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Elementary Engineering Education (EEE) Adoption and Expertise Development Framework: An Inductive and Deductive Study

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Abstract

Elementary engineering education (EEE) is an educational innovation. Using Rogers's innovation diffusion model, the Concerns-Based Adoption Model (CBAM), and Dreyfus's skill acquisition model as its theoretical frameworks, this study investigated elementary teachers' EEE adoption and EEE expertise development. Data of this study were collected through face-to-face interviews and open-ended online surveys conducted with 73 elementary teachers who received one-week EEE training from INSPIRE, the Institute for P-12 Engineering Research and Learning at Purdue University. An analytic induction approach was adopted in the analyses of the data. Based on the data analyses results, an evidence-based EEE adoption and expertise development framework was constructed to describe the process of EEE adoption and EEE expertise development and to capture individual elementary teachers' differences in this process. This framework includes the four-staged EEE adoption dimension and the five-staged EEE expertise development dimension. This framework is able to reveal the "synchronic differences" and the "diachronic progression" in EEE adoption and EEE expertise development. While the "synchronic differences" indicate elementary teachers' different standings in the EEE adoption and EEE expertise development stages at a given time, the "diachronic progression" indicates progress along the stages over time. This framework is proposed to be used by EEE professional development programs to conceptualize, assess, and track their teacher learners' standings and progress in EEE adoption and EEE expertise development for the purpose of program improvement and the purpose of providing teacher learners with effective and on-going support.

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Introduction

Integrating engineering into elementary classrooms is an innovative educational practice that promotes technological literacy (Cunningham, Lachapelle, & Lindgren-Streicher, 2006) and addresses the national concern about the shrinking Science, Technology, Engineering, and Mathematics (STEM) workforce (Nugent, Kunz, Rillet, & Jones, 2010). 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) (Yasar, Baker, Robinson-Kurpius, Krause, & Roberts, 2006). 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 (Carr, Bennett, & Strobel, in press), and that the new national science education framework contains for the first time engineering as explicit content (Committee on Conceptual

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Framework for the New K–12 Science Education Standards, 2011). An ever-increasing number of professional development programs are currently offering training to elementary teachers to prepare them for engineering teaching (e.g., CIESE PD workshops in CIESE, 2010; EiE workshops in Cunningham, 2008; INSPIRE summer academies in Strobel & Sun, 2011).

Previous research on professional development in elementary engineering education (EEE) reported the positive impact of professional development on both elementary teachers' engineering content knowledge and their teaching practices (Cunningham, Lachapelle, & Keenan, 2010; Hsu, Cardella, & Purzer, 2010). However, findings from previous research also revealed elementary teachers' misconceptions about engineering and technology (Cunningham et al., 2006), their varying degrees of unfamiliarity with Design, Engineering and Technology (DET) (Hsu, Cardella, Purzer, & Diaz, 2010), and their perceived barriers to integrating engineering into elementary classrooms (Lee & Strobel, 2010). These misconceptions, unfamiliarity with DET, and perceived barriers have contributed to elementary teachers' fear of teaching engineering and skepticism about integrating engineering into their classrooms (Cunningham, 2008; Liu, Carr, & Strobel, 2009).

What we can learn from the above referenced research is that, given the innovative nature of EEE and elementary teachers' unpreparedness for engineering teaching, both elementary teachers' EEE adoption and EEE expertise development will be a process over time. To improve the effectiveness of engineering professional development for elementary teachers, we need to have a systematic and comprehensive understanding about the EEE adoption and EEE expertise development process. Unfortunately, however, such an understanding is missing in the literature. 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 framework.

Adopting theoretical perspectives furnished by (a) Rogers's (2003) diffusion of innovation model, (b) the Concerns-Based Adoption Model (CBAM) (Hall & Hord, 1987, 2005; Hord, Rutherford, Huling-Austin, & Hall, 1987), and (c) Dreyfus and Dreyfus's skill acquisition model (Dreyfus, 2004; Dreyfus & Dreyfus, 1980), the researchers of this study constructed an EEE adoption and expertise development framework. The construction of the framework 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.

Purpose and Research Questions

The purpose of this study was to construct an EEE adoption and expertise development framework by

investigating elementary teachers' adoption and implementation of engineering teaching. This framework is intended to capture the developmental process of elementary teachers' EEE adoption and EEE expertise development diachronically, and to reflect individual differences and personal experiences synchronically at a given time during the EEE adoption and EEE expertise development process.

The construction of this framework was guided by two research questions:

- (a) What are the stages of EEE adoption and what are the descriptive characterizations associated with each stage?
- (b) What are the stages of EEE expertise development and what are the descriptive characterizations associated with each stage?

The EEE adoption and expertise development framework construction in this study includes two diagnostic dimensions: the EEE adoption dimension and the EEE expertise development dimension. This two-dimensional framework is proposed to help professional development programs conceptualize, assess, and track elementary teachers' EEE adoption and EEE expertise development so as to provide the learners with appropriate needs-based instruction and support that promotes sustainable integration of engineering into elementary classrooms.

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 (Cunningham, 2008) and that engineering is a discipline not taught or learned in the majority of schools in the United States (Cunningham et al., 2006). This level of innovation entails great challenges in preparing elementary teachers because "the education of the vast majority of elementary school teachers (such as the bulk of our population) did not include engineering or technology activities or information" (Cunningham et al., 2006, 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 (Buczynski & Hansen, 2010) and by DET (Yasar et al., 2006). In addition, it has been shown that engineering teaching has its idiosyncratic properties rendering generic teaching strategies ineffective (Strobel & Sun, 2013). This presents another challenge for preparing elementary teachers for engineering teaching.

Elementary teachers are not prepared for engineering teaching. Their unpreparedness can be seen in their misconceptions and overly broad ideas about engineering and technology (Cunningham et al., 2006), their

Table 1

The innovation–decision process of Rogers’ diffusion of innovation model

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.

unfamiliarity with DET (Hsu et al., 2010), and their hesitance to teach engineering as reflected in their concerns such as meeting state standards, lack of time, resources, and administrative support (Hsu et al., 2010; Strobel & Sun, 2011). Moreover, 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, but also elementary teachers’ decisions about future implementation were quite different. 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 (Carson & Campbell, 2007). Individual elementary teachers also differed in their perceptions of the importance of DET, and these differences were reported to be related to previous full-time teaching experience in general and science teaching experience in particular (Hsu et al., 2010).

Two overarching themes identified from previous research are: (a) given elementary teachers’ unpreparedness for engineering and engineering teaching, it will be a process for elementary teachers to become prepared for teaching engineering; (b) 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. Although 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 to deal effectively with individual elementary teachers’ differences in adopting and implementing engineering teaching.

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

Diffusion of innovation models (Rogers’s and CBAM)

Rogers’s diffusion of innovations mode

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 (2003) 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 model, Rogers (2003) describes 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 (2003), the innovation–decision process (shown in Table 1) involves five stages.

According to Rogers (2003), five characteristics (shown in Table 2) of an innovation are notably relevant to decisions to adopt.

In addition, Rogers (2003) recognizes individual differences in innovativeness –“the degree to which an individual or other unit of adoption is relatively earlier in

Table 2

The five characteristics of an innovation

Relative advantage	“The degree to which an innovation is perceived as being better than the idea it supersedes” (p. 229).
Compatibility	“The degree to which an innovation is perceived as consistent with the existing values, past experiences, and needs of potential adopters” (p. 15).
Complexity	“The degree to which an innovation is perceived as relatively difficult to understand and use” (p. 15).
Triability	“The degree to which an innovation may be experimented with on a limited basis” (p. 16).
Observability	“The degree to which the results of an innovation are visible to others” (p. 16).

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%), *early adopters* (13.5%), *early majority* (34%), *late majority* (34%), and *laggards* (16%).

The Concern-Based Adoption Model (CBAM)

Unlike Rogers, who argues for and was committed to the development of a general diffusion model across various disciplines (Rogers, 2004), the CBAM team roots the development of CBAM in school contexts and specifically focuses 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 (Hall & Hord, 1987) 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 uses the first two frames of *stages of concern* and *levels of use* owing to the fact that our framework is not based on classroom observation – a requirement for the third framework.

The *stages of concern* framework (Hall & Hord, 1987) identifies the seven developmental stages of concern (shown in Table 3) that teachers go through in adopting and implementing an educational innovation.

Although 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 (Hall & Hord, 1987) 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 seven levels (which include both non-users and users of the new program) (shown in Table 4), 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 (Hall & Hord, 1987).

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 (Anderson, 1997; Hall, Loucks, Rutherford, & Newlove, 1975). The CBAM framework furnished the researchers of this study with new lenses to approach the adoption and implementation of EEE by elementary teachers.

The 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 (Casey, Harris & Rakes, 2004). So, when investigating elementary teachers’ EEE expertise development, the researchers of this study included the Dreyfus skill acquisition model (Dreyfus, 2004; Dreyfus & Dreyfus, 1980) as one of the theoretical frameworks.

The Dreyfus skill acquisition model (Dreyfus, 1982, 2004; Dreyfus & Dreyfus, 1980, 1986) consists of five stages of skill acquisition (Dreyfus, 2004): 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. According to Dreyfus (2004), however, “Still, at this stage, learning can be carried on in a detached, analytic frame of mind” (p. 177).

Learners at the stage of “competence” are learning to deal with performance overload by developing a plan or choosing a perspective that helps them to focus on a few of the vast body of possible relevant elements and aspects and to consequently make understanding and decision making easier. Characteristic of this stage is that the detached

Table 3
The *stage of concern* framework of CBAM

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.

Table 4
The level of use framework of CBAM

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 become involved.
Level 1: Orientation	The teacher has acquired or is acquiring information about the new program and is exploring its value orientation. <i>Decision point A: The teacher decides to take action to seek more detailed information about the new program.</i>
Level 2: Preparation	The teacher is preparing for first use of the innovation. <i>Decision point B: The teacher decides to use the innovation.</i>
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. <i>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.</i>
Level 4a: Routine Use	The teacher establishes a routine pattern of innovation use. <i>Decision point D1: The teacher makes a few attempts to improve the innovation practice or its consequences.</i>
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. <i>Decision point D2: The teacher makes changes in the use of the innovation to improve student outcomes.</i>
Level 5: Integration	The teacher collaborates with other teachers to extend the impact of the innovation beyond his/her individual classroom. <i>Decision point E: The teacher makes changes based on input of peer teachers and in coordination with what they are doing.</i>
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. <i>Decision point F: The teacher begins making major modifications to the innovation and/or exploring alternative, better innovations.</i>

stance of the novice and the advanced beginner 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.

Learners at the stage of "proficiency" assimilate experience into the ability to discriminate important aspects from unimportant aspects among a variety of situations and the ability to act accordingly. However, a proficient learner still has to make decisions about the best course of action consciously in a specific situation the best course of action in a specific situation. With enough experience in a wide variety of situations, a proficient learner 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 has been adopted by researchers to study expertise development in areas such as nursing (e.g., Benner, 2004; Benner, Hooper-Kyriakidis, & Stannard, 1999) and teaching (e.g., Berliner, 1988a, 1988b; Crawford, 2003). Based on the Dreyfus skill acquisition model, Berliner's research (1988a, 1988b) 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" (1988a, p. 33) among teachers in teaching-expertise development and that these differences "have important implications for the policies we adopt for the education of teachers" (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.

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 framework. Four presumptions about the EEE adoption and expertise development framework were derived from these theoretical framework.

- The adoption and implementation of EEE as an innovation is a process.
- During the process, there exist different EEE adoption stages along a continuum, with identifiable traits and qualities associated with each stage.

- (c) During the process, there exist different EEE expertise development stages along a continuum, with identifiable traits and qualities associated with each stage.
- (d) 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 framework, 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 patterns and emergent understandings” (Patton, 2002, p. 454).

The four theory-derived presumptions served as guidance for the construction of a prototype framework and as sensitizing concepts (Blumer, 1969), 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 to refine the prototype. 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 (Patton, 2002), and then used them to create analyst-constructed typologies (Marshall & Rossman, 2010; Patton, 2002). The typologies are explanatory in nature, assuming both the classificatory and descriptive roles

(Elman, 2005). The classificatory role functions to divide elementary teachers’ EEE adoption and expertise development into “parts along a continuum” (Pattern, 2002, p. 457), whereas the descriptive role functions to provide a description of these parts based on an inductive analysis of the patterns that emerged from the data.

The theoretical and methodological framework of this study is illustrated in Figure 1.

Research Design

Data for this study were collected from the participating teachers of INSPIRE’s 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 framework.

INSPIRE 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. 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

Figure 1. Theoretical and methodological framework.

Figure 2. Demographic information of teacher participants.

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, TX with funding from a private foundation. The summer academy uses EiE (Engineering is Elementary[®]) curriculum¹ materials such as Storybooks, Lesson Plans, and Student assessments and models the teaching of two of the twenty EiE units to elementary teachers to familiarize them with the structure of EiE curriculum and some elementary engineering teaching pedagogy.

Participants

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

Approximately half of the elementary teachers interviewed hold B. A. degrees in fields such as English, Early Childhood Education, Interdisciplinary Studies, and Government (see Figure 3). Twenty-eight out of twenty-nine B.S. degrees held by the teachers are in non-STEM fields such as Education, Advertising, and Photography. Nine of these 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.

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. The 33 teachers interviewed in 2009 were Cohort I, who attended the 2008 summer academy. Although it was planned to interview all these 33 teachers again in 2010, only 13 of them were available during the time of 2010 interview. So, among the 42 teachers interviewed in 2010, 29 were Cohort II, who attended the 2009 summer academy, and the remaining 13 teachers were Cohort I, who were interviewed both in 2009 and 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

Figure 3. Educational background of teacher participants.

¹ The EiE curriculum is authored by Engineering is Elementary[®], an elementary engineering curriculum development project primarily funded by the National Science Foundation (NSF).

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. Three rounds of data analyses (summarized in Figure 4) were conducted on these data.

In the first round of data analysis, the individual interviews in 2009 and 2010 were respectively arranged into four 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."

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 and the answers carefully first for verifying the four presumptions and for developing the prototype framework 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. The prototype framework was modified and refined based on the comparisons and discussions of the analytical memos to ensure reliability and validity. The modified and refined framework was then tested against new randomly selected interview data. Each time, five new interviews were selected and the researchers read through the interviews, independently taking analytical memos of newly emerged themes and patterns. Whenever finishing five newly selected interviews, the researchers joined together to compare and discuss their analytical memos and made revisions of the framework 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 (Strauss & Corbin, 1998). All themes and patterns thus yielded were collected and compared to organize into appropriate EEE adoption and EEE expertise development classificatory categories and stages. Analyzing the themes and patterns at each stage, the researchers developed terms to name each of the stages. A two-dimensional, multiple-staged EEE adoption and EEE expertise development framework was finally constructed.

In the second round of data analysis, the researchers of the study checked the reliability and validity of the EEE adoption and expertise development framework. During the framework check process, each time the researchers randomly selected two individual interviews and rated the two

Figure 4. Three rounds of data analysis in this study.

interviewed teachers into specific EEE adoption and EEE expertise development stages while taking notes of evidence supporting their ratings. After finishing the ratings, 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 framework. A total of three rounds of framework check were conducted, and the results are as follows: in the first round, the two researchers reached 57% agreement (four categories out of seven); in the second round, the researchers reached 71% agreement (five categories out of seven); and in the last round, the researchers reached 100% agreement (seven categories out of seven).

For the third 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 was agreed upon by the researchers. This list is reported in the next section to show the elementary teachers' progress over the two years of 2009 and 2010.

Findings and Discussion: The EEE Adoption and Expertise Development Framework

Data analysis results of this study verified the four theory-derived presumptions. The final EEE adoption and expertise development framework includes the EEE adoption dimension and the EEE expertise development dimension. We present the two dimensions in this section, specifying the classificatory categories included in each dimension and elaborating 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 although receiving the same EEE training and practicing engineering teaching for the same amount of time. Four themes emerged from the data analyses as factors that influenced elementary teachers' EEE adoption process: (a) perception of practicality and sustainability of EEE; (b) comfort level with engineering teaching; (c) perception of EEE benefits to elementary students; (d) 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*. Table 5 lists the four different EEE adoption stages and the descriptive characterizations of each stage.

Attempter

I-1: perception of practicality and sustainability of EEE. Elementary teachers in this study voiced their perceived barriers to integrating engineering into their classrooms in their responses to the online open-ended survey. Some major perceived barriers included time issues, lack of administrative support, lack of resources, personal unpreparedness, accountability issues, and student learning-related issues. 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. So barriers related to time issues, administrative support, and accountability issues such as high-stakes tests drew most of their attention. These elementary teachers became rather overwhelmed by these barriers and regarded EEE as impractical and unsustainable because, as some mentioned in the interview, "I need to prepare the students for the state-tests," or "I'm required to teach certain objectives throughout the year, and I don't have enough time to teach it [engineering]." 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 typical answers they gave were "I don't know" or "It's really a tough question."

I-2: comfort level with engineering teaching. Elementary teachers at the *attempter* stage felt unprepared for engineering teaching or not comfortable with it. The comment from a fourth grade teacher that "I don't feel the same comfort with it [engineering] as I do with math" was common among *attempters* and was indicative of their low comfort level with engineering teaching.

I-3: perception of EEE benefits to elementary students. Elementary teachers at the *attempter* stage demonstrated low levels of understanding of the benefits of EEE to elementary students. As indicated by some elementary teachers in the interview, engineering teaching and learning for elementary

Table 5
Stages of EEE Adoption.

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	I-2: Feeling uncomfortable with teaching engineering as indicated by unwillingness to teach engineering and by the rushing-through of engineering content when teaching	I-3: Holding an “engineering as anti-illiteracy” view about EEE benefits (i.e., learning engineering helps understand some engineering related concepts)	I-4: Teaching engineering discontinuously and sporadically and treating engineering teaching as isolated and as an add-on
Stage II: Adopter	II-1: Fully aware of the perceived barriers of EEE but viewing engineering as practical in elementary classrooms	II-2: Feeling more comfortable with teaching engineering as indicated by covering expected amount of engineering content and allowing more time elaborating engineering content and answering student questions	II-3: Hold an “engineering as an extension” view about EEE benefits (i.e., learning engineering helps review knowledge and skills learned in other disciplines)	II-4: Devoting more time for engineering teaching and starting to make occasional attempts to integrate engineering into the teaching and learning of other non-engineering disciplines
Stage III: Ameliorator	III-1: Proving EEE practicality through engineering teaching practice and becoming conscious of the need to make EEE sustainable	III-2: Feeling quite comfortable with teaching engineering as indicated by regular engineering teaching practice and expanding engineering learning with additional engineering teaching materials	III-3: Hold an “engineering as application and enrichment” view about EEE benefits (i.e., learning engineering helps broaden students’ horizon and enrich their skill sets)	III-4: Practicing engineering teaching on regular basis and being more frequent in integrating engineering into the teaching and learning of some of other non-engineering disciplines
Stage IV: Advocate	IV-1: Convinced of EEE practicality based on successful personal engineering teaching experiences and starting to make efforts to make EEE sustainable	IV-2: Feeling fully comfortable with teaching engineering as indicated by confidence gained through successful engineering teaching experiences and willingness to make the successful engineering teaching stories known to others	IV-3: Holding an “engineering as empowerment” view about EEE benefits (i.e., learning engineering promotes students’ development as real-life problem solvers and their understanding of the career potentials in engineering)	IV-4: Making engineering teaching an integral part of teaching practice as a result of being able to integrating engineering into all other non-engineering disciplines all the time

students was “having fun” or allowing them to know “what the word engineering means and be familiar with some terms.” Such a view toward the benefits of EEE was referred to by the researchers of the study using the code of *engineering-as-anti-illiteracy* emerging from the coding process of the interview data. This *engineering-as-anti-illiteracy* view toward the benefits of EEE denoted the *attempters’* 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.

I-4: degree of engineering integratio. 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. A consequence of this was that these elementary teachers were very inflexible about their plans for teaching engineering. A good example of this came from an elementary teacher who told the researchers in the interview that “Another thing that was hard was I needed to get the EiE [Elementary is Engineering] unit done before I had taught capacity, so they [the elementary students] didn’t quite know some of the measuring techniques and things like that.” In fact, integrating the EiE unit with the teaching and learning of capacity would have solved the problem. But unfortunately, with the notion that engineering teaching and learning was isolated from the teaching and learning of other disciplines, these elementary teachers

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, sporadicity, and discontinuity.

Adopter

II-1: perception of practicality and sustainability of EEE. 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. One of the elementary teachers talked about her experience of teaching the concept of *What is Engineering* to her students: “We talked about what is engineering throughout the year, we have talked about, ‘Oh, we’re being engineers because we’re asking what the problem is, how can we find a solution; we’re coming up with restraints, we’re asking questions, we’re talking about a plan and coming up with solutions.’ So, engineering can be built in a lot through the classroom, not just through engineering.” Like this elementary teacher, those in the *adopter* stage 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.”

II-2: comfort level with engineering teaching. According to the *adopters*, there was no need to rush through the engineering content or activities because they felt comfortable with teaching engineering to their students. Also indicative of the *adopters*’ comfort with teaching engineering is that fact that they began to allow their students to pose questions and to argue with each other in engineering class.

II-3: perception of EEE benefits to elementary students. Representative of the elementary teachers was the view voiced in the interview that the benefits of learning engineering lay in its serving as a review or an extension of what their students had learned in other disciplines, such as helping them review a lot of math or supporting some of their existing skills or vocabulary. The researchers of this study labeled this as an *engineering-as-an-extension* view toward the benefits of EEE to elementary students.

II-4: degree of engineering integration. 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, but they also allowed their students to go back and forth with various engineering concepts to enable a deeper understanding of these concepts. The *engineering-as-an-extension* view held by the *adopters* enabled them to find some opportunities to connect engineering with the teaching and learning of other disciplines. Although such connections were occasional and engineering was still appended to other disciplines, certain amounts of initiative, absent among the *attempters*, could be identified 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

III-1: perception of practicality and sustainability of EEE. The elementary teachers in the *ameliorator* stage proved the practicality of EEE by practicing engineering teaching on a regular basis. In addition, the *ameliorators* began to think about the sustainability of EEE. The *ameliorators* told the researchers in the interview that they were alone or with only a few colleagues in their schools implementing engineering teaching and, to use their own words, “engineering teaching still sounds appended to the main business of school” because “it’s not state mandate” and “it’s not included in the TAKS (Texas Assessment of Knowledge and Skills).” In face of such status quo of engineering teaching at their schools, the *ameliorators* expressed their concerns about the sustainability of integrating engineering into elementary classrooms. However, although the *ameliorators* became aware of the need and the importance of make EEE sustainable, they had no specific ideas about how to do it. This is an important characteristic distinguishing the *ameliorators* from the *advocators* in the next EEE adoption stage.

III-2: comfort level with engineering teaching. The above mentioned concern about the sustainability of EEE reflects that the elementary teachers in the *ameliorator* stage have moved out of the confinement of their immediate classroom environments to think about the larger educational environment making EEE more widely accepted and sustainable. The breakthrough of such a confinement was a strong indicator of the *ameliorators*’ confidence in teaching engineering in their classrooms. Teaching engineering on regular basis and searching for additional engineering teaching materials were evidence that *ameliorators*’ comfort level with engineering teaching has greatly improved. The interview data indicated that the *ameliorators* became more confident in teaching engineering because of their regular engineering teaching practices.

III-3: perception of EEE benefits to elementary students.

Compared to the elementary teachers in the *attempter* and *adopter* stages, the *ameliorators* held a considerably broadened view about the benefits of EEE to elementary students. As some *ameliorators* mentioned in the interview, 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 teaching and learning as an application and an enrichment. The code “engineering as application and enrichment” was used in this study to represent the *ameliorators*’ view of the benefits of EEE to elementary students. 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.

III-4: degree of engineering integration. The *ameliorators* taught engineering on regular basis. Some of them chose to do engineering on every Friday, and named the day “Engineering Friday” or “Freaky Friday.” One of the *attempters* told the researchers in the interview that she had covered only four out of ten engineering lessons she had planned to do, and this was quite typical of the *attempters*. The following is an example of what an *ameliorator* did about engineering. This example shows the stark contrast between a typical *ameliorator* and a typical *attempter*:

There is also a tremendous amount of activities online. We got through what you [the interviewing researcher] taught us last summer [at the summer academy], but we thought, “Well, gosh, we still have three weeks, four weeks of school left. If we do one every Friday, we’ve got to work this in, you know, we need some extra lessons.” And so I went online to look at, you know, like power tower and other things that the kids can do. There are tremendous resources out there for engineering.

This elementary teacher’s students kept asking her: “Are we doing Freaky Friday?” and the teacher responded to her students’ love and enthusiasm to engineering by doing engineering regularly and by actively searching for supplemental activities and lesson plans.

In addition to implementing engineering on a regular basis, the *ameliorators* explored more resources to help their students, to use one of the *ameliorators*’ own words, “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.

Advocator

IV-1: perception of practicality and sustainability of EEE. The data analysis results of this study indicated that the elementary teachers at the *advocator* stage were convinced of the practicality of EEE because of their successful engineering teaching experiences. More important than this is that the *advocators* became aware of the persuasive power of their successful practice-based engineering teaching experience in winning sustainable integration of engineering into elementary classrooms. One of the *advocators* said in the interview, “What I also think would help is just letting the teachers who had done the EiE units, to say, ‘listen, this really does work’, and to be an advocate for the units.” Many elementary teachers in the *advocator* stage, such as the one quoted, expressed their intention of becoming an *advocator* of EEE and drawing other elementary teachers onboard by using personal teaching success stories.

Compared with those in the *ameliorator* stage, the elementary teachers in the *advocator* stage came up with specific plans of how to win support for EEE and how to make it sustainable. There were such plans quoted from the interview data as holding an “Engineering Open House” to showcase what the elementary students had learned or achieved through EEE, and using TV or the internet to publicize what the elementary students and their teachers were doing with engineering in the classrooms. For some *advocators*, making EEE sustainable required the whole school to become engaged or a whole-school push starting with the principal. One of the elementary teachers at the *advocators* stage suggested in the interview that we “put the principals through the training...make them come to an after-school thing so they can kind of get a feel for what engineering is about.” Interview data from the study showed that one of the *advocators* actually put her advocacy plan 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.

IV-2: comfort level with engineering teaching. The elementary teachers at the *advocator* stage had practice-based success in engineering teaching. According to the *advocators*, such success enabled them to be fully confident in teaching engineering to their students. The *advocators* indicated in the interview that they were fully comfortable with teaching engineering. Great confidence in and high comfort level with engineering teaching explained why the *advocators* not only implemented engineering teaching extensively but also wanted to make their success

in engineering teaching known to others to ensure sustainable integration of EEE into elementary classrooms.

IV-3: perception of EEE benefits to elementary students.

The *advocators* were able to understand the benefits of EEE to elementary students from broader and more comprehensive perspectives than teachers at earlier stages. The following is a good example of those broader and more comprehensive perspectives:

I think they're learning more about a profession that they can choose when they grow up, but they're also learning that engineering is all around us, and that is what's important ... I think that they've learned a lot this year. You know, I have a lot of girls who think that they want to become engineers, and that's important because, you know, like you said, it's not a girl-driven or a woman-driven field, and so we've at least opened the doors for them to see what's out there for them.

As exemplified by the quote above, the elementary teachers at the *advocator* stage viewed EEE not only as something about making real-life connections, but also 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 within another culture. The code *engineering-as-empowerment* was used by the researchers to refer to the advocates' view about the benefits of EEE to elementary students. This *engineering-as-empowerment* view toward EEE was behind the advocates' extended integration of engineering in their classrooms and their efforts to make EEE sustainable.

IV-4: degree of engineering integration. For the elementary teachers at the *advocator* stage, engineering became an integral part of their teaching practice like other disciplines. The advocates made extensive integration of engineering into their teaching. To use one of the advocates' own words, engineering "permeated the teaching and learning of all other disciplines." The connections the advocates made between engineering and other disciplines were not only extensive but systematic. The analysis of the interview data showed that the connections were systematic in two senses. Firstly, the connections were carefully planned ahead of time by taking the engineering content and the content of other discipline into comprehensive consideration. Secondly, the connections were made for specific purposes. Such purposes might be "to promote the understanding of science and math concepts through engineering" or "to allow

the students to see through engineering relevant applications of what's learned in school," just to mention a few comments made by the advocates in the interviews.

The EEE expertise development dimension

Findings from this study indicated that synchronic differences were also apparent in the elementary teachers' EEE expertise development. 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; and 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 classifying the elementary teachers into the five stages of EEE adoption: *mechanical imitator*, *skillful imitator*, *adaptor*, *improver*, and *creator* (see Table 6).

Mechanical Imitator

I-1: contextualization of engineering learning. It was illuminated by the data of this study that typical of the elementary teachers at the *mechanical imitator* stage is that they 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. An example of this is a 2nd grade teacher who used one of the EiE lesson plans provided by the summer academy as it was and did not realize that this lesson was too long for her seven- or eight-year-olds. This teacher told the researchers that she noticed her students "getting antsy" and "keeping looking around." Despite this, she followed the lesson plan strictly and, as she mentioned in the interview, "did the book all in one sitting." She attributed her students' responses to the lesson to her poor planning. But perhaps such responses were attributable more to her lack of understanding of elementary students' learning needs and of what would work better for them when learning engineering.

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 definitions learned at the INSPIRE summer academy such as the definitions mentioned by a *mechanical imitator* in the interview that "an engineer is the person who designs, a craftsman is the person who makes it, and a technician is the person who uses it." Some elementary teachers at the *mechanical imitator* stage told the researchers in the interview that they taught engineering concepts "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." These mechanical imitators seemed

Table 6
Stages of EEE Expertise Development.

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 unaware of students' engineering learning needs and making no efforts to relating engineering learning to real life	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	I-3: Having no idea how engineering can be integrated into the teaching and learning of other disciplines
Stage II: Skillful Imitator	II-1: Contextualizing engineering teaching by adding some daily life engineering examples into engineering teaching but still unaware of students' learning needs	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 but with no attempts to make actual interdisciplinary connections
Stage III: Adaptor	III-1: Contextualizing engineering by giving students opportunities to find out by themselves engineering around them and by accommodating some generic learning needs of the students	III-2: Being able to develop some teaching strategies and methods specific to engineering content to deal with engineering learning 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: Contextualizing engineering learning by making changes to engineering teaching procedures and materials based on situated engineering learning needs and by enabling students to see that engineering is for solving real-life problems	IV-2: Improving engineering learning experiences by making appropriate changes to engineering teaching materials, procedures and/or steps learned in professional development, and by providing hands-on, concrete, and real-life examples	IV-3: Being able to combining engineering with the teaching and learning of all other disciplines and to combine them in such a way as to allow students to see through engineering the real-world application of knowledge and skills learned in non-engineering disciplines
Stage V: Creator	V-1: Contextualizing engineering learning by creating engineering learning opportunities meeting students' learning needs and promoting engineering through real-life problem solving and real-world applications	V-2: Creating opportunities for students to become active agents in the engineering teaching and learning process and to construct knowledge through active participation and exploration	V-3: Being creative in making interdisciplinary connections that make EEE possible within time constraints and enable elementary students to learn other non-engineering disciplines through a new lens and practical

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. So it is not surprising that when the question "Do you think your lessons changed your students' perceptions of engineering?" was asked, the typical answer heard was "I don't know because I don't know if they had a perception of engineering in the first place."

I-2: development of engineering teaching pedagogy. Numerous learning problems and issues were reported by the elementary teachers of this study. The following are some examples of such problems or issues

quoted from the interview data: 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," to use the exact words of a *mechanical imitator*.

I-3: making interdisciplinary connections. 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

II-1: contextualization of engineering learning. The elementary teachers at the *skillful imitator* stage, though mostly still taught engineering in a de-contextualized manner paying little attention to students' learning needs, began to realize the need to allow the students to realize "the penetration of engineering in all parts of life" or "there is engineering everywhere," just to quote two of the *skillful imitators* from the interview. They responded to such a need by adding some daily life engineering examples outside the EiE teaching materials provided by the INSPIRE summer academy into their engineering teaching. Although the *skillful imitators* still relied on the EiE teaching materials provided by the summer academies and what they learned there as their main engineering teaching resources, the idea of opening up their students' eyes for engineering around them had already begun to burgeon.

II-2: development of engineering teaching pedagogy. 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 who behave well as a group to demonstrate how to work in groups, or they physically arranged the seats and guided the students to the seat arrangements to make engineering activity groups work better. The teaching methods used by *skillful imitators* were not specifically aimed to engineering learning problems. Rather, such methods were generic in nature and could possibly be used to in any other disciplines to address some general learning issues. However, we were able to see in these methods the progress the *skillful imitators* were making in engineering teaching.

II-3: making interdisciplinary connections. While the elementary teachers at the *mechanical imitator* stage taught engineering completely in isolation, 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 activity², a science unit about matter was helpful for the Play-Dough activity³, 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

III-1: contextualization of engineering learning. An important characteristic that distinguished *adaptors* from *skillful imitators* is that *adaptors* became aware of students' learning needs during the engineering teaching process and began to make efforts to accommodate the learning needs. For example, some *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 right away. Another example came from a third grade teacher who told the researchers in the interview that "kids in contemporary society are being very visual, with everything geared to them visually." He, therefore, accommodated such learning need by integrating some pictures or video clips in his engineering teaching.

As illustrated in the above examples, those learning needs that caught the *adaptors'* attention were generic in nature rather than specifically related to engineering learning, rendering the *adaptors* unable to contextualize engineering teaching based on students' real engineering learning needs. Compared with *skillful imitators*, *adaptors* did a better job in contextualizing engineering learning by

²Paper folder activity (Taylor, 2007) is an elementary engineering design activity in which students are required to design and create paper folders based on a specific engineering design process model.

³Play-Dough activity (Cunningham, DeCristofano, Hester, Higgins, Knight, Lachapelle, ... Yocom de Romero, 2007) is an elementary engineering activity in which elementary students are asked to improve their play dough recipe and to prepare quality play dough by exploring the properties of solids and liquids, and by experiencing the sequenced process of mixing the two.

relating engineering to real life. Unlike *skillful imitators*, who simply placed some daily life engineering examples before their students, *adaptors* found ways to place engineering lessons like what is engineering and what is technology into real life contexts. There were some elementary teachers at the *adaptor* stage asking parents or acquaintances who were engineers to speak with their students and talk about what real engineers do. Some *adaptors* asked their students to look for examples of technology in their houses and to explain why these examples were identified as technology. Giving students opportunities to see or find out by themselves how close engineering was to them characterized *adaptors'* way of contextualizing engineering learning.

III-2: development of engineering teaching pedagogy. Compared with the elementary teachers in the previous two stages, the elementary teachers in the *adaptor* stage demonstrated understandings of the nature of engineering activities and important things elementary students need to learn from these activities. Such understandings are well demonstrated in what two of the *adaptors* told the researchers in the interviews: "It didn't really matter to me whether they failed or they succeeded in the book staying on top [in the paper table activity⁴], but did they carry out their design with all members contributing?" And: "We needed to make sure that they [the students] knew when they would try to make something and it wouldn't work, that, in and of itself, was being an engineer." With understandings as such, elementary teachers at the *adaptor* stage were able to employ teaching strategies and methods that were more specifically aimed to engineering learning problems as compared to those strategies and methods used by *skillful imitators*.

Examples of some of such strategies and methods from the interview include (those with quotation mark were direct quotes from the interview): 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"; and 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?,". These examples showed that elementary teachers in the *adaptor* stage began to adapt engineering teaching in ways that, from their perspective, would better meet their students'

engineering learning needs and to improve engineering learning outcomes⁵.

III-3: making interdisciplinary connections. As compared to *skillful imitators*, who made no attempts to make interdisciplinary connections, *adaptors* began to make some attempts to connect engineering with the teaching and learning of other disciplines. These attempts included combining the engineering assembly line activity⁶ with the topic of the assembly line in social studies, and adding the engineering pop-up card⁷ 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, these connections were superficial and in these connections engineering remained its own separate entity, appended to but not truly integrated with other disciplines.

Improver

IV-1: contextualization of engineering learning. 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 with an intention to improve the engineering learning outcomes.⁸ A 4th grade teacher told the researchers in the interview that she realized "the 4th grade is really important for packaging engineering," so she "found a great book out of our basal that talked about packaging, and used that, and used it throughout the year..." (The basal was the elementary students' reader, and to use the elementary teacher's words, "it is called a basal because it's not novels, it's either snippets of long books or it's a compilation of a lot of books.") According to this elementary teacher's own words from the interview, she "decided to use the story out of the basal for packaging engineering and talking about it" because "it was more suited toward kids' lingo."

⁵ The claim that the adaptations made by the *adaptors* would improve student learning outcome is reported here totally based the *adaptors'* perspective. This study did not provide evidence to support this claim, and it was not the focus of this study to do so. Future research is needed to furnish such evidence.

⁶ Engineering assembly line activity (see lesson 2 in National Center for Technological Literacy, 2005) is 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.

⁷ Pop-up card activity (Whiting, 2001) is 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.

⁸ The changes made by the *improvers* were intended by them to improve student learning outcome. This study did not provide evidence to show this was the case, and it was not the focus of this study to do so. Future research is needed to furnish such evidence.

⁴ Paper table activity (Design Squad, 2008) is an elementary engineering design activity in which students are required to design and create paper tables based on a specific engineering design process model.

When this elementary teacher went deeper into her story, it became more obvious how her ideas about engineering teaching and learning were different from those of the elementary teachers in previous stages:

the book [the EiE story book meant to be used by INSPIRE summer academy elementary teachers] was not bad by any means, but I was worried that the kids would not have been interested in it, and so I did change the story, I read the story out of the basal instead. It's about a little boy who decides to—he goes to the grocery store for his mother, she needs toothpaste, and it's \$1.50. He was like, “Why does it cost \$1.50?” So he comes up with his way to package his toothpaste, and he ends up being a millionaire. It's a play, so the kids just really enjoyed it, but I got to use the same lingo as packaging engineers and talked about how they help even with income and gross income, and also talked about money... So I thought it was a better fit.

This elementary teacher presented us an example of how the *improvers* thought would improve student learning experiences by making appropriate changes to engineering teaching procedures and materials based on situated engineering teaching and learning needs. This elementary teacher told the researchers in the interview that it was also her intention to enable her students to see from this engineering packaging story that “engineering is for solving real life problems” and thus feel motivated to learn engineering. Such intention was also expressed by a 2nd grade *improver* who compared and contrasted a candle, a flashlight, and a light bulb with her students. From such an intention that was typical among *improvers* we can see that improvers were contextualizing engineering learning by showing her students engineering is for solving real-life problems.

IV-2: development of engineering teaching pedagogy. One elementary teacher at the *improver* stage made an impressive comment about assessing engineering learning: “That [assessing engineering learning] 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 so much in the sense that it reflects the teacher's heightened understanding of assessment of learning as in the sense that it gives a good summary of the principle *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. To these elementary teachers, engineering teaching was not giving students “isolated mental pictures and images,” as mentioned by an *improver* in the interview, but giving students hands-on, concrete, and real-life examples, and opportunities to think, to experience, and to improve. One elementary teacher found that it had stuck in her students' heads “that technology was something that was robotic or required batteries.” Here is her approach for correcting the misconception:

I brought in things like one of those little vacuums that it's—it has automatic sensors and when something's dropped or spilled—it'll move. And we picked it apart and we talked about all the little pieces in it. I brought in band-aids. I brought in nut crackers and pencil sharpeners and they were able to just play with it and talk about it, and I think that really helped.

This approach is a great example of bringing in hands-on, concrete, and real-life examples to meet learning needs and to promote engineering learning. Another elementary teacher at the *improver* stage decided, instead of doing the paper folder activity she learned in 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, such as 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, while rulers and “just various items in the classroom,” as one *improver* said in the interview, were utilized in teaching engineering and engineering concepts. 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.

IV-3: making interdisciplinary connections. Compared with the *adaptors* who were limited in their abilities to see the opportunities of making interdisciplinary connections and who made only occasional and sporadic interdisciplinary connections, the *improvers* were able to make more comprehensive interdisciplinary connections. Not only did the *improvers* find opportunities to connect engineering with all other disciplines they taught but they also were becoming able to show through the connections the relevance and usefulness of engineering. In the interdisciplinary connections made by the *improvers*, engineering was not an add-on. Rather, engineering and other disciplines were tied together in such a way allowing

elementary students to see that engineering requires knowledge and skills in other disciplines, and these knowledge and skills found real-world applications through engineering.

An example came from an *improver* who combined writing in language arts and the learning of measuring and fraction with the paper folder activity. In making these interdisciplinary connections, this *improver* made conscious efforts to allow her students to see that writing skills facilitated the documentation of their design solutions and their design improvement plans, and that skills in measuring and knowledge of fraction were indispensable for the success of creating the paper table. As this *improver* mentioned in the interview, it was her hope that her students' interests in learning engineering and motivation in learning other disciplines would increase as a result of seeing through engineering the applications of what they were learning or had learned in other disciplines. This *improver's* hope served as a good summary of what the *improvers* tried to achieve in their efforts to connect engineering with the teaching and learning of other disciplines. And this hope also helped explain the progress the *improvers* make in making connections between engineering and other disciplines.

Creator

V-1: contextualization of engineering learning. The *creator* stage is aptly named, for “creative” and “creating” are perfect descriptors for the elementary teachers who had progressed past the *improver* stage. The elementary teachers at the *creator* stage contextualized engineering learning by creating real life contexts to allow their students to experience engineering and its relevance. One of the elementary teachers at the *creator* stage came up with a new way for her kids to experience the engineering design and re-design process:

I had some kindergarteners come down. They were our consumer group and the kids made their design. And they told the kids whether it was a really nice picture, was it colorful enough, was it easy to put together, and the kids took that information and started redesign.

Among the elementary teachers participating in this study, there were three elementary teachers who did the egg-drop activity instead of the EiE plant packaging activity⁹ introduced in the INSPIRE summer academy. The following teacher is the one among the three who did this activity differently:

I thought it really went along well with the kids because it was springtime, and we needed to find answer to the

question of how to transport eggs from one place to another. We've got to develop a package. And so then we imagined, “Okay, how could we do this?” I gave them constrictions. I told them, “It can't be bigger than this and this,” and materials were really important. And then we developed it, we came up with the steps, we created a test from 6 feet off a ladder; and then we came back, we redesigned it, picked up our flaws, and then we took it to the roof and dropped it from the roof. So we kind of changed our packaging...

This elementary teacher re-created the egg-drop activity by tying it into finding solutions to a real-world problem. Within the context of this real-world problem, the students experienced the engineering design process and the relevance of engineering in solving real-world problems.

V-2: development of engineering teaching pedagogy.

An important element in the above egg-drop activity is that the elementary teacher got her students involved in the process of creating the activity. As illustrated by this example, elementary teachers at the *creator* stage created opportunities for their students to become active agents in the engineering learning process. This is a big progress the *creators* made in their development of engineering teaching pedagogy. The following are two more examples illustrating this progress.

In the Play Dough activity, a *creator* gave her students the opportunity to decide on their own methods for testing their play dough. This *creator* talked about her students' creative testing methods in the interview such as the “stick to hands or desk test” and “the stamp test” of pressing erasers of various shapes down into the play dough to see if it “kept the shape or closed back.” This *creator* made her students actively participate in the engineering activity by allowing them some decision power in the teaching and learning process. According to this teacher, allowing the students to come up with their own methods for testing their products would not only motivate the students to learn but would also allow them to have a clear picture about the goal of their design from the very beginning and the aspects they needed to work on for improvement to reach the goal. Another example came from a third grade teacher, who asked his students to work in groups, do research on what engineers do through websites about engineers, and report back to the class about their findings. This teacher told the researchers that he thought his student learned “a great deal more than they would by listening to my lecture on engineering and engineers.”

Although the roles of active agent the students were allowed to play in the above example differed, the underlying pedagogical purpose was the same: enabling students to construct knowledge through active participation and exploration. This pedagogical purpose characterized and explained the *creators'* improved pedagogical practices over teachers in previous stages.

⁹ An engineering design activity for 3rd–5th graders in the EiE unit of Thinking Inside the Box: Designing a Plant Package (see <http://www.mos.org/eie/plants.php> for reference).

V-3: making interdisciplinary connections. 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 quality¹⁰ 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 some elementary teachers in the study explained, electricity and magnetism are in the 4th grade TAKS (Texas Assessment of Knowledge and Skills) and are the content 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 other non-engineering disciplines through a new lens. One of the two elementary teachers put this in some plain words of her own, “if you would align it [engineering] 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, an elementary teacher added engineering in and asked her students to produce a boat out of aluminum foil, to use the teacher’s own words, “by sketching it, testing it, and re-designing it.” Another teacher combined engineering with her science lesson about filters, asking her students 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, to use her own words, “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 their students, including: 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.

¹⁰Quality is used here only in terms of how the engineering teaching practices enhanced the possibility of teaching engineering within time constraints and created new lenses for students to learn other non-engineering disciplines, not in terms of student learning outcomes.

Discussion: An Analytical Look at the EEE Adoption and Expertise Development Framework

The EEE adoption and expertise development framework constructed in this study is two dimensional: the EEE adoption dimension and the EEE expertise development dimension. When the elementary teachers in this study were looked at collectively and at a given time, their EEE adoption and EEE expertise development were characterized by synchronic differences showing that they stood at different EEE adoption and EEE expertise development stages despite the fact that they received the same training in engineering teaching and practicing engineering teaching for the same amount of time. In the second round of data analyses, when the elementary teachers were looked at over time and when comparisons and contrasts were made of the interview data of the same teacher collected in the two consecutive years of 2009 and 2010, diachronic progression along the EEE adoption and the EEE expertise development stages was discernible.

In the EEE adoption dimension, four overarching classificatory categories (i.e., *perception of practicality and sustainability of EE*, *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. These four stages are different from those stages in Rogers’ (2003) diffusion of innovation model and the CBAM (Hall & Hord, 1987) in the sense that the four EEE adoption stages are not general in nature. Instead, these four stages are contextualized in the specific contexts of teaching engineering to elementary students. Another aspect making the four EEE adoption stages differ from the Rogers’ (2003) and the CBAM (Hall & Hord, 1987) stages is the fact that the investigation of EEE adoption in this study did not include the process of knowing about an innovation and the process of making a decision about whether or not to implement the innovation, both of which are part of Rogers’ (2003) diffusion of innovation model and the CBAM (Hall & Hord, 1987). In other words, the four EEE adoption stages are different in the sense that they focus on the EEE implementation process to reveal how elementary teachers are different in their EEE adoption.

Focusing on the EEE implementation process, the four EEE adoption stages reveal how elementary teachers might be different, both attitudinally and behaviorally, in their adoption of engineering teaching. So the four EEE adoption stages could be seen as a combination of the *stages of concern* framework and the *levels of use* framework that is specifically situated in the context of implementing engineering teaching. The four EEE adoption stages could be used as a tool for visualizing elementary teachers’ synchronic differences and diachronic progression in EEE adoption. Whereas the four EEE adoption classificatory

categories provide a general sense about what to look at when assessing an elementary teacher's EEE adoption, the staged descriptive characterizations in each of the four categories furnish more detailed and more structured information for the assessment.

Rogers (2003) concluded that an individual's perception of the five characteristics of an innovation (i.e., relative advantage, compatibility, complexity, triability, and observability) determines the innovation adoption rate, defined as "the relative speed with which an innovation is adopted by members of a social system (p. 221)." The EEE adoption category of *perception of practicality and sustainability of EEE* reflects elementary teachers' perceptions about whether EEE is compatible with their teaching schedule or tasks and whether the effects of EEE could be observable to others. Although the category of *comfort level with engineering teaching* shows how elementary teachers feel about the complexity and triability of EEE, the category of *perception of EEE benefits to elementary students* reveals how elementary teachers think about the relative advantage of EEE. So the first three EEE adoption categories (*perception of practicality and sustainability of EEE*, *comfort level with engineering teaching*, *perception of EEE benefits to elementary learners*) reflect, in varying degrees, practice-based perception of the five innovation characteristics associated with EEE.

Although the EEE adoption dimension is meant to capture elementary teachers' differences in their EEE adoption, the EEE expertise development dimension presents a structured picture of how elementary teachers might be different in their knowledge and skills of teaching engineering. In this picture, the three EEE expertise development categories (*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. These overarching EEE expertise development categories (shown in Table 6) provide us with a framework that could be used to guide research on elementary teachers' EEE expertise development. In comparison with this specific EEE expertise development framework, Dreyfus's skill acquisition model would be too generic to render contextualized understanding about elementary engineering teaching.

As mentioned earlier, Berliner (1988a, 1988b) applied the Dreyfus skill acquisition model in studying teaching expertise development and pointed out that there are developmental differences between novice and expert teachers in seven areas of teaching expertise (*interpreting classroom phenomena*, *discerning the importance of events*, *using routines*, *predicting classroom phenomena*, *judging typical and atypical events*, and *evaluating teaching performance*). Berliner's model deals with general teaching expertise without setting in the teaching and

learning context of any particular subject matter. Therefore, the EEE expertise development framework constructed in this study extends Berliner's model by focusing on the teaching of the specific subject matter of engineering. This study contributed to the literature of teaching expertise development research by identifying specific engineering teaching expertise areas as denoted by the three EEE expertise development categories shown in Table 6. These engineering teaching expertise areas and their corresponding developmental stages enable us to scrutinize elementary teachers' EEE expertise development through a focused lens that would not be available if a generic view about teaching expertise is guiding the research.

Conclusion

An EEE adoption and EEE expertise development framework was constructed in this study. This framework identified respective classificatory categories in the EEE adoption dimension and the EEE expertise development dimension. With the staged descriptive characterizations, we would be able to classify elementary teachers practicing engineering teaching into specific EEE adoption or EEE expertise development stages falling within each of the classificatory categories. This detailed, operationalized EEE adoption and expertise development framework provides us with useful tools to conceptualize, assess, and track elementary teachers' EEE adoption and EEE expertise development in their engineering teaching practice. Using the EEE adoption and EEE expertise development framework, professional development providers would be able to map their elementary-teacher learners' standings at a given time and to assess or track their progress over time in the EEE adoption and EEE expertise development, and may consequently be able to provide elementary teachers with appropriate and most-needed help supporting EEE adoption and EEE expertise development.

Despite the potential usefulness of the EEE adoption and EEE expertise development framework, this study is limited in the sense that the construction of the framework was based on the interview and survey data collected from the participating elementary teachers. In other words, the coding of engineering teaching practices into different EEE adoption or EEE expertise development stages was based on the elementary teachers' personal and subjective opinion and judgment of how well they did in their engineering teaching, and this study provided no objective evidence about how well these teachers really did in their engineering teaching. It is, therefore, envisaged that, in future research, classification of elementary teachers' engineering teaching practices could be tied with objective evidence about the actual effects of the teaching practices. Also, it is hoped that survey instruments or observation protocols could be developed in the future for more effective and efficient classification.

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