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A Conceptual K-6 Teacher Competency Model for Teaching Engineering

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Abstract

The *status quo* of elementary teachers indicate that their unpreparedness for integrating engineering into their classrooms is tri-dimensional, including engineering subject matter dimension, engineering teaching related dimension, and attitudinal dimension related to engineering integration. Based on a competency perspective, the purpose of this study is to develop a conceptual K-6 teacher competency model, which can be utilized in engineering professional development for in-service teachers who are novices in teaching engineering. Based on literature reviews on teacher competency models in general education as well as in engineering education, this study presents a conceptual K-6 teacher competency model for teaching engineering. This model encompasses the following seven dimensions: engineering concept knowledge; engineering skills; knowledge about engineering disciplines; engineering pedagogical content knowledge; attitudes toward engineering; attitudes toward teaching engineering; and integration of engineering with other subjects. The competencies falling within each of these seven dimensions are also identified. This study further proposes a subsequent model verification study using a Delphi method with four rounds of surveys.

Keywords: Engineering Education, Teacher Competency Model, K-6, Delphi Method;

1. Introduction

Engineering Education has been brought into the K-6 classrooms since the early 1990s (Katehi, Pearson, & Feder, 2009) with the development of STEM project. Many programs and institutions, practitioners and researchers have made efforts to design and implement programs to increase the awareness of and the participations of engineering design and career among elementary students (Nugent, Kunz, Rilett, & Jones, 2010). Previous research indicates that incorporating engineering education into K-12 classrooms has several potential benefits: enhance student learning and achievement in related subjects such as science and mathematics (Katehi et al., 2009; Wicklein, 2003); increase students' awareness of engineering and access to engineering careers (Katehi et al., 2009; Wicklein, 2003); increase the technological literacy of all students (Katehi et. al, 2009); and improve students' problem-solving skills such as problem formulation and assessing alternative solutions (Benenson, 2001). However, the professional development opportunities for elementary engineering education, compared to other STEM subjects, such as science, technology, and mathematics, are few and "the qualifications for engineering educators at the K-12 level have not been described (Katehi et al., 2009, p9)".

In order to help make up this gap, based on literature review, the purpose of the present study is to develop a conceptual K-6 teacher competency model that is needed to be considered by engineering professional development for in-service elementary teachers who are novices in teaching engineering. The researchers reviewed the nature of engineering content knowledge and pedagogical engineering knowledge (Hynes, 2007). In terms of engineering content knowledge, the interdisciplinary nature of engineering epistemology among basic sciences (science, mathematics, and technology) and design has been considered. The pedagogical engineering knowledge, a special amalgam of engineering content and pedagogy, has also been explored. In addition, the skills and attitudes that are emphasized in representative programs providing pre-service and in-service professional-development programs for engineering teachers have been investigated. The guiding question of this study is "what are the dimensions and the competencies falling within each of the dimensions required of K-6 teacher for successful implementing engineering in elementary classrooms?" As this study is a preliminary research and the next phase is to verify this model to enhance its reliability and validity, this conceptual model may ultimately be utilized by elementary teacher for self-check and by professional development programs as guidelines for teacher training and assessment.

The paper will present the theoretical framework of this study, which is followed by a literature review on teacher professional development in K-6 engineering education, competency models for general teaching, and the existing competency models for engineering education. Then the conceptual K-6 teacher competency model will be displayed with a discussion of the subsequent verification study using a Delphi method.

2. Theoretical framework--a competency-based perspective

As is suggested by the definition of competency not only as knowledge and skills but also as attitudes, values, motivations and beliefs people need in order to be successful in a job (Gupta, 1999), the competency-based perspective is more holistic and inclusive than the knowledge-based perspective guiding previous teacher knowledge research (see, e.g. Grossman, 1990; Shulman, 1986, 1987; Turner-Bisset, 1999).

The competency-based perspective means to approach teaching practice and teacher preparation not in terms of teacher knowledge but in terms of teacher competence—"the ability of a teacher to deal adequately with the demands of the teaching profession using an integrated set of knowledge, skills and attitudes as manifested in both the performance of the teacher and reflection on his or her performance' (Nijveldt, Beijaard, Brekelmans, Verloop & Wubbels, 2005, p. 90)." Constructing a K-6 teacher competency model for engineering teaching is therefore intended to identify an integrated set of knowledge, skills, and attitudes that will improve elementary teachers' engineering teaching performance and engage them in reflective practice (Schön, 1983). Elementary teachers are weak in science knowledge, lack subject matter knowledge in engineering and previous experience with engineering teaching, and are skeptical and fearful of including engineering in their classrooms. Taking elementary teachers' unpreparedness for engineering teaching into consideration, a teacher competency model for engineering teaching will also benefit elementary teachers in the sense that "large skill sets are broken down into competencies, which may have sequential levels of mastery. Competencies reinforce one another from basic to advanced as learning progresses; the impact of increasing competencies is synergistic, and the whole is greater than the sum of the parts (Council on Education for Public Health, 2006, p. 1)."

3. Literature Review

3.1 Teacher professional development in K-6 engineering education

The national concern about the shrinking STEM workforce pipeline (Jobs for the Future, 2007) and the dramatic decrease of undergraduate and graduate enrollment in engineering science (U.S. Government Accountability office, 2005) are much of the impetus for the educational innovation of integrating engineering into elementary classrooms. Introduction to engineering at elementary level is viewed as a means to develop among young children an interest in engineering and encourage them to consider it as a career (Petroski, 2003; Wicklein, 2003). Introducing engineering into elementary education is also intended to foster elementary students' problem solving skills (e.g. iteration, testing of alternative solutions, and evaluation of data to guide decisions) (Benenson, 2001) and to motivate them to learn math and science concepts through illustration of relevant applications (Engstrom, 2001; Wicklein, 2003).

To achieve these desired outcomes of integrating engineering into elementary classrooms we need to address the challenge of preparing elementary teachers for effective engineering teaching. Elementary teachers are unconfident in teaching engineering and are skeptical of integrating engineering into their classrooms (Cunningham, 2008; Liu, Carr & Strobel, 2009). The way elementary teachers feel about engineering has much to do with their disinterest and unpreparedness in teaching science (Buczynski & Hansen, 2010) and teaching design, engineering, and technology (DET) (Yasar, Baker, Robinson-Kurpius, Krause, & Roberts, 2006). Research on elementary professional development in engineering also reveals that elementary teachers have misconceptions about engineering and technology (Cunningham, Lachapelle, & Lindgren-Streicher, 2006) and view engineering as a difficult and unapproachable discipline (Cunningham, 2008). This view corresponds to the common misconception among school teachers that engineering is intellectually challenging and inclusion of engineering education serves only a few students who are intellectually and passionately geared to math and science (Brophy, Klein, Portsmore, & Rogers, 2008). A misconception as such would influence elementary teachers' attitudes and instructional decisions about engineering integration. Research-based evidence reveals that elementary teachers' various concerns, like state-mandated testing, lack of time, resources, and administrative support (Hsu, Cardella, Purzer & Diaz 2010; Strobel &

Sun, 2011), are also factors wielding impact on elementary teachers' attitude and instructional decisions about engineering integration.

3.2 Teacher competency models

Growing emphasis on competence-based training is firmly wedded to the tradition of teaching performance assessment systems. Much research has shown that the educational experience for students is significantly dependent on the quality and effectiveness of teachers, more than any other single alterable factor (Darling-Hammond, 1999; Rowan, 2004). This has led the efforts to identify teaching core competencies based on effective teaching attributes in terms of subject matter knowledge, pedagogical content knowledge, knowledge of teaching and learning, curricular knowledge, teaching experience, certification status, and so on (Grossman, 1995; Rice, 2003; Wayne & Youngs, 2003; Westera, 2001). As a result, various instruments of teaching performance assessment have been developed and implemented at various stages in the context of selection, certification, and professional development (Dwyer, 1998; Tigelaar, Dolmans, Wolfhagen, & Van der Vleuten, 2004)

Teaching competencies are defined as an integrated set of personal characteristics, knowledge, skills, and attitudes that are needed for effective performance in various teaching contexts (Smith & Simpson, 1995; Tigelaar et al., 2004). Competencies are dynamic in nature and depend on the relevant social context, it is thus very critical to distinguish between different levels of teaching competencies (Spector, 2001). In terms of teacher competency in engineering education, because of its developing nature as teaching content for K-12 schools, there is neither clear description of required knowledge, skills, and attitude for teachers; nor license/certification for engineering teacher preparation. Katehi et al. (2009) indicated "most instructors who have a background in technology education teach engineering in middle and high schools; a smaller number have backgrounds in science education; and an even smaller number have backgrounds in engineering" (p.103).

Currently, multiple government agencies and corporate foundations have invested significant resources in efforts to improve teacher professional development program in the science, technology, engineering, and mathematics (STEM) disciplines. Much effort has been consequently made to determine whether teacher training procedure could modify teachers' behaviours by identifying essential knowledge and skills for K-12 teachers (Tigelaar et al., 2004). However, this resultant view of the interaction between program developers and representatives of the profession (i.e. STEM teachers) are based on 'program-oriented' or 'development-oriented' perspective toward teacher professional development; and as a result most professional development programs seek to improve a set of knowledge-based competencies for teachers according to each of STEM disciplines. In other words, there is no sound and broad-based scientific framework for what constitutes competent engineering teaching from which inferences can be drawn to assess teacher competence.

For example, Duggan-Haas, Enfield, and Ashman (2000) pointed that the NSTA Standards for science teacher education proposes a linear model including two dimensions, such as 'Content' and 'Pedagogy', which does not accurately reflect the views of the entire science education community. Therefore, they argued that both 'Content' and 'Pedagogy' should not be treated as mutually exclusive, rather competencies of pedagogical content knowledge (PCK) should be included in the Standards, as an essential tenet in the current thinking about science teacher education. In terms of mathematical teaching competencies, the National Council of Teachers of Mathematics (2000) reported that teachers who have strong subject matter knowledge give details in their lesson, link the topic to other topics, ask students many questions, and stray from the textbook. Subject matter knowledge of teachers has been an interest for educators, but more recently there has been a shift to pedagogical content knowledge (Johnston & Ahtee, 2006). Similarly, Adedoyin (2011) emphasized the importance of identification of competencies about mathematics pedagogical content knowledge.

To build a comprehensive model of teaching competencies, the Delphi method has been widely used to identify the needs of teaching community and predict future educational trends and (Benjamin, Carroll, Dewar, Lempert, & Stockly, 2000; Iwu, 1988; McCoy, 2001; Rickman, 1987; Williams, 2000). Furthermore, with the advanced online capability, the Delphi method became a very popular educational research method by saving time and cost to do research. Rickman (1987) conducted a Delphi study to identify emerging competencies, which would be beneficial to business educators planning the curriculum for training future employees to be prepared to work in the changing environment. Iwu (1988) identified the importance of computer competencies needed for the certification of secondary school business teachers, determined the degree of importance of those competencies, and ranked the categories of competencies. McCoy (2001) conducted a three-round Delphi study to identify the computer competencies needed for business education teachers in the 21st century. As such, the literature indicates that the Delphi method has been used in many studies to identify teaching competencies by drawing group consensus from a panel of educational experts.

3.3 Existing K-12 teacher competency models in engineering education

"Knowledge base for teaching" is "a codified or codifiable aggregation of knowledge, skill, understanding, and technology, of ethics and disposition, of collective responsibility, as well as a means for representing and communicating it" (Shulman, 1987, p. 4). Based on Shulman (1987)'s work, Grossman (1990) refined the categories of teacher knowledge into subject matter knowledge, general pedagogical knowledge, knowledge of context, and pedagogical content knowledge. Similarly, Ball, Thames, and Phelps (2008) argued that teachers must have the knowledge of the content and be able to motivate students, interpret students' thinking, as well as sequence the instructional content. Gess-Newsome (1999)'s model further highlighted that pedagogical content knowledge is the overlap of the subject matter, pedagogical, and contextual knowledge bases. As this paper focuses on the context of engineering education, the knowledge bases of general pedagogical knowledge and knowledge of context which cover a more general and broader scope will therefore be excluded in this literature review.

"Subject matter content knowledge consists of an explanatory framework in the discipline and the rules of evidence and proof within the discipline" (Manouchehri, 1997, p.199). Hynes (2007, p. 27) researched on the teacher knowledge base of K-12 engineering education based on literature review and proposed a teacher competency model concerning the subject matter content knowledge: engineering design and the technology development process; basic concepts of engineering and technologies from various fields (i.e., mechanics, electrical circuits, manufacturing technologies, communications systems, or computer programming); materials (e.g., advantages/disadvantages of metals, plastics/polymers, ceramics or organic materials); the profession and what engineers do; the requisite fundamental math and physics/science concepts.

Pedagogical content knowledge (PCK) is related to the topics and concerns of teaching particular topics (Viri, 2003). The following is a proposed K-12 teacher competency model in engineering education concerning pedagogical content knowledge (Hynes, 2007, p. 41):

1) PCK of students
    - Common misconceptions (math and science)
    - Common difficulties (spatial reasoning, multivariate problems/decision-making)
    - What is engaging and relevant in their lives
2) PCK of real world examples
    - Design activities that are engaging for students
    - Design activities that contain relevant math, science, engineering content
3) PCK of appropriate examples
    - Examples or analogies students can relate to
    - Examples/activities appropriately challenging for students level of competence
4) PCK of managing the lesson/design activities
    - Managing students within groups working on unique engineering projects
    - Managing groups to be on track to complete a fruitful project (balance between not enough and too much guidance or direction)
    - Assessing projects at various levels of progression
5) PCK of strategies for student understanding
    - Simpler forms of the concept at hand to relate to something students understand
    - Physical demonstrations that reveal concepts to students
    - Probing questions that elicit exploration and thought from the students

4. Methods

In order to identify the major dimensions involved with K-6 teacher competence in engineering education, the following books were investigated to come up with the components in our conceptual competency model:

1) Danielson, C. (1996). Enhancing professional practice: a framework for teaching. Alexandria, VA: Association for Supervision and Curriculum Development.

2) Katehi, L., Pearson, G., & Feder, M. (Eds.) (2009). Engineering in K-12 education: understanding the status and improving the prospects. Washington, D.C.: The National Academic Press.

3) National Academy of Engineering (2010). Standards for K-12 engineering education. Washington, D.C.: The National Academic Press.

In addition, other academic publications have been explored (Hynes, 2007; Maddocks, Dickens & Crawford, 2002; New Hampshire Department of Education, 2008; Sun & Strobel, 2011). The five researchers of this study first worked independently to identify the dimensions and relevant competencies falling within each of the dimensions concerning K-6 engineering education. Then the five researchers presented their individual work to each other to compile the final conceptual model by adding/removing dimensions or competencies as well as categorizing competencies into distinctive dimensions upon discussion. In this sense, the researcher triangulation (Patton, 2002) was achieved in the data analysis.

5. Results

While the competency is defined as "a cluster of related knowledge, skills and attitudes that affects a major part of one's job (a role or responsibility), that correlates with performance on the job, that can be measured against well-accepted standards, and that can be improved via training and development" (Parry, 1996, p. 50), the efforts to define teachers' competencies always tend to overemphasize the cognitive skills (Olson & Wyett, 2000). To this end, the competencies identified and covered by the conceptual K-6 teacher competency model constructed in this study is of multiple-levels from basic to advanced and of multiple-dimensions covering the dimensions mentioned earlier-- engineering subject matter dimension, engineering teaching related dimension, and attitudinal dimension related to engineering integration. The multi-facetedness and complexity involved herein indicate that determining which competencies to be bundled together as optimal in the model would be a great challenge. Based on literature review, the researchers tentatively developed a conceptual K-6 teacher competency model for engineering education, which encompasses the 7 dimensions as shown in Table 1.

Table 1. A Conceptual K-6 Teacher Competency Model for Engineering Education

Dimension 1. Engineering Concept Knowledge: this dimension refers to the essential content of engineering, such as systems, constraints, modeling, optimization, and so on.
Competency • Knowledge of design • Knowledge of system, subsystem, and control • Knowledge of structure-behavior-function (SBF) • Knowledge of trade-offs, constraints • Knowledge of technology development process • Knowledge of modeling Knowledge of optimization • Knowledge of engineering & society • Knowledge of nature of engineering • Knowledge of materials (e.g., advantages/disadvantages of metals, plastics/polymers, ceramics or organic materials) • Knowledge of the professional and ethical responsibilities of engineers • Knowledge of fundamental science/physics and math
Dimension 2. Engineering Skills: This dimension refers to engineering skills, such as visualization, sketching, and engineering graphics; teaming and oral and written communication skill development; design, prototyping etc.
Competency • Skills in defining the problem • Skills in specifying requirements • Skills in decomposing systems • Skills in analysis • Skills in generating solutions • Skills in drawing and creating representations • Skills in experimenting and testing

- Skills in systems thinking
- Skills in visualization
- Skills in engineering graphics
- Skills in engineering design
- Teamwork skills in engineering projects
- Communication skills in engineering projects
- Skills in prototyping
- Skills in information technology

Dimension 3. Knowledge about Engineering Disciplines: this dimension refers to knowledge on the different disciplines such as civil engineering, mechanical, electrical etc.

Competency

- Knowledge of basic concepts of engineering and technologies from mechanics
- Knowledge of basic concepts of engineering and technologies from electrical circuits
- Knowledge of basic concepts of engineering and technologies from manufacturing technologies
- Knowledge of basic concepts of engineering and technologies from communications systems
- Knowledge of basic concepts of engineering and technologies from computer programming
- Knowledge of basic concepts of engineering and technologies from civil engineering
- Knowledge of the historical evolution of technological inventions as societies needs and wants change

Dimension 4. Engineering Pedagogical Content Knowledge: this dimension refers to specific pedagogies necessary to teach engineering. These would go beyond general pedagogical knowledge.

Competency

- Knowledge of selecting doable and manageable engineering instructional goals
- Knowledge of student common misconceptions about engineering
- Knowledge of student common engineering learning difficulties
- Knowledge of the engineering design process appropriate for students' level of understanding
- Knowledge of the engaging design activities for students
- knowledge of examples or analogies students can relate to
- Knowledge of examples/activities appropriately challenging for students' level of competence
- Knowledge of managing students within groups working on unique engineering projects
- Knowledge of managing groups to be on track to complete a fruitful project (balance between not enough and too much guidance or direction)
- Knowledge of organizing physical space for efficient engineering teamwork
- Knowledge of assessing projects at various levels of progression
- Knowledge of both formal and informal assessment methods for assessing engineering work
- Knowledge of using assessment data to give feedback to students for improving engineering learning
- Knowledge of making connections between engineering and real world applications
- Knowledge of simpler forms of the concept at hand to relate to something students understand
- Knowledge of physical demonstrations that reveal concepts to students
- Knowledge of probing questions that elicit exploration and thought from the students
- Knowledge of using technology resources to promote engineering learning

Dimension 5. Attitudes toward Engineering: this dimension refers to affective components and general attitudes towards engineering.

Competency

- Willing to improve engineering concept knowledge
- Willing to learn about innovative concepts and ideas in engineering
- Understanding of the impact of engineering solutions on society
- Enthusiastic, in the application of their knowledge and skills in pursuit of the practice of engineering

Dimension 6. Attitudes toward Teaching Engineering: this dimension refers to teachers' attitudes towards teaching engineering.

Competency

- Confident in teaching engineering concept knowledge
- Confident in applying engineering pedagogical content knowledge in teaching
- Enthusiastic, in the application of their knowledge and skills in teaching engineering
- Willing to design and implement innovative engineering curricula
- Willing to discuss and share engineering teaching experience with other teachers
- Willing to take the feedback on engineering teaching from students, parents and the teacher community
- Positive about the benefits of teaching engineering to P-6 graders

Dimension 7. Integration of Engineering with other subjects: this dimension refers to competencies aimed to integrate engineering within the context of other subject areas.

Competency

- Knowledge of differences between teaching engineering and physics/chemistry
- Knowledge of integrating engineering teaching with science teaching

- Knowledge of integrating engineering teaching with mathematics teaching
- Knowledge of information and communication
- Knowledge of energy and power
- Knowledge of transportation
- Knowledge of food and medicine
- Knowledge of construction
- Knowledge of helping students use knowledge in other subjects like math and science to accomplish engineering learning activities
- Knowledge of aligning engineering teaching with the teaching and learning of other subjects
- Knowledge of demonstrating the connections between engineering other subjects to students

6. Future Work--Model Verification using a Delphi Method

The next phase of our study is to use the Delphi method to conduct four rounds of Delphi surveys. For the last 20 years, Delphi has been the chief methodology to construct core competency models (Tough, 2009). Applying the Delphi technique, the researchers will conduct the surveys among an aptly focused panel consisting of experts of elementary engineering professional development, elementary engineering education researchers, and elementary teachers experienced in engineering teaching to verify the dimensions and relevant competencies in our conceptual competency model for effective engineering teaching in K-6 elementary classrooms. The four rounds of surveys, which are demonstrated in Table 2, are intended to take advantage of the talent, experience, and knowledge of the panelists in a structured manner and to identify an integrated set of competencies these panelists agreed to be essential for successful and effective engineering teaching in elementary classrooms.

More importantly, the surveys will help display the interrelationship between the competencies in different dimensions by identifying the essential competencies; optional (meaning not required) competencies; frequently used (by teachers) competencies; competencies that are difficult for teachers to develop; competencies having impact on student achievement; competencies addressed in current TPD programs and the ones that are difficult to be assessed. These dimensions and competencies will thus be finally structured, according to the panelists' ranking, into a K-6 competency model for elementary engineering teaching.

Table 2. The Intended Delphi Method for Model Verification

Surveys	Round I	Round II	Round III	Round IV
Using a Delphi technique	1)Demographic information 2) Participants will be asked to modify the list of competency dimensions about ENE teaching, by adding and/or deleting, in whatever ways they see appropriate.	Participants will share their opinions on competencies by categorizing, ranking, adding and/or deleting, in whatever ways they see appropriate.	Participants will be asked to think of an exemplary engineering teacher and share their thoughts and comments on what makes that person an exemplary engineering teacher.	Participants will be asked to identify the interrelationship between the competencies.

7. Conclusion

The aforementioned status quo of elementary teachers indicate that their unpreparedness for integrating engineering into their classrooms is tri-dimensional, including engineering subject matter dimension, engineering teaching related dimension, and attitudinal dimension related to engineering integration. This study constructed a conceptual K-6 teacher competency model capturing competencies in each of the seven dimensions elementary teachers need to develop for successful and effective engineering teaching. To construct such a model, the researchers of this study adopted a competency-based perspective toward teaching practice and teacher preparation. It is hoped that the K-6 competency model based on these dimensions and the relevant competencies would help improve elementary teacher professional development in engineering and would benefit elementary teachers by guiding them in and through the process of building teacher competence for engineering teaching.

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