, but as something that can promote elementary students' development as real-life problem solvers, and as something that would enable elementary students to see the career potential in engineering-related fields. There were also some advocators who viewed EEE as something that would allow elementary students to see "the contributions that they are able to make" to society and even the huge impact of "what they can do on another culture." Findings from this study revealed that at the *advocator* stage, the elementary teachers held an "engineering-as-empowerment" view toward EEE. This view was what behind their extended integration of engineering in their classrooms and their efforts to make EEE sustainable.

The EEE Expertise Development Dimension

Findings from this study indicated that synchronic differences were also apparent in the elementary teachers' EEE expertise development. Five EEE expertise development stages were identified. Three themes regarding the elementary teachers' EEE expertise development emerged from the data analysis: 1) contextualization of engineering learning; 2) development of engineering teaching pedagogy; 3) making interdisciplinary connections. These three themes are the overarching classificatory categories, and specific data-derived patterns falling under these three categories serve as the descriptive characterizations used to classify the elementary teachers into the five stages of EEE adoption: *mechanical imitator, skillful imitator, adaptor, improver,* and *creator*. The five stages and their corresponding descriptive characterizations are listed in the following table (*Table 2*).

Stages of EEE Expertise Development	Contextualization of Engineering Learning		Development of Engineering Teaching Pedagogy		Making Interdisciplinary Connections	
Stage I: Mechanical Imitator	I-1: Focusing solely on delivery of engineering content with little efforts made to contextualize engineering teaching in terms of accommodating engineering learning needs and relating engineering to real life	**De-contextualized**	I-2: Sticking to the engineering teaching procedures and steps as learned in professional development with no particular teaching strategies and methods used to address engineering learning problems and issues	**Absent**	I-3: Having no idea how engineering can be integrated into the teaching and learning of other disciplines	**Non-connected**
Stage II: Skillful Imitator	II-1: Taking initial steps to accommodate engineering learning needs and relating engineering to real life.	↓	II-2: Relying mostly on the engineering teaching procedures and steps learned in professional development but being able to apply some generic teaching strategies and methods to address engineering learning problems and issues	↓	II-3: Becoming aware of some potential opportunities to integrate engineering into the teaching and learning of other disciplines	↓
Stage III: Adaptor	III-1: Demonstrating deeper understanding about engineering learning needs and becoming more capable of accommodating engineering learning needs and allowing students to see how engineering is related to real life	↓	III-2: Being able to develop some engineering teaching strategies and methods to deal with engineering problems and issues	↓	III-3: Being able to find some opportunities to connect existing engineering activities with the teaching and learning of other disciplines but engineering is still largely appended in such connections	↓
Stage IV: Improver	IV-1: Carrying out engineering teaching based on perceived engineering learning needs and through hands-on and exploratory experiences	↓	IV-2: Improving engineering learning outcomes by making appropriate changes to engineering teaching materials, procedures, and/or steps of engineering learned in professional development	↓	IV-3: Being able to make more comprehensive interdisciplinary connections between engineering and other disciplines	↓
Stage V: Creator	V-1: Contextualizing engineering teaching and learning by making engineering knowledge understandable and meaningful to learners, and creating opportunities to experience the relevance of engineering through problem solving and real world applications	**Contextualized**	V-2: Creating new and appropriate ways of teaching engineering and creating new engineering activities that help overcome contextual constraints and promote engineering thinking.	**Well-developed**	V-3: Being creative in making interdisciplinary connections that allow students to learn non-engineering disciplines through new lenses and to learn engineering through practical applications	**Well-connected**

Table 2: Stages of EEE Expertise Development

Mechanical Imitator. Typical of the elementary teachers at the mechanical imitator stage was that they followed what they learned in the INSPIRE summer academies strictly, and as a consequence, they carried out their engineering teaching in a de-contextualized manner. Many specific examples yielded from the data of this study illuminate this trend. Some of the elementary teachers at this stage transferred what they learned in the INSPIRE summer academies into their lesson plans and "really followed the lesson plans pretty closely" without paying much attention to the particular contexts where engineering learning took place. Some of the elementary teachers at the mechanical imitator stage introduced engineering concepts (e.g., "what technology is," "what engineering is," and "what an engineer is") to their students by giving them definitions learned at the summer academy like "an engineer is the person who designs, a craftsman is the person who makes it, and a technician is the person who uses it," by pulling out the notebook used in the INSPIRE summer academies and using "the notebook a lot," or by asking the students to work on the exercises in the book. Other than these, these elementary teachers seemed to have no better ideas about how these concepts could be taught to their students, and there was no evidence that they taught these concepts by relating them to real-life experience.

A lot of learning problems and issues were reported by the elementary teachers at the *mechanical imitator* stage, such as the problem that the elementary students "just did not cooperate," they "just cannot handle anything in a group," they "had hard times understanding the engineering design process," the engineering activities were messy because of "a lot of arguments" or "clowning around," there were frustrations resulting from unsuccessful production of engineering final products, etc. In the face of these problems and issues, the *mechanical imitators* did not know how to respond except to hope things would be better next year or when there was more time for planning, or just to attribute these problems or issues to engineering's being "a little too difficult for this age group." One question the researchers asked the elementary teachers during the interviews was about their thoughts on assessing student learning during the engineering activities. It seemed that when there were no ready-made INSPIRE assessment materials or models to refer to, the elementary teachers at the *mechanical imitator* stage had a hard time carrying out assessment.

Also characteristic of the elementary teachers in the *mechanical imitator* stage is that they made few interdisciplinary connections in their engineering teaching and seemed to have no idea how to integrate engineering into the teaching and learning of other disciplines. Some of these elementary teachers told the researchers frankly in the interviews that they did not do a good job in this, or they just expressed the intention of looking at the curricula of other disciplines to see how engineering could possibly be tied in.

Skillful Imitator. The elementary teachers at the *skillful imitator* stage, though mostly still teaching engineering in a de-contextualized manner, began to realize the need to build a sense among their students that "engineering is interesting" or to get their students' minds thinking. Although the *skillful imitators* were merely adding some pictures or video into their teaching of engineering concepts, their improvement over the *mechanical imitators* was still easily discernable. Another improvement the *skillful imitators* made was expanding their teaching resource base. Although the *skillful imitators* still relied on the teaching materials from the INSPIRE summer academies and what they learned there as their main engineering teaching resources, they began looking for other resources to supplement their engineering teaching. Some of them tried to go to United Streaming or other websites looking for engineering activities or videos, some tried to "Google more information" about elementary engineering teaching. These efforts were based on an improved, albeit general, understanding about elementary students' learning needs, such as more information being necessary for "kids to see the penetration of engineering in all parts of life," or kids in contemporary society "being very visual, with everything geared to them visually."

When it came to the pedagogy of engineering, the *skillful imitators* had begun to take some initial steps to deal with the problems and issues they encountered during their engineering teaching. For example, they employed some realia like maps and pictures to help students with language problems in understanding the engineering content, they used model student groups to demonstrate how to work in groups during engineering activities, or they physically arranged the seats and guided the students to the seat arrangements to make engineering activity groups work better. Admittedly, these methods were generic in nature and might not be as creative and sophisticated as those employed by elementary teachers at more advanced stages of EEE expertise development, but we were able see in these methods the progress the *skillful imitators* were making in engineering teaching.

While the elementary teachers at the *mechanical imitator* stage taught engineering in a completely de-contextualized manner, those at the *skillful imitator* stage became aware of some potential opportunities to integrate engineering with the teaching and learning of other disciplines. For example, some elementary teachers mentioned that fractions and measurements in math were necessary for the paper folder activity[1], a science unit about matter was helpful for the Play-Doh activity[2], and an understanding of the writing process and scientific process would facilitate the learning of the engineering design process. With their practice-derived understanding that some knowledge and skills from other disciplines were necessary or conducive for their students' engineering learning, the *skillful imitators* saw potential opportunities for interdisciplinary connections between engineering and other disciplines. Although this could be regarded as an improvement over the mechanical imitator stage, there was little evidence from the interview data that these elementary teachers had more specific ideas about how interdisciplinary connections could be made in their engineering teaching practice, or that they actually made some interdisciplinary connections in their engineering teaching.

Adaptor. An important characteristic that distinguished *adaptors* from *skillful imitators* is that *adaptors* began to contextualize engineering teaching in wider and deeper scopes. This characteristic was manifested in the *adaptors'* understanding of how engineering should be taught to make it workable for elementary students. For example, the *adaptors* paid attention to elementary students' inadequate teamwork abilities and learned to prepare the students better for engineering teamwork rather than simply putting them into small groups and having them begin group engineering activities. *Adaptors* also found ways to place engineering lessons, like "What is engineering?" and "What is technology?", into real life contexts. There were some elementary teachers who asked parents or acquaintances who were engineers to speak with their students and talk about what real engineers do. Some elementary teachers asked their students to look for examples of technology in their houses and explain why these examples were identified as technology.

Compared with the elementary teachers in the previous two stages, the *adaptors* demonstrated better understandings of the nature of engineering activities and what was important for elementary students to learn from these activities. In addition, the elementary teachers at the *adaptor* stage also employed teaching strategies and methods to help their students learn better through engineering activities: creating flow maps of a recipe to guide elementary students' design and improvement of engineering products; asking students to brainstorm what could be done to improve the products; having students discuss what "limitations and time constraints and material constraints" had contributed to their failure to "get their job finished"; guiding and improving student learning through questioning: "Did you work together to the end?," "Did you give up?," "What were the problems?," and "Do we have any suggestions?"…

It is clear that the elementary teachers in the *adaptor* stage became more knowledgeable about how to adapt engineering teaching to better meet their students' engineering learning needs and to improve engineering learning outcomes. What's equally important is that these elementary teachers based their adaptation of engineering teaching on the assessment of student learning during the engineering activities. As the *adaptors* became better at assessing engineering learning and using assessment results to guide their engineering teaching practice, they also made attempts to connect engineering with the teaching and learning of other disciplines. These attempts included combining the engineering assembly line activity[3] with the topic of the assembly line in social studies, and adding the engineering pop-up card[4] activity as part of the author study activity in language arts. Although the elementary teachers at the *adaptor* stage were able to find some opportunities to connect engineering with the teaching and learning of other disciplines, in these connections engineering remained its own separate entity, appended to but not truly integrated with other disciplines.

Improver. The elementary teachers in the *improver* stage practiced their engineering teaching in a more student-oriented way than those in the *adaptor* stage. The *improvers* went beyond adapting what they had learned in the summer academies to their students' learning needs. They actually made changes to the learned teaching procedures and steps to improve the engineering learning outcomes. When it came to assessment, the improvers also showed progress compared to earlier stages. One elementary teacher at the improver stage made an impressive comment about assessing engineering learning: "That is a difficult piece because kids think outside the box, and you, as grading them, have to also think very outside of the box. It's hard to give a student that tries hard a bad grade, because they're using all that they have. If they haven't been shown a world, it's hard for them to think." This comment is impressive not only in the sense that it reflects the heightened understanding of assessment of learning that characterized the *improvers* but in the sense that it gives a good summary of the principle the *improvers* used to guide their engineering teaching—the principle of teaching engineering by "showing the students a world of engineering."

The *improvers* showed their students a world of engineering by giving them opportunities to explore the world around them to see what engineering is and what engineering is about. For these elementary teachers, engineering teaching was not giving students "isolated mental pictures and images," but giving them hands-on, concrete, and real-life examples, and opportunities to think, to experience, and to improve. An elementary teacher at the *improver* stage decided, instead of doing the paper folder activity from the INSPIRE academy to teach the engineering design process, to do an activity her students wanted—"design a bed for a doll" using materials they could find around them. She worked with her students on discussing "the components of the bed," designing and drawing the components in the journals, and exploring the possibilities of using materials they found around them, like Styrofoam cups and strings, for the components.

In other *improvers'* engineering classes, window shades in the classroom became good realia for the students to learn gear machines and levers, or rulers and "just various items" in the classroom were utilized in teaching engineering and engineering concepts, etc. Guiding their students to interact with their physical environment was a way the improvers showed their students a world of engineering, or perhaps more accurately, an engineering world for elementary students.

Creator. The *creator* stage is aptly named, for "creative" and "creating" are perfect descriptors for the elementary teachers who had progressed past the *improver* stage. They created not only new methods of teaching engineering to their students but new engineering activities for their students to explore. One of the elementary teachers at the *creator* stage created a new way for her kids to experience the engineering design and re-resign process: she invited some kindergarteners to come to the classroom as the consumer group giving the kids feedback on their design and the kids took that information and started redesign. Among the elementary teachers involved in this study, there were three elementary teachers who did the "egg drop activity" instead of the plant packaging activity learned from the INSPIRE academy. One of the three elementary teachers re-created the egg drop activity by tying it into finding solutions to a practical problem. More important than this is that this teacher got her students involved in creating the activity to experiment with the engineering design process. To use another *creator's* words, this elementary teacher was having her students "design their own experiment and do it." Engineering activities created in such a way are more driven by problem-solving and are more hands-on and minds-on.

If the word "creating" is used to emphasize what the elementary teachers in the *creator* stage did in their engineering teaching practice, the word "creative" highlights the quality of what they did. These elementary teachers' creativity could be seen in how they combined engineering with the learning and teaching of other disciplines in a way that helped to overcome the contextual constraints of EEE. As the elementary teachers in the study explained, electricity and magnetism are in the 4th grade TAKS (Texas Assessment of Knowledge Skills) and are subjects 4th grade teachers are required to teach to their students. One 4th grade teacher created an engineering unit on "circuit design" and combined this unit with the teaching of electricity and magnetism. Another teacher did something different in her teaching of electricity and magnetism: asking her students to design a box with an alarm to keep people out. Although the two teachers tied engineering into the curriculum in different ways, both of them were doing the same thing: making EEE possible within time constraints and enabling elementary students to experience science through a new lens. One of the two elementary teachers put this in some plain words of her own, "if you would align with what you had to do versus trying to wiggle room for it, that would be helpful."

Many similar examples emerged from the data. When teaching about buoyancy, a *creator* added engineering in and asked her students to produce a boat out of aluminum foil by "sketching it, testing it, and re-designing it." In another *creator's* science class, engineering was with the lesson about filters and the students were asked to design and produce water filters to help people in countries with limited water resources. One of the creators came up with a unit "on the engineering design process to design and improve a telescope" and integrated it into her lessons on the solar system in order to show her students "how it is possible to see the solar system without traveling through space." During the interviews, *creators* identified in this study talked about their engineering teaching experience and focused on different aspects that elementary engineering teaching needed to build up for elementary students: confidence, motivation to take risks in order to learn rather than necessarily to gain academic points, accepting mistakes, problem-solving, willingness to work as a team, and ability to redesign and improve. Despite these different focuses, one common thing these *creators* showed us is how being "creating" and "creative" may transform engineering teaching.

Discussion: synchronic differences and diachronic progression

The EEE adoption and expertise development model constructed in this study is two dimensional. In the EEE adoption dimension, four overarching categories (i.e., *perception of practicality and sustainability of EEE*, *comfort level with engineering teaching*, *perception of EEE benefits to elementary learners*, and *degree of engineering integration*) emerged from the data of the study and serve the classificatory function of distinguishing elementary teachers' EEE adoption into four different stages. In the EEE expertise development dimension, the three EEE expertise development classificatory categories (i.e., *contextualization of engineering learning*, *development of engineering teaching pedagogy*, and *making interdisciplinary connections*) overarch the five EEE expertise development stages and specify areas of engineering teaching expertise where elementary teachers would differ in their engineering teaching practices. Each of the EEE adoption and EEE expertise development classificatory categories is accompanied with staged descriptive characterizations that can be used to identify elementary teachers into respective EEE adoption or EEE expertise development stages .

In this study, when the EEE adoption and expertise development model was used to look at the elementary teachers collectively and at a given time, their EEE adoption and EEE expertise development were characterized by synchronic differences showing that the elementary teachers stood at different EEE adoption and EEE expertise development stages. In the second round of data analyses, when the EEE adoption and expertise development model was used to look at the elementary teachers over time and when comparisons and contrasts were made of the interview data of the same teacher collected in two consecutive years, diachronic progression along the EEE adoption and the EEE expertise development stages was found. How the EEE adoption and expertise development model was used to reveal the elementary teachers' synchronic differences and the diachronic progression well demonstrated the usefulness of this model for EEE professional development providers.

Using the EEE adoption and expertise development model, EEE professional development providers would be able to conceptualize elementary teachers' EEE adoption and EEE expertise development by accessing the performance in these two dimension at a given time and by tracking the progress in the two dimension over time. With information collected through such a way, EEE professional development providers would become better informed about what to work on to improve future programs, and more importantly, to provide effective and timely support for their teacher learners to facilitate their EEE adoption and EEE expertise development

Conclusion

The present study investigated elementary teachers' EEE adoption and EEE expertise development based on the analyses of their engineering teaching practices as conveyed through interviews and online open-ended surveys. As a result of the analyses, the EEE adoption and expertise development model was constructed in this study. This model consists of two dimensions: the EEE adoption dimension and the EEE expertise development dimension. The EEE adoption dimension includes four data-derived classificatory categories, based on which four different adoption stages were identified: *attempter*, *adopter*, *ameliorator*, and *advocator*. The EEE expertise development dimension consists of three classificatory categories, and there are five stages within each of these categories. Each of the four EEE adoption stages and the five EEE expertise development stages can be identified through a corresponding descriptive characterization. This detailed, operationalized EEE adoption and expertise development model provides useful tools to conceptualize, assess, and track elementary teachers' EEE adoption and EEE expertise development in their engineering teaching practice.

The construction of the EEE adoption and expertise development model was mainly based on analyzing, both deductively and inductively, the 75 individual and 26 group interviews with the 73 elementary teachers participating in this study. The model construction process also allowed the researchers of this study to discern the synchronic differences and the diachronic progression the elementary teachers demonstrated in their EEE adoption and EEE expertise. It was shown in this study that the EEE adoption and expertise development model can be used to collect information about elementary teachers' synchronic differences and diachronic progression in EEE adoption and expertise development. This demonstration offers a compelling illustration of the usefulness of the EEE adoption and expertise development model to EEE professional development programs. Using this model, professional development providers would be able to map their elementary-teacher learners' standings at a given time in the EEE adoption and EEE expertise development stages and to assess or track their progress over time. It is envisaged that future research will continue to investigate how the EEE adoption and expertise development model could be use to its full potential as a tool helping EEE professional development programs conceptualize, assess, and track elementary teachers' EEE adoption and EEE expertise development, and ultimately improve the quality of EEE professional development for elementary teachers.

Notes:

① Paper folder activity: an elementary engineering design activity in which students are required to design and create paper folders based on a specific engineering design process model.

② Play-Doh activity: an elementary engineering activity in which elementary students are asked to improve their play dough recipe and prepare quality play dough by exploring the properties of solids and liquids, and by experiencing the sequenced process of mixing the two.

③ Engineering assembly line activity: an elementary design activity in which students are asked to address questions of scale-up in the production of different prototypes designed in previously projects.

④ Pop-up card activity: an elementary engineering design activity in which students are required to design and create pop-up greetings cards following a specific engineering design process model.

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