

**BECOMING STEM TEACHERS: EXAMINING CHANGES IN SCIENCE
TEACHERS' CONCEPTUAL UNDERSTANDING ABOUT EARTHQUAKE
ENGINEERING**

A Dissertation

by

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ABSTRACT

This multi-paper dissertation reports results from three related research studies centered on the development and use of an authentic measure, concept mapping, to assess changes in workshop teachers' conceptual understanding of earthquake engineering. My review of the literature indicated few research studies examining how traditionally trained science teachers develop STEM-related understandings about the complex relationships between concepts associated with STEM-related contexts, such as those existing within the context of earthquake engineering. STEM researchers currently know little about how teachers develop deep conceptual understanding of complex and interdisciplinary content knowledge. To address the gap I found in the literature, I designed three studies to: (1) conduct a modified Delphi study to create a list of key concepts as a knowledge base in earthquake engineering, (2) examine changes in science teachers' conceptual understanding of earthquake engineering as a result of their participation to an engineering-oriented teacher professional development (EOTPD), and (3) investigate changes in the quality of science teachers' argumentation discourse after their participation in a week-long EOTPD.

Researchers suggest identification of key concepts in critical engineering content areas for high school science teachers to increase their engineering content knowledge. In my first study, I identified and verified key concepts in earthquake engineering necessary for high school learners to acquire a basic understanding of earthquake engineering.

Results included a key concepts list and an interdisciplinary strand map with 35 earthquake engineering key concepts in five domains.

Furthermore, stakeholders suggest providing opportunities for STEM teachers to improve their conceptual understanding in critical engineering areas within EOTPDs. In my second study, I developed a conceptual framework, *Meaningful Conceptual Learning*, for successful conceptual understanding of complex and interdisciplinary content knowledge, implemented the framework into an EOTPD on earthquake engineering, used individual and group concept mapping as authentic assessment method. Results indicated science teachers enhanced their conceptual understanding of the earthquake engineering content knowledge after the EOTPD.

Stakeholders in science education also emphasize the critical role of using argumentation discourse in teaching science and indicate most science teachers still lack the pedagogical skills to introduce and enhance students' argumentation discourse skills. In my third study, I implemented argumentation discourse with a procedural guideline involving EOTPD participants' reasons for the inclusion of various concepts in their concept maps. I used a modified method for collecting and analyzing discourse data and found significant enhancement in teachers' argumentation discourse levels after the implementation.

DEDICATION

To The Memory of My Father

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NOMENCLATURE

AAAS	American Association for the Advancement of Science
CCSSM	Common Core State Standards for Mathematics
EEEP	Earthquake Engineering Education Project
EOTPD	Engineering Oriented Teacher Professional Development
ITEEA	International Technology and Engineering Educators Association
MCL	Meaningful Conceptual Learning
NGACPB	National Governors Association Center for Best Practices
NGSS	Next Generation Science Standards
NRC	National Research Council
NSF	National Science Foundation
S&E	Science and Engineering
SSMA	School Science and Mathematics Association
STEM	Science, Technology, Engineering, and Mathematics

TABLE OF CONTENTS

	Page
ABSTRACT.....	ii
DEDICATION.....	iv
ACKNOWLEDGEMENTS	v
NOMENCLATURE.....	vi
TABLE OF CONTENTS	vii
LIST OF FIGURES.....	ix
LIST OF TABLES	xi
CHAPTER	
I INTRODUCTION.....	1
The Purpose of the Study	4
Conceptual Framework	5
Research Questions	10
Definition of Key Terms	12
Significance of the Study	14
Organization of the Dissertation	15
II REVIEW OF THE LITERATURE.....	17
STEM Integration.....	18
The NGSS Framework	19
Challenges for Traditional Teachers	23
Professional Development for STEM Teachers.....	28
Meaningful Conceptual Learning.....	38
Conclusion.....	60
III IDENTIFYING AND VERIFYING EARTHQUAKE ENGINEERING CONCEPTS TO CREATE A KNOWLEDGE BASE IN STEM EDUCATION: A MODIFIED DELPHI STUDY	62
Introduction	62

	Page
Background	63
Methodology	70
Procedures and Results.....	75
Conclusion.....	86
Implications.....	87
Limitations	88
IV EXAMINING CHANGES IN SCIENCE TEACHERS' CONCEPTUAL UNDERSTANDING ABOUT EARTHQUAKE ENGINEERING.....	90
Introduction	90
Background	91
Methodology	120
Results	129
Discussion and Conclusion	135
Implications.....	141
Limitations	143
V EXAMINING SCIENCE TEACHERS' ARGUMENTATION DISCOURSE IN AN ENGINEERING-ORIENTED TEACHER PROFESSIONAL DEVELOPMENT	145
Introduction	145
Background	147
Method	157
Results	168
Conclusion and Discussion	172
Limitations	177
VI SUMMARY OF RESULTS AND RECOMMENDATIONS FOR STAKEHOLDERS.....	179
Identifying and Verifying Earthquake Engineering Concepts ...	181
Examining Changes in Science Teachers' Conceptual Understanding about Earthquake Engineering.....	182
Examination of Science Teachers' Argumentation Discourse in an Engineering-Oriented Teacher Professional Development ...	184
Final Summary and Recommendations.....	186
REFERENCES.....	190
APPENDIX.....	203

LIST OF FIGURES

FIGURE	Page
2.1 The NGSS framework with emphasis on practices, concepts, and core ideas.....	22
2.2 The percentage of STEM teachers' with college degrees in science and mathematics for elementary, middle, and high school levels (Data adapted from Banilower et al., 2013).....	25
2.3 Conceptual framework of MCL in complex and interdisciplinary content knowledge.....	41
2.4 A concept map showing the key ideas and principles (Adapted from Novak, 2010).....	44
3.1 The three dimensions of the NGSS framework with emphasis on practices, concepts, and core ideas.	65
3.2 Modified Delphi research design used in this study.....	73
3.3 Strand map linking concepts identified within the five Domain Areas (i.e., “strands”) of Earthquake Engineering.....	85
4.1 An illustration of the Meaningful Conceptual Learning framework developed to guide the research in this study.	101
4.2 A concept map showing the key ideas and principles in a “good concept map” (Adapted from Novak, 2010).....	111
4.3 Pictures of two science teachers' individual concept maps.....	126
4.4 Mean scores of teachers' pre- and post-concept maps in individual and group levels.....	134
5.1 Toulmin's argumentation model with descriptions for each component.	151
5.2 Pictures of two constructed concept maps teachers used for argumentation discourse in the EEEP workshop.....	163
5.3 Frequency of pre-workshop and post-workshop argumentation levels for ten engineering education science teachers.....	170

5.4	Ten teachers' (indicated as A-L) levels of argumentation discourse before and after the EEEP workshop.....	171
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LIST OF TABLES

TABLE	Page
2.1	Percent of STEM Teachers Taking Coursework in Specific Science Disciplines by School Level 26
3.1	Source Documents for Identifying Key Concepts in Earthquake Engineering..... 76
3.2	Identified Key Concepts List in Panel 3 78
3.3	Final Version of Identified Key Concepts List..... 79
3.4	Results for Key Concepts Verification 81
3.5	Final Version of Key Concepts List 83
4.1	Percent of Science Teachers Taking Coursework in Specific Science Disciplines by School Level 93
4.2	Earthquake Engineering Key Concepts..... 124
4.3	Results of Inter-Scorer Analysis..... 127
4.4	Results of Wilcoxon-Sign Test between Pre and Post Scores on Individual Concept Maps 130
4.5	Results of Science Teachers’ Pre- and Post-Conceptual Understanding within Each Domain Area of Earthquake Engineering 131
4.6	Results of Wilcoxon-Sign Test between Pre and Post Scores on Group Concept Maps 132
5.1	Argumentation Levels and Examples from Teachers’ Arguments..... 166
5.2	Results of Wilcoxon Signed-Test between Number of Argument Statements Before and After the Workshop 169
5.3	Results of Wilcoxon Signed-Test between Pre and Post Argumentation Discourse Levels..... 172

CHAPTER I

INTRODUCTION

Science, Technology, Engineering, and Mathematics (STEM) education in the last two decades has been a critical focus for stakeholders in public education (Lopez et al., 2011; Nathan, Atwood, Prevost, Phelps, & Tran, 2011; Wilson, 2011). Stakeholders (i.e., policymakers, researchers, and educators) recognize the role of STEM education on the economic welfare and leadership status of the U.S. (President's Council of Advisors on Science and Technology, 2010) as well as on students' development of science literacy (Duschl, Schweingruber, & Shouse, 2007). Recent reports, however, indicate STEM education requires greater promotion to enhance students' readiness for future careers reliant on STEM content knowledge (National Research Council [NRC], 2012). To do so, many stakeholders (Greene, Lubin, Slater, & Walden, 2013; Wilson, 2011) have suggested using professional development (e.g., workshops, webinars, symposia) specifically designed to assist traditionally prepared science teachers (Daugherty, 2009; Nathan et al., 2011) to increase both teachers' and students' conceptual understanding of STEM content knowledge (Martínez, Pérez, Suero, & Pardo, 2013).

Professional development provides opportunities for learners, including science teachers with domain-specific background knowledge, to improve their conceptual understanding of STEM content knowledge (Custer & Daugherty, 2009; Darmofal, Soderholm, & Brodeur, 2002; Greene et al., 2013; Katehi, Pearson, & Feder, 2009; Nathan et al., 2011; NRC, 2014b; Walshe, 2007). Conceptual understanding of STEM

content knowledge is an essential component in the design of professional development for these learners (Lopez et al., 2011; Nathan et al., 2011; Wilson, 2011). STEM content knowledge is complex and interdisciplinary, requiring learners to become familiar with diverse knowledge domains and to make connections among those domains (NGSS, 2013; NRC, 2012, 2014a, 2014b). Effective STEM teachers possess the ability to convert STEM content knowledge into meaningful learning for their students. In this sense, professional development is vital for traditionally educated science teachers to understand the unique nature of domain specific knowledge within STEM content knowledge (Custer & Daugherty, 2009; Daugherty, 2009; Nathan et al., 2011; Wilson, 2011).

Furthermore, new theories of learning have come into focus leading to very different ideas about teaching, learning, and assessment (NGSS, 2013; Novak, 2010; NRC, 2000, 2014a, 2014b). With these theories emerging from research and practice in cognitive science, psychology, and learning, teacher learning has received new recognition as a legitimate field for research. In a prescient observation to changes emerging in the opening decade of the 21st century, Darling-Hammond (1997) eloquently stated:

If teachers are to prepare an ever more diverse group of students for much more challenging work—for framing problems; finding, integrating, and synthesizing information; creating new solutions; learning on their own; and working

cooperatively—they will need substantially more knowledge and radically different skills than most now have and most schools of education now develop.

(p. 190)

Traditional science teachers are faced with new paradigms for teaching, learning, and assessment as they are confronted with new standards for integrating science and engineering concepts within STEM contexts (NGSS, 2013; NRC, 2014a, 2014b). Therefore, STEM teachers require familiarity with both science and engineering content knowledge. While traditionally educated secondary school teachers may possess deep understanding in science content knowledge, these same teachers may have had no prior experiences or course work to support emerging STEM needs to integrate engineering content knowledge into their teaching.

Teaching and/or learning engineering content knowledge requires expertise across multiple content domains (Daugherty, 2009; Nathan et al., 2011; Wilson, 2011). Knowing this, the NGSS has announced the need for science teachers who are traditionally prepared to teach in one of the domains of science (e.g., life science, chemistry, physics, earth science) to broaden their expertise to include engineering content knowledge (NGSS, 2013; NRC, 2014a, 2014b). To achieve this need, professional development has been identified as an effective medium to accommodate new goals requiring science teachers to become familiar with and integrate new content, teaching, learning, and assessment associated with STEM education.

Previously, stakeholders in science education have created policies targeting science domain areas separately. However, reformers moving in the direction of STEM

education (e.g., see NGSS) have recognized the importance of learners' skills and strategies in connecting knowledge across multiple content areas (NGSS, 2013). New K-12 STEM education guidelines stress STEM integration (NRC, 2014b) connecting science and engineering content knowledge among rather than within individual domains. These guidelines, thus, encourage the exploration of assessment strategies specifically investigating learners' abilities to connect knowledge from multiple content domains to develop conceptual understanding about how designed and natural systems interact (NRC, 2014a).

In the summer of 2013, an interdisciplinary team of civil engineers, science educators, and cognitive scientists delivered an earthquake engineering education workshop for traditional science teachers to learn more about becoming STEM teachers. The goal of this workshop was to provide effective professional development incorporating learning experiences modeling STEM teaching, learning, and assessment strategies. The workshop modeled classroom applications of new socio-cognitive theories in teaching, learning, and assessment and emphasized the enhancement of traditionally trained science teachers' understanding of the multiple content domains associated with earthquake engineering.

The Purpose of the Study

The purpose of this dissertation is to examine changes in science teachers' conceptual understanding of earthquake engineering as a result of their participation in a summer Earthquake Engineering Education Project (EEEP) teacher workshop. Most research studies reporting results of professional development have used traditional

assessments (i.e., multiple choice tests, short answer tests, or essays) to measure change in teachers' understanding as a result of professional development interventions. Until very recently, little research has existed where authentic assessments were used to measure changes in teachers' conceptual understanding, particularly in professional development workshops centering on teachers' development of complex and interdisciplinary knowledge (NRC, 2014a), such as provided in the EEEP teacher workshop. In this dissertation, I propose to address gaps in the literature by investigating changes in science teachers' conceptual understanding of STEM content (i.e., earthquake engineering) using an alternative measure of conceptual understanding. In doing so, I propose concept mapping as the authentic assessment strategy to document workshop teachers' development of conceptual understanding during a week-long professional development workshop centered on earthquake engineering.

Conceptual Framework

I bounded the conceptual framework for this dissertation, *Meaningful Conceptual Learning* (MCL), with the study of literature describing necessary components needed to improve science teachers' conceptual understanding of complex and interdisciplinary content knowledge. Previous researchers have suggested cognitive scaffolds, collaboration, argumentation discourse, and authentic assessment strategies to increase and sustain changes in teachers' conceptual understanding. I used the MCL framework to guide my examination of changes in learners' conceptual understanding of earthquake engineering as a result of participation in a weeklong workshop for traditionally prepared science teachers.

To explain the MCL framework, I first address the distinction between meaningful learning and rote learning. Cognitive learning theorists explain meaningful learning as that which occurs when learners consciously chooses to integrate new knowledge into their existing knowledge (Ausubel, 2000; Novak, 2002, 2010; Novak & Canas, 2008). These theorists argue that meaningful learning results in the retention of new knowledge embedded within a well-organized knowledge structure. This structure helps learners acquire related materials as well as make connections among different domains. In addition, meaningful learning results in a high commitment for learners to seek relationships between new and existing knowledge. This knowledge from meaningful learning “can be applied in a variety of new problems or contexts” (Novak, 2010, p. 68). Rote learning, however, occurs when learners make no effort to integrate new knowledge into their existing mental structures of knowledge. With rote learning, Novak (2010) contends new knowledge is retained in short-term memory and results in a poorly organized knowledge structure.

MCL in complex and interdisciplinary content knowledge (e.g., STEM content knowledge) requires four critical components: (1) cognitive scaffolds, (2) collaboration, (3) argumentation discourse, and (4) authentic assessment. According to research on socio-cognitive theories of teaching, learning, and assessment (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt., 1999; Novak, 2010; NRC, 2000, 2014a, 2014b), these four components are necessary for learning to occur in complex and interdisciplinary learning environments. Thus, I included these components as I developed the design of an authentic measure to assess change in workshop teachers’

conceptual understanding during the course of the EEEP professional development workshop experience.

Cognitive scaffolds are crucial in providing a support structure to enhance learners' conceptual understanding (Novak, 2002, 2010, Novak & Canas, 2008; NRC, 2014b). Effective cognitive scaffolds, however, are best chosen when learners understand the content domains giving students' difficulty. Hence, providing experiences with effective cognitive scaffolds is crucial for learners to understand the important role of cognitive scaffolds while enhancing their conceptual understanding of STEM content knowledge. In this regard, concept mapping can be considered as an effective cognitive scaffold tool for meaningful conceptual learning (O. Kaya, 2008; Novak, 2010; NRC, 2014b). Concept mapping can help learners develop thinking, analyzing, and problem solving skills and improve conceptual understanding. Moreover, concept mapping is useful in establishing a sort of "road map" for connections among knowledge domains (Novak, 2010). For example, the use of concept maps in learning and teaching engineering content knowledge, which requires expertise across multiple content domains (Duschl et al., 2007), can act as cognitive scaffolds for the conceptual understanding of engineering content knowledge.

Collaboration is vital for engaging learners through social interactions (Good & Brophy, 2008). Collaboration provides critical opportunities for learners to express and discuss their ideas (Gilbert, Boulter, & Elmer, 2000), facilitates learning from others (Bilgin & Geban, 2006; NRC, 2000), and allows learners to refine misconceptions (Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Martínez et al., 2013). In addition,

researchers have indicated collaboration provides argumentation discourse opportunities for learners to increase conceptual understanding through social interactions.

Argumentation discourse has become a critical component in today's learning environments for meaningful conceptual learning. According to the findings of recent researchers (e.g., E. Kaya, 2013), argumentation discourse supports the development of conceptual understanding. Argumentation discourse scaffolds cognitive development of content knowledge, improves critical thinking, and empowers learners' abilities to talk and write with scientific language (Duschl et al., 2007; Duschl & Osborne, 2002; E. Kaya, 2013a; Simon et al., 2006). Moreover, this discourse allows learners to be more active in the learning process by giving opportunities to share, reflect, and revise their ideas with an audience of peers (Goldman et al., 1999; Passmore & Svoboda, 2012). Through argumentation discourse in collaboration, learners can clarify misconceptions as well as establish deep conceptual understanding in complex and interdisciplinary content knowledge, such as that required in STEM fields. In addition, argumentation discourse is best measured via authentic assessments to understand how learners' conceptualization occurs and to provide timely feedback so that the learners can revise their thinking as needed.

Authentic assessments are better measures of learners' conceptual understanding in complex and interdisciplinary content knowledge learning environments (Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013). Traditional assessments do not provide detailed information about learners' conceptual understanding of complex content knowledge. Additionally, traditional assessments are not sufficient in assessing

learners' interdisciplinary content knowledge (i.e., earthquake engineering) as they are incapable in showing relationships among content areas (NRC, 2014a). Also, traditional assessments do not provide sufficient opportunities for learners to revise understanding and receive timely feedback (Ingec, 2008, 2009; NRC, 2014a; Ozdemir, 2005). In contrast, authentic assessments, such as concept maps, are capable in assessing learners' conceptual understanding of complex and interdisciplinary content knowledge (Cavlazoglu et al., 2013; Darmofal et al., 2002; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013; Novak, 2010; Walshe, 2007). Concept maps are authentic assessment tools that provide detailed information about learners' conceptual understanding and show relationships among different content domains (Ingec, 2009; Lopez et al., 2011; Novak, 2010). Furthermore, the use of concept maps is also a learner-centered strategy providing learners with the opportunity to revise their understanding and receive timely feedback. As a result, concept maps can be used as an authentic assessment tool in measuring conceptual understanding of complex and interdisciplinary content knowledge.

As STEM education has become a critical focus for the economic welfare and leadership status of the U.S., teachers need to develop meaningful conceptual understanding of complex and interdisciplinary content knowledge to effectively translate their knowledge about STEM into classrooms (NGSS, 2013; NRC, 2012, 2014b). To do so, professional development for traditionally prepared teachers is crucial in providing learning experiences with new socio-cognitive theories of teaching, learning, and assessment while enhancing their conceptual understanding of complex

and interdisciplinary STEM content knowledge. The conceptual framework of MCL suggests integrating cognitive scaffolds, collaboration, argumentation discourse, and authentic assessment into learning environments for conceptual understanding of complex and interdisciplinary content knowledge. However, the roles of these components and relationships between them have yet to be fully understood. Thus, this study will reveal the effectiveness of this conceptual framework in developing assessment strategies to document the changes in teachers' conceptual understanding of earthquake engineering as a result of a weeklong professional workshop.

Research Questions

This multi-paper dissertation reports results from three research studies centered on the development and use of an authentic measure to assess changes in workshop teachers' conceptual understanding of earthquake engineering.

Study 1: Identifying and Verifying Earthquake Engineering Concepts to Create A Knowledge Base in STEM Education: A Modified Delphi Study

The first study reports methods and results associated with the identification of key concepts in earthquake engineering. Three research questions guided this first study:

1. What process was used to identify and verify the key concepts necessary for EEEP workshop teachers to develop a conceptual understanding of earthquake engineering?
2. What interdisciplinary content areas were identified as critical in developing EEEP workshop teachers' understanding of earthquake engineering?

3. What domain-specific key concepts were identified as critical in developing EEEP workshop teachers' understanding of earthquake engineering?

Study 2: Examining Changes in Science Teachers' Conceptual Understanding about Earthquake Engineering

The second study reports result from examining changes in science teachers' conceptual understanding of earthquake engineering content as a result of their participation in the EEEP teacher workshop. Three research questions guided this second study:

1. What differences in individual workshop science teachers' conceptual understanding of earthquake engineering were observed in their pre- and post-concept maps?
2. What differences in science teacher groups' conceptual understanding of earthquake engineering were observed in their pre- and post-concept maps?
3. What differences between individual and group conceptual understanding of earthquake engineering were observed in pre- and post-concept maps?

Study 3: Examining Science Teachers' Argumentation Discourse in An Engineering-Oriented Teacher Professional Development

The third study reports results from examination of changes in science teachers' argumentation discourse about earthquake engineering before and after the EEEP workshop. Two research questions guided this third study:

1. What differences in science teachers' argumentation discourse were observed in their pre- and post-workshop argumentation discourse assessments?

2. Were there significant differences between science teachers' pre- workshop argumentation discourse levels and post-workshop argumentation discourse levels?

Definition of Key Terms

- **Argumentation Discourse:** Argumentation discourse is “the substance of any meaningful discourse that seeks to generate improved knowledge and understanding” (Duschl & Osborne, 2002, p. 51). A primary goal for argumentation discourse is the establishment of dialogue in which learners participate in social interactions and collaboration opportunities leading to enhanced knowledge and understanding about content.
- **Authentic Assessment:** A form of assessment allowing learners opportunities to improve knowledge structures by receiving feedback and revising for conceptual understanding (Goldman et al., 1999; Ingec, 2009; O. Kaya, 2008; NRC, 2000, 2014b). Reformers (e.g., Ingec, 2009) claim that authentic measures provide a better assessment of learners' conceptual understanding of complex and interdisciplinary content knowledge.
- **Cognitive Scaffolds:** Throughout this dissertation study, cognitive scaffolds are defined as learning tools providing support to learners as they organize knowledge structures. Cognitive scaffolds serve as temporary frameworks to support the process of knowledge construction. In learning complex and interdisciplinary content knowledge, cognitive scaffolds can be vital for facilitating learners' knowledge

construction through conceptual understanding (Novak, 2002, 2010, Novak & Canas, 2008; NRC, 2014b).

- Collaboration: Collaboration describes how learners work together to accomplish common goals (Goldman et al., 1999; NRC, 2000, 2014b). Collaboration is vital in engaging learners through social interactions for meaningful learning (Good & Brophy, 2008). Social interactions via collaboration facilitate learning from others (NRC, 2000; 2014b, Vygotsky, 1978), enhance conceptual understanding (Miyake, 2013; Vosniadou, 2013) and scaffold learning complex and interdisciplinary content knowledge (Cunningham & Carlsen, 2014; Daugherty, 2009; Katehi et al., 2009).
- Concept Maps: Concept maps are “graphical tools for organizing and representing knowledge” (Novak & Canas, 2008, p. 1), which can be used as authentic assessment tools to estimate learners’ conceptual understanding.
- Meaningful Conceptual Learning (MCL): The conceptual framework of this dissertation, MCL, which describes essential components needed to improve learners’ conceptual understanding of complex and interdisciplinary content knowledge (e.g., STEM knowledge) within new paradigms of STEM teaching, learning, and assessment. The conceptual framework consists of four components including (1) cognitive scaffolds, (2) collaboration, (3) argumentation discourse, and (4) authentic assessment.
- Science Teachers: Teachers of science traditionally prepared to design learning environments for students to learn science concepts in one of the traditional science domains (e.g., life science, physics, chemistry, earth science).

- STEM Teachers: The new “brand” of teachers prepared to design learning environments for students integrating the domains of science, technology, engineering, and mathematics (e.g., earthquake engineering).
- Workshop Teachers: A specific distinction applied to the secondary science high school teachers attending a professional development workshop on earthquake engineering.

Significance of the Study

The Next Generation Science Standards (NGSS) has called for a focus on teaching disciplinary core ideas with increased depth and sophisticated conceptual understanding of content knowledge rather than a superficial teaching of general science knowledge (NGSS, 2013; NRC, 2012). Also, the NRC (2011) has announced an immediate focus on STEM education in the U.S. for teaching STEM content to help students create positive attitudes towards STEM careers and become lifelong STEM learners. Each focus has created a need for developing authentic assessments to measure learners’ conceptual understanding of STEM content knowledge. In addition, little research exists regarding conceptual understanding of STEM content knowledge for teachers (Darmofal et al., 2002; Daugherty, 2009; Nathan et al., 2011). To address these concerns, several reformers have recommended professional development activities for teachers to increase their conceptual understanding of engineering content knowledge while creating authentic assessments to measure and examine teachers’ conceptual understanding (Duschl et al., 2007; NRC, 2011). Moreover, although conceptual change for learners in many content domains (i.e., physics, biology, chemistry, and geography)

has been investigated (Bilgin & Geban, 2006; Ingec, 2009; E. Kaya, 2013; O. Kaya, 2008; Walshe, 2007), conceptual change for learners in the domain of earthquake engineering has yet to be explored. Thus, this study proposes a method for assessing changes in teachers' conceptual understanding in the earthquake engineering content as a result of participation in the EEEP teacher workshop.

Organization of the Dissertation

This dissertation is organized into six chapters. In Chapter I, I identify a current problem in STEM teachers' conceptual understanding of content knowledge. In this chapter, I also present the purpose of the dissertation, a brief conceptual framework, research questions, definitions of key terms, and the significance of the study. In Chapter II, I provide a review of literature with emphasis on the conceptual understanding in STEM teacher education and teacher professional development. In this chapter, I also propose a conceptual framework for conceptual understanding of complex and interdisciplinary content knowledge in STEM education. In Chapters III, IV, and V, I present three connected but independent research papers. The first of these papers (Chapter III) describes the processes and results of identifying the key concepts of earthquake engineering. In Chapter IV, I provide the results of a study using concept mapping as an authentic assessment tool for estimating conceptual understanding and answer three research questions used to examine changes in teachers' conceptual understanding of earthquake engineering content knowledge. In Chapter V, I provide answers to two research questions regarding changes in teachers' argumentation discourse by analyzing teachers' monologic argumentation discourse levels before and

after the EEEP workshop. Finally, in Chapter VI, I present conclusions from all previous chapters with reflections on the three papers and discussions regarding future research.

CHAPTER II

REVIEW OF THE LITERATURE

STEM education, as opposed to science education, has been a critical focus during the last two decades for stakeholders (i.e., policy makers, researchers, and educators). The crucial role of STEM education on the economic welfare and leadership status of the U.S. has been remarked in recent reports (NRC, 2011). In addition, reports (i.e., NGSS, 2013; NRC, 2014b) from leading stakeholders have noted the need for improving and expanding STEM education across the nation. These improvements and expansions are critical for students to increase their STEM literacy as they become thoughtful participants in making democratic decisions (NRC, 2014b) and life-long learners of the natural and physical worlds (NGSS, 2013).

Stakeholders have highlighted the importance of STEM literacy for successful STEM education (Duschl et al., 2007). Currently, no single definition for STEM literacy exists (NRC, 2014b). Although each discipline within STEM education has been defined, until very recently STEM literacy was only defined as a combination of four disciplines (i.e., Science, Technology, Engineering, and Mathematics). A report from the NRC, *STEM Integration in K-12 Education: Status, Prospects, and an Agenda for Research*, attempted to define STEM literacy as some combination of the following:

- awareness of the roles of science, technology, engineering, and mathematics in modern society

- familiarity with at least some of the fundamental concepts from each area
basic level of application fluency (e.g., the ability to critically evaluate
the science or engineering content in a news report, conduct basic
troubleshooting of common technologies, and perform basic
mathematical operations relevant to daily life. (NRC, 2014b, p. 34)

STEM Integration

Reports by the NRC (2014b) and NGSS (2013) suggest definitions for STEM literacy should highlight the importance of STEM integration. The NRC report further suggests integration of each STEM component for enhancing STEM literacy because “STEM education serves to prepare a scientific and technical workforce, where integration is becoming increasingly common in cutting-edge research and development, as well as a scientifically and technologically literate and more informed society” (NRC, 2014b, p. 13). Therefore, STEM integration is vital for increasing students’ STEM literacy and should be considered for improving and expanding STEM education across the nation.

The idea of STEM integration is not new. However, the focus of integration, until recently, has been on science and mathematics (NRC, 2014b). For example, the School Science and Mathematics Association (SSMA) was established in 1901 to address the issue of integration and has continuously encouraged science and math teachers to consider integration of science and mathematics subjects in classrooms and schools. The SSMA has worked for over a century towards the integration of science and mathematics while generally ignoring technology and engineering. However, important

policy documents, such as *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993), have announced the need for the integration of all STEM content areas, including engineering. For example, in *Benchmarks for Science Literacy*, the authors approached STEM integration in defining science literacy as possessing “basic and applied natural and social science, basic and applied mathematics, and engineering and technology, and the interconnections” (AAAS, 1993, p. 321). In 2007, the International Technology and Engineering Educators Association (ITEEA) stressed the necessity for understanding connections across science, technology, engineering, and mathematics (ITEEA, 2007). Similarly, authors of the *Common Core State Standards for Mathematics* ([CCSSM]; National Governors Association Center for Best Practices [NGACPB], 2010), suggested linking mathematics applications with science and engineering. Finally, the NGSS framework (NGSS, 2013), based on *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012), called for deeper connections among STEM subjects (NGSS, 2013; NRC, 2014b). Specifically, this framework has critical implications for enhancing STEM education by focusing on the integration of science and engineering (S&E) in K-12 science education.

The NGSS Framework

The NGSS framework was outlined around ideas expressed for K-12 science education from existing documents, including the *National Science Education Standards* (NRC, 1996), the *Benchmarks for Science Literacy* (AAAS, 1993), the *Atlas of Science Literacy* (AAAS, 2001; AAAS, 2007), the *Science Framework for the 2009 National*

Assessment of Educational Progress (National Assessment of Educational Progress, 2009), and the *Science College Board Standards for College Success* (College Board, 2009). The NGSS framework is not based on only one new idea. Instead, the NGSS framework reflects a combination of previous standards considered crucial for successful K-12 science education. The goal of the framework is:

To ensure that by the end of 12th grade, *all* students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology. (NRC, 2012, p. 1)

For successful K-12 science education, the NGSS framework suggests three major dimensions; (a) Scientific and Engineering Practices, (b) Crosscutting Concepts, and (c) Disciplinary Core Ideas (see Figure 2.1).

The framework stresses meaningful learning in S&E through the integration of the three dimensions into standards, curriculum, instruction, and assessment (NRC, 2012). The first dimension, *Scientific and Engineering Practices*, emphasizes the essential role of practices for learning science and engineering in grades K-12. Mastering these practices help students see similarities and differences between science and engineering. In addition, this dimension helps students establish a better understanding of how scientific knowledge and engineering solutions are developed (NRC, 2012). The

second dimension, *Crosscutting Concepts*, stresses critical concepts that “provide students with an organizational framework for connecting knowledge from the various disciplines into a coherent and scientifically based view of the world” (NRC, 2012, p. 83). Becoming familiar with these concepts in grades K-12 helps students understand applications from disciplines within S&E and provides a common method for looking across these disciplines. The third dimension, *Disciplinary Core Ideas*, outlines a limited number of ideas that K-12 S&E education should focus on. Mastering these core ideas through progressive learning (Duschl et al., 2007) helps students continually learn core ideas within S&E rather than a shallow coverage over a large number of topics. This dimension, therefore, allows more time for teachers to teach and students to learn each topic deeper over the course of a students’ K-12 education.

Scientific and Engineering Practices	Asking questions (for science) and defining problems (for engineering) Developing and using models Planning and carrying out investigations Analyzing and interpreting data Using mathematics and computational thinking Constructing explanations (for science) and designing solutions (for engineering) Engaging in argument from evidence Obtaining, evaluating, and communicating information
Crosscutting Concepts	Patterns Cause and effect: Mechanism and explanation Scale, proportion, and quantity Systems and system models Energy and matter: Flows, cycles, and conservation Structure and function Stability and change
Disciplinary Core Ideas	Physical Sciences (PS) 1: Matter and its interactions PS2: Motion and stability: Forces and interactions PS3: Energy PS4: Waves and their applications in technologies for information transfer Life Sciences (LS) 1: From molecules to organisms: Structures and processes LS2: Ecosystems: Interactions, energy, and dynamics LS3: Heredity: Inheritance and variation of traits LS4: Biological evolution: Unity and diversity Earth and Space Sciences (ESS) 1: Earth's place in the universe ESS2: Earth's systems ESS3: Earth and human activity Engineering, Technology, and Applications of Science (ETS)1: Engineering design ETS2: Links among engineering, technology, science, and society

Figure 2.1. The NGSS framework with emphasis on practices, concepts, and core ideas.

The NGSS framework considers all three dimensions to satisfy the overall goal of meaningful learning: “In the sciences and engineering in which students, over multiple years of school, actively engage in scientific and engineering practices and apply crosscutting concepts to deepen their understanding of the core ideas in these fields” (NRC, 2012, p. 8). Therefore, implementing these three dimensions in science classrooms has become critical for meaningful learning in STEM education. However,

additional challenges (e.g., teachers' conceptual understanding of STEM content knowledge) for effective STEM education should also be considered.

Challenges for Traditional Teachers

Recent calls (e.g., CCSSM, 2010; ITEEA, 2007; NGSS, 2013) from stakeholders in each of the STEM content areas have centered on the need for meaningful STEM learning with integration of at least two STEM content areas. In making these calls, stakeholders have once again brought attention to the critical need for effective STEM teachers (Wilson, 2011). Research on effective STEM teachers' preparation indicates two essential teacher needs for supporting students' meaningful learning (Ausubel, 1968; Ausubel, 2000; Novak, 2002; Novak, 2010) are STEM content knowledge (Bilgin & Geban, 2006; Darmofal, Soderholm, & Brodeur, 2002; Lopez et al., 2011) and pedagogical content knowledge (NRC, 2000, 2014b).

Teachers' STEM Content Knowledge

Teachers' content knowledge is thought to be associated with students' learning (Hill et al., 2005; NRC, 2014b); therefore, STEM teachers need sufficient content knowledge for effective teaching. In addition, recent calls from stakeholders (e.g., CCSSM, ITEEA, and NGSS) suggest expertise in multiple content areas for STEM teachers is necessary for STEM integration. However, research also indicates current teachers' STEM content knowledge is insufficient and they often lack confidence in teaching STEM (Banilower et al., 2013).

In a national study, Banilower et al. (2013) identified STEM teachers' undergraduate degrees as an important indicator of content knowledge. These

researchers found disturbing trends in the college education of STEM teachers across elementary, middle and high school levels (see Figure 2.2). Although these researchers found STEM teachers at the elementary level were least likely to have college degrees in either Science or Mathematics, the majority of recent policy reports in this review focus on STEM teachers at the middle and high school levels. Banilower et al. (2013) noted the majority of STEM teachers lack content preparation. The most recent calls in STEM education emphasize meaningful conceptual learning of STEM content knowledge and deeper connections among the STEM content areas. However, STEM teachers' limited content knowledge continues to be a concern (NRC, 2000, 2012, 2014b).

Another important indicator for STEM teacher content knowledge is teachers' college coursework (NRC, 2014b). According to recent reports in STEM education (NGSS, 2013; NRC, 2012), teachers require expertise in at least two STEM content areas for effective teaching. However, research indicates STEM teachers' coursework in their respective areas, as well as other STEM areas, is often lower than recommended by STEM professional organizations (NRC, 2014b). For example, a study of science teachers' college coursework shows STEM teachers take courses across science disciplines (e.g., chemistry, life sciences, earth/space science, physics, and environmental science); however, engineering coursework is often limited (Banilower et al., 2013, see Table 2.1), with middle and high school science teachers taking 7% and 14% college coursework in engineering, respectively. Overall, Banilower et al. concludes STEM teachers' engineering content knowledge is limited when compared to their science and mathematics content knowledge.

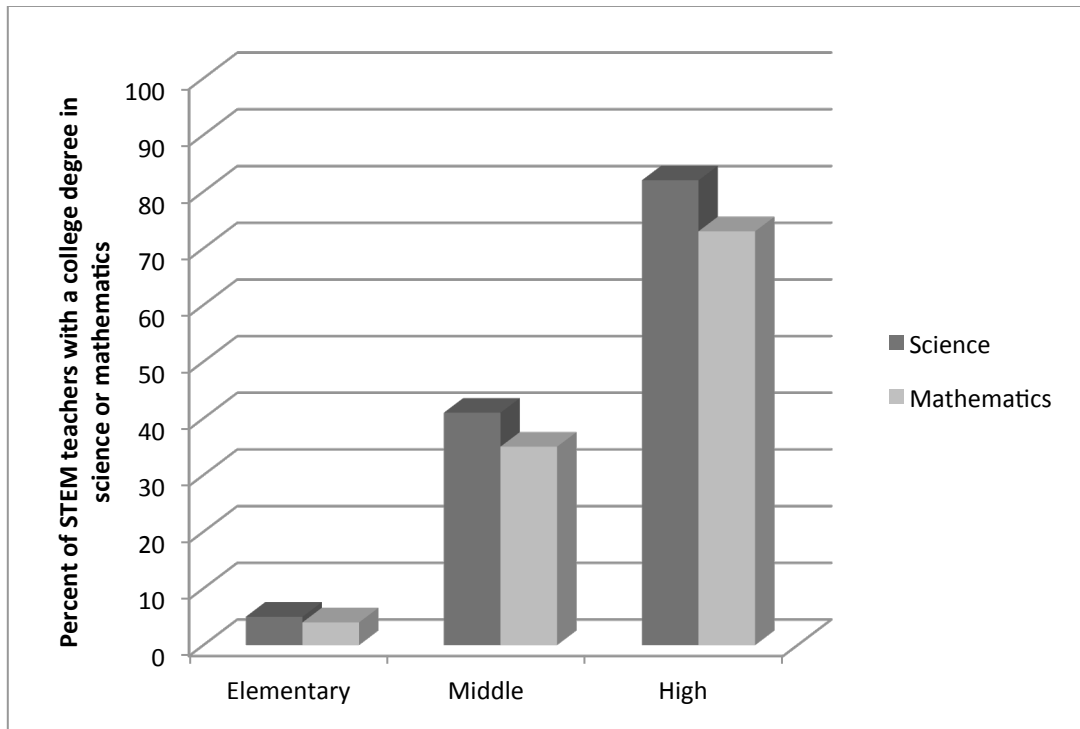


Figure 2.2. The percentage of STEM teachers' with college degrees in science and mathematics for elementary, middle, and high school levels (data adapted from Banilower et al., 2013).

Table 2.1

Percent of STEM Teachers Taking Coursework in Specific Science Disciplines by School Level

Discipline	Teachers' school level		
	Elementary (%)	Middle (%)	High (%)
Engineering	1	7	14
Physics	32	61	86
Environmental science	33	57	56
Chemistry	47	72	93
Earth/Space science	65	75	61
Student teaching in science	70	73	72
Science education	89	89	85
Life sciences	90	96	91

Adapted from Banilower et al. (2013).

Teachers' Pedagogical Content Knowledge

Although STEM teachers' content knowledge is important for effective STEM education, pedagogical content knowledge (Shulman, 1987), the ability to effectively transfer STEM knowledge and understanding to students, is also critical. If STEM education requires expertise across multiple STEM content areas (NRC, 2014b), teachers need the ability and confidence to teach across these STEM areas (Banilower et al., 2013b; NRC, 2014b). In this regard, knowing how to provide appropriate instructional strategies for meaningful conceptual understanding of STEM content is

critical (Dierking, Falk, Rennie, Anderson, & Ellenbogen, 2003; Martínez, Pérez, Suero, & Pardo, 2013; Novak, 2002, 2010). Teachers need to know how new theories of learning work within STEM areas and should be able to apply their pedagogical content knowledge (NRC, 2000, 2012, 2014b). With these theories emerging from research and practice, teacher learning, as a combination of cognitive science, psychology, and learning, has received new recognition as a legitimate field for research. The NRC (2000) cites comments made by Darling-Hammond in 1997:

If teachers are to prepare an ever more diverse group of students for much more challenging work—for framing problems; finding, integrating, and synthesizing information; creating new solutions; learning on their own; and working cooperatively—they will need substantially more knowledge and radically different skills than most now have and most schools of education now develop.
(p. 190)

STEM teachers are faced with new paradigms for teaching, learning, and assessment as they are confronted with new standards for integrating STEM areas (NGSS, 2013). Thus, teachers need opportunities to improve pedagogical knowledge within new theories of teaching, learning, and assessment for effective STEM education.

For effective STEM education, researchers (Greene, Lubin, Slater, & Walden, 2013; Wilson, 2011) have suggested creating professional development (e.g., workshops, webinars, symposia) specifically designed for enhancing the abilities of teachers to effectively create STEM learning environments (Daugherty, 2009; Nathan, Atwood, Prevost, Phelps, & Tran, 2011). These activities enhance teachers' STEM

content knowledge and pedagogical skills. Professional development specifically designed for enhancing STEM teachers' effectiveness, therefore, is important in supporting teachers' STEM content knowledge and effectively transferring STEM knowledge and understanding to students (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Katehi, Pearson, & Feder, 2009; Nathan et al., 2011; Wilson, 2011).

Professional Development for STEM Teachers

As stakeholders continue working to facilitate STEM integration, develop frameworks (e.g., NGSS), and identify challenges for STEM teachers, opportunities for teachers to enhance their STEM content knowledge have become indispensable.

Opportunities to Enhance STEM Teachers' Content Knowledge

Conceptual understanding of STEM content knowledge is essential for effective STEM teaching (Lopez et al., 2011; Nathan et al., 2011; Wilson, 2011); therefore, STEM teachers require opportunities to enhance their conceptual understanding of STEM content knowledge (National Science Foundation [NSF], 2010; Walshe, 2007). This understanding is necessary because specific STEM content knowledge (e.g., engineering content knowledge) can be complex, interdisciplinary, and loosely defined, requiring expertise across STEM areas. This requires teachers to possess conceptual understanding of STEM content as well as STEM knowledge to properly instruct their students. Within the context of recent standards for STEM education (e.g., CCSSM, 2010; ITEEA, 2007; NGSS, 2013), learners have to become familiar across STEM areas and make connections among those areas. Effective STEM teachers possess the abilities

required to convert STEM content knowledge into meaningful conceptual learning for students (Martínez et al., 2013; Novak, 2002, 2010). Therefore, all STEM teachers need opportunities to understand the unique nature of STEM content knowledge (Katehi et al., 2009). These opportunities are often found in STEM teacher education programs and professional development (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Greene et al., 2013; Katehi et al., 2009; Nathan et al., 2011; NRC, 2000, 2014b; Wilson, 2011).

STEM teacher education programs. Teacher education programs vary across STEM areas (Banilower et al., 2013b). Currently, a large number of science and mathematics teacher education programs and a small number of technology teacher education programs exist (NRC, 2014b); however, the number of engineering teacher education programs is very limited (Banilower et al., 2013b; Katehi et al., 2009; NRC, 2014b). Some researchers suggest, STEM teachers have “the fear of engineering” due to the complexity of engineering content (NRC, 2014b) resulting in a lack of confidence in their STEM teaching (Banilower et al., 2013b). Therefore, opportunities (e.g., STEM teacher professional development) to address this fear are vital for improving teachers’ STEM content knowledge, especially in engineering.

STEM teacher professional development. STEM teacher professional development provides critical opportunities for both pre- and in-service teachers to enhance STEM content knowledge (NRC, 2014b). According to results from a national survey study (Banilower et al., 2013), more than 80% of STEM teachers participated in discipline-focused professional development within the last three years. This data

showed current STEM teachers have a high interest in participating professional development, thus, stakeholders in professional development see these kind of activities as critical opportunities for enhancing STEM teachers' quality (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Greene et al., 2013; Katehi et al., 2009; Nathan et al., 2011; NRC, 2000, 2014b; Wilson, 2011).

Teachers' anxieties due to limited conceptual understanding of STEM content knowledge may lessen their effectiveness (Banilower et al., 2013b; NRC, 2014b); therefore, STEM teacher professional development is likely crucial in reducing teachers' anxiety with STEM content (NRC, 2014b). In the national survey study conducted by Banilower et al. (2013), STEM teachers were asked how well they felt prepared to teach STEM content. Only 4% of Elementary school teachers, 6% of Middle school teachers, and 7% of High school teachers responded as feeling very well prepared to teach engineering content. Furthermore, only 39% of Elementary school teachers in science versus 77% in mathematics reported feeling very well prepared. In contrast, between 5% and 58% of Middle school teachers and 19% and 83% of High school teachers reported similar attitudes towards teaching science; whereas, between 48% and 88% of Middle school teachers and 30% and 90% of High school teachers reported similar attitudes towards teaching mathematics. The authors of this study conclude STEM teachers should participate in engineering-oriented teacher professional development (EOTPD) to reduce their anxiety by increasing engineering content knowledge (Banilower et al., 2013).

Engineering-Oriented Teacher Professional Development

As recent calls emphasize increasing teachers' engineering content knowledge (e.g., CCSSM, 2010; ITEEA, 2007; NGSS, 2013) and the critical role of professional development on engineering content for STEM teachers (Daugherty, 2009; Nathan et al., 2011; Wilson, 2011), EOTPD has become crucial for students' successful STEM education. Although previous documents (e.g., *Benchmarks for Science Literacy*) indicate the critical role of engineering and its integration with other STEM content areas (AAAS, 1993), engineering remains the least developed and implemented of the STEM areas at the K-12 level (NRC, 2014b). Recent calls from interested organizations (e.g., AAAS and NRC) and research in the field (Daugherty, 2009; Nathan et al., 2011; Wilson, 2011) have recommended creating EOTPDs to enhance STEM teachers' engineering content knowledge.

Engineering knowledge for STEM integration. As previously mentioned, there is a need for the integration of engineering with other STEM content areas (NGSS, 2013; NRC, 2012, 2014b). In this way, the nature of engineering knowledge may be suitable for facilitating such integration (Katehi et al., 2009). The nature of engineering knowledge "utilizes concepts in science and mathematics as well as technology tools" (NRC, 2014b, p. 14), leading some researchers to conclude engineering might serve as a catalyst for the integration of all STEM areas (Katehi et al., 2009). Engineering content knowledge, therefore, has the potential in its nature for answering recent calls for the integration of STEM areas.

Teachers' integration of engineering content knowledge in classrooms may result in improved science and mathematics achievement for K-12 students (Katehi et al., 2009). For example, in a K-12 engineering program, with teachers having greater engineering content knowledge, students scored higher on science and mathematics in a national level exam than students from random comparison groups (Bottoms & Uhn, 2007). However, research suggests the majority of STEM teachers have little experience in the integration of science and mathematics with engineering (Nathan et al., 2010) or in teaching engineering content (Baniflower et al., 2013; NRC, 2014b). Hence, EOTPDs may provide critical opportunities for STEM teachers to increase engineering content knowledge (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Katehi et al., 2009; Martínez et al., 2013), gain confidence in teaching engineering (Nathan et al., 2011; NRC, 2014b), and allow integration of all STEM areas (Custer & Daugherty, 2009; Katehi et al., 2009; NRC, 2014b).

Engineering integration efforts in other STEM areas. In other STEM content areas (i.e., science, mathematics, technology), teachers have been encouraged to teach content through integration of engineering rather than focusing on specific STEM areas. For example, recent developments in science education have led to a renewed interest in the integration of science with engineering thus science and engineering are both embodied in the NGSS framework. The integrated NGSS (2013) framework stresses active engagement in S&E practices to deepen understanding in all content areas as well as establishing meaningful connections between S&E concepts (NRC, 2012). Since a majority of states in the U.S. are expected to adopt the new NGSS into their curriculum

and aim for greater inclusion of engineering education (NRC, 2014b), current STEM teachers need opportunities to learn engineering content. In a similar vein, the authors of the *Common Core State Standards for Mathematics* (CCSSM, 2010) announced the need for the integration of mathematics with science and engineering. Therefore, creating effective EOTPDs for STEM teachers, especially for those traditionally educated, is vital for understanding engineering content knowledge (Martínez et al., 2013) and establishing meaningful connections across STEM areas.

Teachers' fear of engineering. National teacher surveys, such as the one conducted by Banilower et al. (2013), reported few teachers felt prepared to teach engineering. Previous studies have reported a high number of STEM teachers still have “the fear of engineering” and lack confidence in teaching content within this STEM area (Banilower et al., 2013b; Cunningham & Carlsen, 2014; NRC, 2014b). Thus, EOTPDs should help STEM teachers gain sufficient levels of confidence with and an improved ability to teach engineering content.

The role of EOTPDs on beliefs and expectations about engineering education. EOTPDs are critical in helping STEM teachers develop positive beliefs and expectations about engineering education (Nathan, 2011). In a research study, Nathan (2011) examined the influence of EOTPDs on beliefs and expectations of STEM teachers about engineering education, reaching three conclusions. First, school support is important in teachers' development of engineering content knowledge and teaching. Second, teachers with advanced engineering content knowledge exhibit stronger beliefs and expectations in connections across science, engineering, and math areas. Finally,

teachers' attending EOTPDs are better able to integrate engineering curriculum materials in their classrooms; therefore, inclusion of more EOTPDs should be considered to improve STEM teachers' beliefs and expectations about engineering education (Nathan, 2011).

Design elements of leading EOTPDs. Daugherty (2009) explored design elements within five leading EOTPDs for STEM teachers in U.S. high schools. The selected EOTPDs for this study were (a) Engineering the Future Science Technology and the Design Process (EtF), (b) Project Lead the Way (PLTW), (c) Mathematics Across the Middle School MST Curriculum (MSTP), (d) the Infinity project, and (e) the INSPIRES project. From Daugherty's study, several design elements emerged in the delivery of engineering content for STEM teachers, including: (a) philosophy towards engineering, (b) format in number of days, (c) the online component, (d) teacher recruitment, (e) design model, (f) instructional design, and (g) instructors.

Specific design elements of leading EOTPDs. Daugherty (2009) described seven design elements used in the delivery of engineering content knowledge. First, the philosophy of EtF and MSTP projects were oriented toward technological literacy for all students while the philosophy of PLWT, The Infinity, INSPIRES projects were oriented towards developing students' aptitudes to pursue post-secondary engineering. Both of these types of philosophical thought might be necessary; while technological literacy for all students helps in developing STEM literacy, students' aptitudes to pursue post-secondary engineering is useful as a way to increase the engineering pipeline. Second, the number of days differed among the projects from two days to two weeks. This

supports current research (Wilson, 2011) suggesting effective projects should go beyond the traditional one-day format found in most teacher professional development. Wilson suggests doing so engages teachers in activities, learning experiences, and effective collaborations. Moving beyond the one-day format also ensures STEM teachers have sufficient time to process the complex engineering content within the projects (Daugherty, 2009). Third, all projects used an online component to provide support to teachers. Online components are essential to establish communication between project leaders and teachers as well as collaboration among teachers for sharing and discussing experiences during and after EOTPDs. Fourth, teacher recruitment was a design element that differed among projects. The EtF, MSTP, and INSPIRES projects used direct mailing for marketing workshops to targeted area schools while PLWT and The Infinity used required agreement from school district administration for teachers' attendance. Fifth, all five projects used curriculum-linked instructional models. Each of these models focused on the desired knowledge, skills, and abilities for teachers' successful implementation of engineering content. However, leaders within the EOTPDs made different decisions regarding coverage of the curriculum provided to the teachers. Sixth, the instructional design was an important element within each project but one that also differed among projects. EtF, MSTP, and PLTW projects used a scaffold problem solving approach while The Infinity and INSPIRES projects used self-guided learning. Finally, the frequency and types of instructor within projects was a design element that varied among EOPTDs. For example, three of the five projects used two different instructor types whereas the remaining two used only one. It should also be noted, the

type of instructors used in the projects varied, to include master teachers, engineering faculty, and project leaders.

In addition to the design elements of leading EOTPDs, Daugherty (2009) noted leading EOTPDs' assessment strategies were insufficient to evaluate effectiveness. For example, the projects only used strategies with surveys and/or informal discussions. By contrast, Daugherty (2009) suggested “projects should incorporate rigorous evaluation into the design of their professional development so that they can provide a better understanding of how teachers learn engineering, change, and impact student learning” (p. 21). Instead of superficial assessments, such as short surveys or informal discussions, comprehensive assessments should be considered in EOTPD design. Additionally, this study revealed the need for continuous monitoring of teachers' conceptual understanding of engineering subjects in order to examine EOTPDs' effectiveness for STEM teachers (Daugherty, 2009). Overall, Daugherty (2009) suggested more research on examining how teachers learn different engineering content knowledge is important for future EOTPDs. This examination may result in better understanding of how effective EOTPDs can be designed (NRC, 2014b) for meaningful conceptual understanding in the engineering content knowledge of STEM teachers.

The important components of effective EOTPDs. Research has suggested (a) providing better subject content and pedagogical content knowledge preparation (Custer & Daugherty, 2009; Darmofal et al., 2002; Martínez et al., 2013; NRC, 2014b; Wilson, 2011); (b) developing opportunities to deepen teacher knowledge and practice on engineering topics (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009;

Daugherty, 2009; Wilson, 2011); (c) using learner-centered instructional strategies (Cunningham & Carlsen, 2014; Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt., 1999; O. Kaya, 2008; NRC, 2000, 2014b; Wilson, 2011); (d) including hands-on activities for collaboration (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Katehi et al., 2009); (d) integrating social, environmental, and other impacts of engineering design (Cunningham & Carlsen, 2014; Katehi et al., 2009; NRC, 2014b); (e) defining an engineering conceptual base (Custer & Daugherty, 2009; NRC, 2014b); (f) using credible instructors to deliver engineering content and pedagogy (Custer & Daugherty, 2009; Daugherty, 2009); and (g) using authentic assessment methods to measure conceptual understanding of engineering subjects (Daugherty, 2009; Katehi et al., 2009; Wilson, 2011) is necessary for effective EOTPDs. Research on effective EOTPDs is limited, however, because the idea of EOTPD is new to the literature. In current research, Cunningham and Carlsen (2014) attempted to create a “design criteria” for effective EOTPDs. According to these authors, an effective EOTPD design for STEM teachers in K-12 engineering education should;

- engage teachers in engineering practices,
- model pedagogies that support those practices,
- give teachers experience as both learners and teachers,
- develop teachers’ understanding of the fundamentals of and interconnections between science and engineering, and
- help teachers to understand engineering as a social practice (Cunningham & Carlsen, 2014, p. 207).

STEM teachers should increase their engineering content knowledge through effective EOTPDs. In doing so, teachers should increase familiarity with paradigms of teaching, learning, and assessment and develop meaningful conceptual understanding of engineering content knowledge.

Recent calls (e.g., CCSSM, 2010; ITEEA, 2007; NGSS, 2013) emphasize the need for integration across all STEM content areas (NRC, 2014b) and research shows that the nature of engineering content knowledge serves as a catalyst in the integration of STEM areas (Katehi et al., 2009). In other STEM areas, stakeholders encourage teachers to teach respective areas through integration of engineering (NGSS, 2013; NRC, 2012, 2014b). Therefore, effective engineering teaching has become crucial for successful STEM education. Since effective engineering teaching requires meaningful conceptual learning of complex content knowledge in engineering (Martínez et al., 2013), a new conceptual framework has become necessary to create effective STEM learning environments (e.g., EOTPDs for STEM teachers) for successful STEM education. This conceptual framework should explain important components for meaningful conceptual learning of engineering content knowledge within new paradigms of teaching, learning, and assessment.

Meaningful Conceptual Learning

The conceptual framework of this dissertation, meaningful conceptual learning (MCL), is bounded by the literature describing necessary components needed to improve STEM teachers' conceptual understanding of complex and interdisciplinary content knowledge (e.g., engineering content knowledge) within new paradigms of teaching,

learning, and assessment. To enhance and sustain change in STEM teachers' conceptual understanding of engineering content knowledge, researchers recommend creation of effective EOTPDs (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Katehi et al., 2009; Nathan et al., 2011; Wilson, 2011) to include cognitive scaffolds (O. Kaya, 2008; Novak, 2002; Novak & Canas, 2008; Novak, 2010; NRC, 2014b), collaboration (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Katehi et al., 2009; NRC, 2014b), argumentation discourse (Duschl, Schweingruber, & Shouse, 2007; E. Kaya, 2013; NRC, 2014b), and authentic assessment strategies (Ingec, 2009; Katehi et al., 2009; O. Kaya, 2008; Lopez et al., 2011) for meaningful conceptual learning (Ausubel, 2000; Martínez et al., 2013; Novak, 2002, 2010; Novak & Canas, 2008) of engineering content knowledge.

To understand the MCL framework for STEM content knowledge, the distinction between meaningful and rote learning needs to be addressed. Meaningful learning occurs when learners conscientiously choose to integrate new knowledge into existing knowledge structures (Ausubel, 2000; Novak, 2002, 2010; Novak & Canas, 2008). New knowledge gained through meaningful learning is retained longer and results in a well-organized knowledge structure (Novak, 2002, 2010; Novak & Canas, 2008). This well-organized structure helps learners acquire related materials as well as to make connections across interdisciplinary content areas (Novak, 2002, 2010) such as STEM content knowledge (NRC, 2012, 2014b). Furthermore, meaningful learning results in a high commitment for learners to seek relationships between new and existing knowledge (Novak & Canas, 2008). With meaningful learning, this acquired knowledge “can be

applied in a variety of new problems or contexts” (Novak, 2010, p. 68). On the other hand, rote learning occurs when learners make no conscious effort to integrate new knowledge into existing knowledge structures. With rote learning, new knowledge is retained in short-term memory and results in poorly organized or unorganized knowledge structure. Thus, meaningful learning should be considered superior to rote learning in frameworks designed to improve conceptual understanding of engineering content knowledge as well as other content knowledge areas in STEM.

Meaningful learning in other STEM areas (i.e., science, mathematics, technology) without integration of engineering content knowledge is difficult; however, a meaningful conceptual learning (MCL) framework addresses the challenge of learning engineering content knowledge and integrating that knowledge with other STEM knowledge via meaningful learning. Therefore, understanding how a MCL framework for engineering content knowledge assists meaningful learning needs special attention. The MCL for engineering content knowledge in the literature review requires four components: (a) cognitive scaffolds, (b) collaboration, (c) argumentation discourse, and (d) authentic assessment (see Figure 2.3). According to research on socio-cognitive theories of teaching, learning, and assessment (Goldman et al., 1999; Novak, 2010; NRC, 2000, 2014b) as well as effective STEM education, engineering education, and EOTPDs (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Greene et al., 2013; Katehi et al., 2009; Nathan et al., 2011; Wilson, 2011), these four components are critical in the MCL framework for engineering content knowledge. Thus, inclusion of

these components into STEM learning environments, including EOTPDs, may result in successful STEM education.

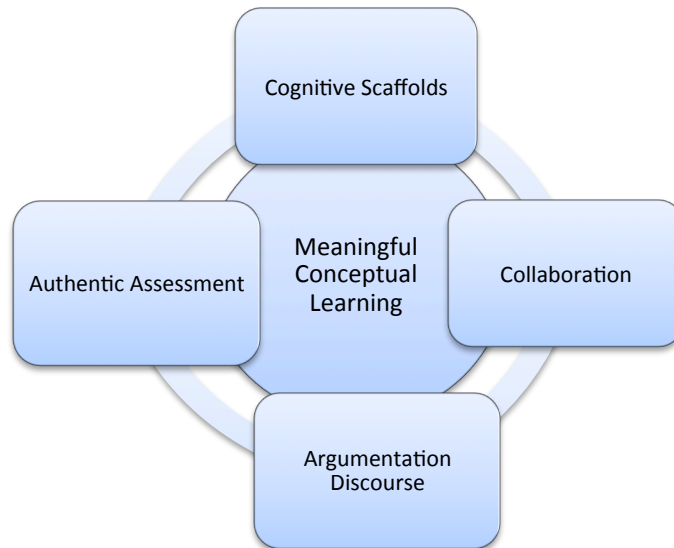


Figure 2.3. Conceptual framework of MCL in complex and interdisciplinary content knowledge.

Cognitive Scaffolds

Cognitive scaffolds are learning tools providing support in the organization of knowledge structures. To understand the role of cognitive scaffolds, the analogy of physical scaffolds can be useful. Physical scaffolds around a building provide a temporary framework in building construction. These scaffolds are temporary supports

removed as the building is completed (Goldman et al., 1999). Similarly, cognitive scaffolds serve as temporary frameworks to support the process of knowledge construction. In learning complex and interdisciplinary content knowledge (e.g., engineering content knowledge), cognitive scaffolds (e.g., concept maps and Vee diagrams) can be vital for facilitating learners' knowledge construction through conceptual understanding (Novak, 2002, 2010; Novak & Canas, 2008; NRC, 2014b); serving as advance organizers for teachers (Ausubel, 1968; Novak, 2010); and improving learners' thinking, analyzing, and problem solving skills (Goldman et al., 1999).

Facilitating learners' conceptual understanding. Conceptual understanding in some content areas (e.g., engineering) can be difficult to acquire (Custer & Daugherty, 2009; Wilson, 2011). For example, the current view of STEM education in K-12 level proposes integrating engineering into all STEM areas (CCSSM, 2010; ITEEA, 2007; NGSS, 2013). However, learning complex content knowledge in engineering can be quite challenging (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Katehi et al., 2009; Nathan et al., 2011; Wilson, 2011), especially for novice learners (NRC, 2000, 2014b). Therefore, use of cognitive scaffolds assists learners in organizing the cognitive learning process for meaningful learning (Ausubel, 2000; Novak, 2002, 2010; Novak & Canas, 2008). In addition, cognitive scaffolds can be crucial tools for rote learners to transition into meaningful learning (Novak, 2002). Cognitive scaffolds, therefore, facilitate conceptual understanding of complex content knowledge and provide opportunities for meaningful learning.

Advance organizers. Cognitive scaffolds can also serve as advance organizers (Ausubel, 1978) for teachers in teaching complex subjects. These organizers help “learners bridge the gap between knowledge they already possess and new knowledge to be learned” (Novak, 2010, p. 79). In doing so, offering a small piece of instruction prior to main instruction helps learners organize targeted information. This prior instruction helps learners relate new knowledge to extant knowledge. For example, using concept maps as cognitive scaffolds before main instruction about a complex topic helps learners represent extant knowledge about complex topics while making connections with new knowledge. Advance organizers, therefore, support teachers in teaching complex topics.

Concept maps. The idea of concept maps was first developed in Novak’s research program to better understand how children develop and organize knowledge in science (Novak & Gowin, 1984). A growing body of cognitive research in the last four decades has indicated concept maps are powerful learning tools (Darmofal et al., 2002; Ingec, 2008, 2009; O. Kaya, 2008; Lopez et al., 2011; Miller et al., 2009; Novak, 2002, 2010; Novak & Canas, 2008; Novak & Gowin, 1984) serving as cognitive scaffolds (Novak, 2002, 2010; Novak & Canas, 2008) and stimulating meaningful learning (Martínez et al., 2013; Novak, 2002, 2010). Concept maps are two-dimensional diagrams representing conceptual knowledge in a visual format (Martínez et al., 2013). A concept map consists of concepts, connection lines, and linking-words/prepositions (see Figure 2.4). Used properly, the use of valid concepts and meaningful connections about a topic in these maps represent learners’ extant knowledge and scaffolds new knowledge.

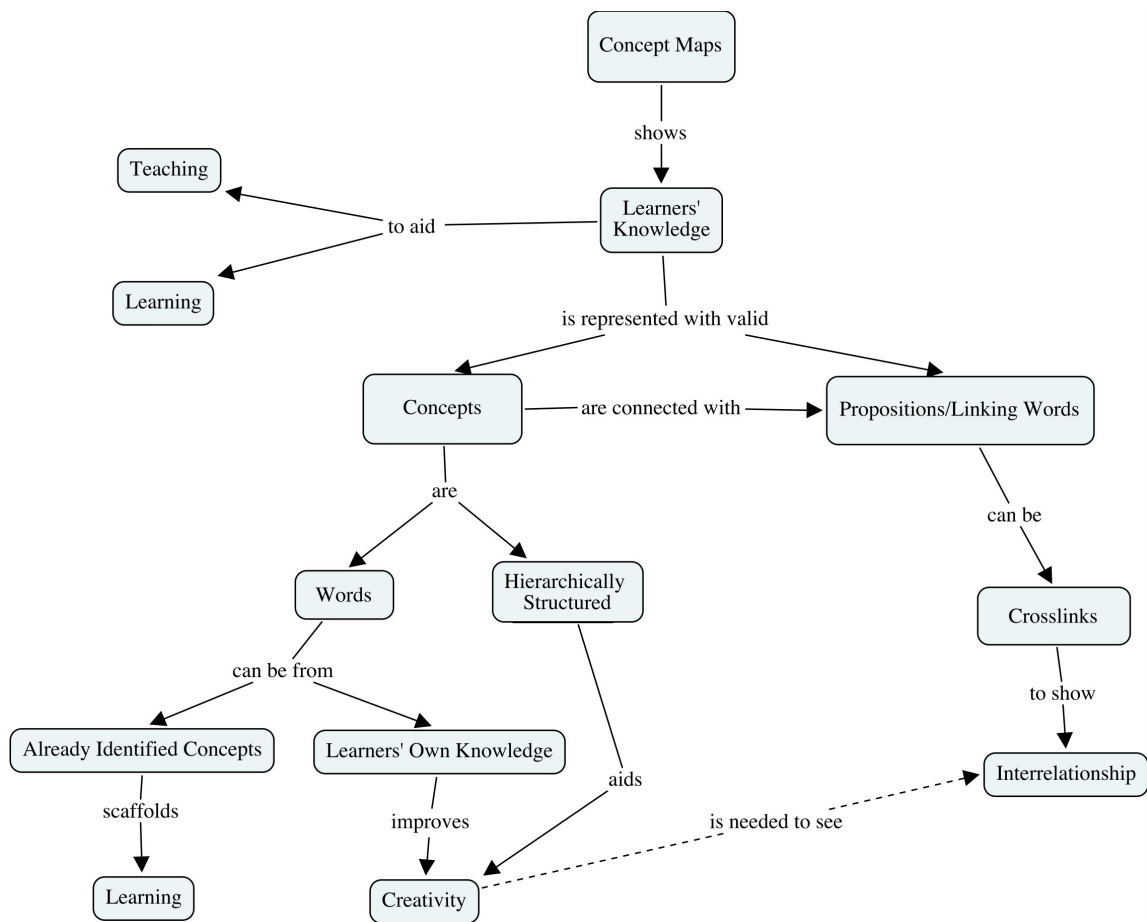


Figure 2.4. A concept map showing the key ideas and principles (Adapted from Novak, 2010).

Concept maps as cognitive scaffolds. Research has shown concept maps serve as effective cognitive scaffolds (Novak, 2010). As cognitive scaffolds, concept maps help learners develop thinking, analyzing, and problem solving skills and improve conceptual understanding (Goldman et al., 1999). Moreover, concept maps are suitable in establishing a “road map” for connections among content knowledge areas (Novak, 2010). For example, concept maps in learning and teaching engineering content

knowledge, requiring expertise across multiple STEM content areas (Duschl et al., 2007), can act as an effective cognitive scaffold for meaningful learning in engineering content knowledge. Therefore, inclusion of concept maps as cognitive scaffolds into STEM learning environments for learning engineering content knowledge is necessary in the MCL framework for meaningful learning.

The use of concept maps as cognitive scaffolds in engineering. Concept maps have been used in various STEM content areas (e.g., science and mathematics) to assess changes in learners' conceptual understanding of content knowledge (Lopez et al., 2011; Walshe, 2007), but their usage as cognitive scaffolds is limited (Darmofal et al., 2002; Lopez et al., 2011; Martínez et al., 2013) in engineering content (Wilson, 2011). Research shows providing cognitive scaffolds (a) improves learners' conceptual understanding (Darmofal et al., 2002; Martínez et al., 2013; Novak, 2010) and encourages reflection on conceptual understanding (Ingec, 2009), (b) identifies learners' knowledge structures and gaps in conceptual understanding (Lopez et al., 2011), (c) facilitates meaningful learning (Martínez et al., 2013) in engineering content knowledge (Darmofal et al., 2002; Martínez et al., 2013). As recent calls highlight increasing engineering content knowledge (e.g., CCSSM, 2010; ITEEA, 2007; and NGSS, 2013) and integrating this knowledge with other STEM areas (NGSS, 2013; NRC, 2012, 2014b), concept maps- as cognitive scaffolds- may be useful in the conceptual understanding of complex content knowledge in engineering as well as establishing integration between/among STEM areas. Hence, using concept maps in engineering

learning environments (e.g., EOTPDs), as cognitive scaffolds should result in meaningful learning.

Collaboration

Collaboration describes how learners work together to accomplish common goals (Goldman et al., 1999; NRC, 2000, 2014b). Collaboration is vital in engaging learners through social interactions for meaningful learning (Good & Brophy, 2008). Social interactions via collaboration facilitate learning from others (NRC, 2000, 2014b; Vygotsky, 1978), enhance conceptual understanding (Bilgin & Geban, 2006b; Chinn, Duncan, Dianevesky, & Rinehart, 2013; Jonassen & Easter, 2013; Miyake, 2013; Siler, Klahr, & Matlen, 2013; Vosniadou, 2013a, 2013b) and scaffold learning complex and interdisciplinary content knowledge (Cunningham & Carlsen, 2014; Daugherty, 2009; Katehi et al., 2009).

Facilitating learning from others. Collaboration provides social interaction opportunities for learners. These opportunities establish learning environments in which social dialogs support learning. In this regard, the Zone of Proximal Development (ZPD) is defined as “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” (Vygotsky 1978, p. 86). Social interaction with more knowledgeable others (e.g., peers or experts) is, therefore, a method for closing the distance defined as ZPD that exists between novice learners and more knowledgeable peers.

Enhancing conceptual understanding. Research has demonstrated appropriate social supports within collaboration helps learners engage meaningfully in learning activities (NRC, 2000), while suitable cognitive supports within collaboration results in better conceptual understanding of subject content knowledge (Novak & Canas, 2008). For example, Bilgin and Geban (2006) conducted a quasi-experimental designed study to examine the effects of collaborative learning approaches on high school students' conceptual understanding of chemical equilibrium. The study provided evidence suggesting collaborative learning approaches increases conceptual understanding. Similarly, collaboration in EOTPDs can establish a format for social dialogue and enhance STEM teachers' conceptual understanding of complex content knowledge in engineering (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Katehi et al., 2009; Nathan et al., 2011; Wilson, 2011). However, research has shown that in today's collaborative learning environments' design, a careful arrangement is necessary by considering complexity and learners' needs (NRC, 2014b).

Collaboration in today's learning environments. As I move toward a more science- and technology rich society in the twenty-first century, learning competencies and expectations have changed. To meet the competencies and expectations of learning, special attention should be given to collaboration in learning environment designs. For example, the competencies in this century "are a blend of cognitive, interpersonal, and intrapersonal characteristics that may support deeper learning and knowledge transfer. Cognitive competencies include critical thinking and innovation; interpersonal attributes include communication, collaboration, and responsibility; and intrapersonal traits

include flexibility, initiative, and metacognition” (NRC, 2014b, p. 35). NGSS (2013), as a learning environment design at the K-12 level, supports S&E integration requiring learners to manifest deeper learning and connect knowledge between/among across STEM areas. As learning content knowledge has become more challenging with recent calls from policy stakeholders (e.g., CCSSM, 2010; ITEEA, 2007; and NGSS, 2013), learners need appropriate collaboration opportunities suitable for learning complex and interdisciplinary content knowledge. Research suggests collaboration in small group structure with peer interaction opportunities and collaborative learning tools (e.g., concept mapping) to organize and scaffold complex content learning process leads to learning this content knowledge (Novak, 2010; NRC, 2000, 2014b).

Small groups and peer interaction. In learning complex and interdisciplinary content knowledge, research suggests creating small learning groups with peer interaction opportunities (NRC, 2014b). Gauvain indicates large groups obstruct active participation, hinder monitoring of the collaborative learning process, and obscure the scaffold learning process in learning complex and interdisciplinary content knowledge. On the other, small groups encourage learners to be active and contributing members, and allow for instructors to monitor collaborative learning process and scaffold learners if they stray from the goal (Gauvain, 2001; NRC, 2014b) of learning the complex and interdisciplinary content knowledge. Further, peer interaction is superior to interaction with adults (NRC, 2014b) as peer interaction is more open and gives equal opportunities for all learners to participate in the learning process (Piaget, 1952). Ellis and Guavin (1992) argue peer interactions (e.g., tutoring, discussion, negotiation, argumentation

discourse) serve different learning opportunities because defining and structuring problems are mutually accessible for peers (as cited in NRC, 2014b, p. 87). Also, different perspectives of learners can be available via peer interaction so that peers conceptualize knowledge through peer interactions (NRC, 2014b). As small group structure is useful and peer interaction is more beneficial in today's learning environments, creating small groups with peer interaction opportunities in learning complex and interdisciplinary content knowledge should take place.

Concept maps as collaborative learning tools. A growing body of research indicates collaborative concept map activities in small groups are useful for conceptual understanding of this knowledge (Bilgin & Geban, 2006b; Darmofal et al., 2002; O. Kaya, 2008; Kwon, 2006; Miller et al., 2009; Miyake, 2013; Novak & Canas, 2008; Novak, 2010; Preszler, 2004). Collaborative concept map activities often establish a format for social dialog in which learners find opportunities for social interactions (e.g., discussion, negotiation, and argumentation discourse). When well designed, these activities also encourage learners to be active and contributing members. For example, having discussions about what concepts to include and how to construct group concept maps, negotiations about which concepts to use, and argumentation discourses about each members point of view on topics makes learners more active and helps them clarify their understanding.

Furthermore, while collaborative concept map activities allow monitoring of learners' conceptual understanding, observations of other members' conceptualization and knowledge structures processes may increase learners' understanding and result in

well-organized knowledge structures. Allowing learners to come up with their own concept maps about topics and sharing ideas via concept maps to the group helps learners see what and how others think about the topics (Cavlazoglu, Akgun, & Stuessy, 2013; Cavlazoglu & Stuessy, 2013). Doing so also scaffolds learners' conceptual understanding of complex and interdisciplinary content knowledge. For example, in conceptual understanding of integrated STEM content knowledge, collaborative concept map activities may have a critical role for deeper learning and result in better connection between/among STEM areas. Using concept maps as collaborative learning tools, therefore, can establish a unique collaboration opportunity for meaningful learning and be critical for better conceptual understanding (Cavlazoglu et al., 2013; Cavlazoglu & Stuessy, 2013).

Argumentation Discourse

Argumentation discourse is “the substance of any meaningful discourse that seeks to generate improved knowledge and understanding” (Duschl & Osborne, 2002, p. 51). A primary goal for argumentation discourse is the establishment of dialogue in which learners participate in social interactions and collaboration opportunities leading to enhanced knowledge and understanding about content (e.g., engineering content). As new learning theories emphasize the importance of social interactions and collaboration opportunities to enhance cognitive learning (NRC, 2000, 2014b), argumentation discourse has become a critical component in effective learning environments. Some researcher in learning theory believe argumentation discourse; (a) increases conceptual understanding (Duschl et al., 2007; Duschl & Osborne, 2002; E. Kaya, 2013a), (b)

improves learners' argumentation skills (Duschl & Osborne, 2002; E. Kaya, 2013a; Simon, Erduran, & Osborne, 2006), and (c) fosters active participation in learning processes (Duschl & Osborne, 2002; E. Kaya, 2013b; NRC, 2014b; Simon et al., 2006).

Argumentation discourse for better conceptual understanding. According to recent research, argumentation discourse among learners supports the development of conceptual understanding (e.g., E. Kaya, 2013a) and facilitates cognitive development of content knowledge (Erduran, Simon, & Osborne, 2004; Jimenez-Aleixandre & Erduran, 2008; E. Kaya, 2013b; Simon et al., 2006). For example, in her quasi-experimental study, E. Kaya (2013) delivered chemical equilibrium content to pre-service teachers using argumentation discourse with an experimental group and traditional lecture with a control group. She found argumentation discourse increased pre-service teachers' conceptual understanding of chemical equilibrium content, as well as their argumentation skills. Argumentation discourse, therefore, should be included in learning environments designed for better conceptual understanding.

Teachers' roles in argumentation discourse. Teachers are still at the center of educational practices and dominate argumentation discourse in classrooms (Duschl et al., 2007; Duschl & Osborne, 2002). Classroom discourse, as described by Duschl and Osborne (2002), more often occurs as whole class discourse led by teachers in which students have limited opportunities for argumentation discourse. Furthermore, students rarely have opportunities for active engagement in whole class argumentation discourse. However, research suggests argumentation discourse for students in small groups provide active opportunities to reason and reflect on their own learning as well as

construct and evaluate their own knowledge (Duschl & Osborne, 2002; NRC, 2000). In addition, research indicates limitations in teachers' pedagogical skills in argumentation discourse (E. Kaya, 2013). These limitations may further prevent teachers from using argumentation discourse in classrooms. To overcome these limitations, teachers should be provided with opportunities to improve their pedagogical skills in argumentation discourse within their respective subject areas (E. Kaya, 2013).

For effective argumentation discourse, teachers should encourage students “to question, to justify and to evaluate their own, and others' reasoning, enculturating the students as learners into discourse processes that support personal knowledge construction and student metacognition” (Duschl & Osborne, 2002, p. 43). In doing so, teachers' roles should include creating such classroom environments to engage students for active participation in argumentation discourse and scaffolding argumentation discourse in small groups rather than t whole classrooms. To accomplish these roles, a distributed learning approach may prove useful.

Distributed learning approach in argumentation discourse. A distributed learning approach gives meaningful roles for members of small groups (i.e., two to four members). These roles allow members to actively participate in collaborative learning (NRC, 2014b). In this approach, it is crucial to give equal opportunities to all members while keeping them active within the group. In doing so, creating a guideline for argumentation discourse can be helpful.

Cohen (1994) notes having no guidelines or structured guidelines may result in poor or unsuccessful argumentation discourse within small groups (as cited in Duschl &

Osborne, 2002, p. 57). Other researchers suggest creating guidelines (e.g., Duschl & Osborne) to keep members of small groups active are necessary while giving these members opportunities to become involved in argumentation discourse. Familiarity with argumentation discourse should also be considered for learners within small groups faced with understanding complex content. Structured guidelines are likely important for learners having no prior experience with argumentation discourse and/or complex content. Therefore, creating guidelines based upon learners' prior experiences in argumentation discourse and levels of content knowledge is necessary for successful argumentation discourse.

Concept maps in argumentation discourse. Concept maps in small groups may provide learners with unique opportunities in argumentation discourse. Research suggests using tools, such as concept maps, facilitate learners' use of argumentation discourse (Duschl & Osborne, 2002; E. Kaya, 2013; NRC, 2014b). For learners in small groups, therefore, concept maps likely assists learners in using argumentation discourse (Duschl & Osborne, 2002) and acquisition of complex content (e.g., engineering; NRC, 2014b). Although little research exists on understanding the influence of argumentation discourse in a single content area, even less research exists on the influence of argumentation discourse across interdisciplinary content areas (e.g., STEM content knowledge). However, asking learners within small groups to construct individual concept maps about a topic and then organizing those learners into small groups may facilitate argumentation discourse. Having multiple concept maps, as visual aids for members' knowledge about a topic, may help learners to actively participate in

argumentation discourse and result in better understanding. Therefore, using concept maps, as tools in argumentation discourse should be considered in learning complex content.

Authentic Assessment

Authentic assessment is a form of assessment allowing learners opportunities to improve knowledge structures by receiving feedback and revising for conceptual understanding (Goldman et al., 1999; Ingec, 2009; O. Kaya, 2008; NRC, 2000, 2014b). As today's learning environments become more challenging to learners, requiring conceptual understanding of complex and interdisciplinary content (NGSS, 2013; NRC, 2014b), the use of authentic assessments has become essential (O. Kaya, 2008; NRC, 2000, 2014b). Research on strategies for assessing learners' conceptual understanding of complex and interdisciplinary content knowledge (NRC, 2014a, 2014b) suggests using authentic assessments over traditional assessments (Ingec, 2009). Traditional assessments (e.g., multiple choice tests and short answer tests) are not capable of measuring conceptual understanding or providing detailed information about learners' conceptual understanding of content knowledge. Additionally, these assessments are not sufficient in assessing learners' content knowledge within an interdisciplinary context (e.g., earthquake engineering) as they are incapable of linking relationships among the content areas. Also, these assessments do not give sufficient opportunities for learners to revise understanding and receive feedback. However, authentic assessments, such as concept maps, are capable in assessing learners' conceptual understanding of complex and interdisciplinary content knowledge and giving these same learners feedback to

revise their understanding (Darmofal et al., 2002; Goldman et al., 1999; Ingec, 2008; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013; Novak & Canas, 2008; Novak, 2010; NRC, 2000, 2014a, 2014b).

Concept maps as authentic assessment tools. The use of concept maps as authentic assessment tools has many advantages in today's learning environments. Concept maps as authentic assessment tools (a) assess conceptual knowledge (Darmofal et al., 2002; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013; Novak, 2010; Walshe, 2007), (b) help learners make thinking visible to themselves and others (Darmofal et al., 2002; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Novak & Canas, 2008; Novak, 2010), (c) provide feedback and revision opportunities to improve learners' thinking and learning (Goldman et al., 1999; Greene et al., 2013; Novak, 2010; NRC, 2000, 2014b), and (d) allow monitoring of learners' progress (Bilgin & Geban, 2006a; Darmofal et al., 2002; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013; Novak, 2002, 2010; Novak & Canas, 2008). When used properly, these maps are valid and reliable tools for assessing learners' meaningful conceptual understanding rather than factual memory (Lopez et al., 2011), and are capable for assessing complex and interdisciplinary content knowledge (e.g., STEM content knowledge and engineering content knowledge) rather than only a single content knowledge (Katahi, 2009; NGSS, 2013; NRC, 2014a, 2014b).

Assessing conceptual knowledge. According to literature (e.g., Star & Stylianides, 2013), there are two primary types of knowledge; conceptual and procedural knowledge. Star and Stylianides (2013) state, "Conceptual knowledge would refer to

knowledge of concepts, including principles and definitions; procedural knowledge would refer to knowledge of procedures, including action sequences and algorithms used in problem solving” (p. 171). This would suggest these two types of knowledge need to be assessed via different assessment methods. Assessing conceptual knowledge requires appropriate assessment methods (Ingec, 2008, 2009; Lopez et al., 2011). Research on methods for assessing conceptual knowledge (Ingec, 2008, 2009; NRC, 2014a; Ozdemir, 2005) indicates some traditional methods (e.g., multiple-choice tests) are not capable in assessing conceptual knowledge. For example, Ozdemir (2005) points out multiple-choice exams and written exams are not capable in assessing conceptual understanding of mathematics content. Therefore, authentic methods (e.g., concept maps) for assessing conceptual knowledge may prove more appropriate.

Using concept maps assessing conceptual understanding. Researchers engaged in assessing learners’ conceptual understanding suggest the use of concept maps (Cavlazoglu et al., 2013; Darmofal et al., 2002; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013; Novak, 2010; Walshe, 2007). Concept maps are designed to provide detailed information about learners’ conceptual understanding (Cavlazoglu et al., 2013; Cavlazoglu & Stuessy, 2013; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013). Results of studies comparing concept maps and traditional methods for assessing conceptual knowledge (e.g., multiple-choice tests; Ingec, 2009; Lopez et al., 2011; O. Kaya, 2007; Ozdemir, 2005) revealed concept maps are powerful tools for assessing learners’

conceptual understanding in various content areas (e.g., chemistry, materials processing, aerospace, and algebra).

Making learners' thinking visible. Concept maps provide concrete information about learners' knowledge structures in a visual form (Darmofal et al., 2002; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Novak, 2010; Novak & Canas, 2008). Learners can therefore display their conceptual knowledge via concept maps. This display of conceptual knowledge is also useful for identifying learners' misconceptions (Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013; Novak & Canas, 2008; Novak, 2010). As recent calls emphasize mastering core concepts through progressive learning (Duschl et al., 2007; NGSS, 2013) and deep coverage of fewer topics (NRC, 2000, 2012, 2014b), having learners' conceptual knowledge in a visual format gives opportunities to observe progress in learners' knowledge construction and misconceptions in knowledge structure (Novak & Canas, 2008).

Opportunities for feedback and revision via concept maps. According to new learning theories (Goldman et al., 1999; NRC, 2000, 2014b), learners should have opportunities for feedback and revision as these opportunities are critical for learners to modify and refine knowledge. Concept maps, as an authentic assessment tool, provide feedback to learners about targeted content knowledge and offer opportunities to revise their knowledge (Cavlazoglu & Stuessy, 2013; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013). Learners' concept maps visually document what knowledge learners have and how they think about the knowledge (Novak, 2010). In addition, instructors may use these maps to determine learners' (a)

levels of content mastery, (b) knowledge structures for content, and (c) responses to the instructor's teaching (O. Kaya, 2008). Ultimately, these maps provide instructors with opportunities to modify their instruction upon learners' needs in learning content and resulting in improved teaching.

Validity and reliability of concept maps. Researchers in prior studies have used concept maps as tools for assessing conceptual knowledge (Cavlazoglu et al., 2013; Darmofal et al., 2002; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013; Novak, 2010; Walshe, 2007). Lopez et al., (2011) reported these maps as valid and reliable instruments in assessing that knowledge. Two concept map construction techniques (i.e., fill-in-the-map and construct-a-map-from-scratch) have been used most often (Ingec, 2009; Lopez et al., 2011). In the construct-a-map-from-scratch technique, learners are asked to construct a concept map by using concepts from a key concept list and identifying prepositions (i.e., linking verbs to make meaningful connections between concepts; Ingec, 2009, Novak, 2010). The fill-in-the-map technique, on the other hand, requires learners to fill in missing information in a pre-constructed concept map (Lopez et al., 2011). Ruiz-Primo, Schultz, Li, and Shavelson (2001) examined the validity and reliability of both techniques and concluded the construct-a-map-from-scratch technique better reflects learners' knowledge structures.

Identifying key concept for better assessment with concept maps.

Identification of key concepts is important for determining the validity and reliability of concept maps (Darmofal et al., 2002; Walshe, 2007). The process of finding key

concepts can be challenging and time consuming for instructors because it requires extensive research across related materials and careful consideration of learners' knowledge mastery. For example, NGSS (2013) has announced a new framework in science education for the integration of science and engineering in K-12 grades. In doing so, the NGSS research team conducted an extensive analysis of related documents (e.g., National Science Education Standards, Benchmarks for Science Literacy, the Atlas, Science Framework for the 2009 National Assessment of Educational Progress, and Science College Board Standards for College Success) and identified crosscutting concepts necessary to generate the framework. This example highlights the use of related materials and careful consideration of learners' knowledge mastery in identifying key concepts necessary for the integration of science and engineering in K-12 grades.

Assessing complex and interdisciplinary content knowledge with concept maps. Concept maps, as authentic assessment tools, can be used to assess learners' conceptual understanding of the complex and interdisciplinary content knowledge existing in today's learning environments. Current research suggests using concept maps for assessing conceptual understanding of this knowledge leads to positive outcomes for learners (e.g., engineering content knowledge; Cavlazoglu et al., 2013; Darmofal et al., 2002; Greene et al., 2013; Martínez et al., 2013). In addition, concept maps provide information about conceptual understanding in interdisciplinary content areas and their connections across the areas (Cavlazoglu & Stuessy, 2013; Novak & Canas, 2008; Novak, 2010; NRC, 2014b). As learning in today's environments become challenging, with the need for conceptual understanding of complex and interdisciplinary content

knowledge (e.g., STEM content knowledge; NGSS, 2013; NRC; 2014b), use of concept maps as authentic tools for assessing conceptual understanding has become indispensable (NRC, 2014b). For example, recent calls by stakeholders in STEM education emphasize establishing deeper connections among the STEM content areas (NGSS, 2013; NRC, 2014b) and developing new tools for assessing conceptual understanding (NRC, 2014a). Furthermore, the aim of these calls is both the designing of learning experiences with coherent progression over years and the assessing of that progression (NRC, 2014a). Concept maps as authentic tools for assessing conceptual knowledge may answer these calls because concept maps provide information regarding learners' conceptual understanding while assessing learners' progression over time. Concept maps, therefore, should be considered as authentic tools in assessing learners' conceptual understanding.

Conclusion

STEM education has been a critical focus in the last two decades due to its critical role on the economic welfare and leadership status of the country and students' development of science literacy. As recent calls from stakeholders in each STEM content areas (e.g., CCSSM, 2010; ITEEA, 2007; NGSS, 2013) and reports from leading authorities (i.e., NGSS, 2013; NRC, 2014b; National Science and Technology Council, 2011) emphasize the need for meaningful STEM learning with integration of at least two STEM content areas and improving and expanding STEM education across the nation, reformers have suggested creating effective professional development for traditionally educated teachers. Professional development provides critical opportunities for teachers

to familiarize with new paradigms of learning, teaching, and assessment as they are confronted with new standards for integrating STEM areas. Also, professional development enhances teachers' conceptual understanding of complex and interdisciplinary STEM content knowledge such as that required in earthquake engineering.

For meaningful conceptual understanding of complex and interdisciplinary STEM content knowledge in today's learning environments cognitive scaffolds, collaboration, argumentation discourse, and authentic assessment are critical components as described in the MCL framework. Reformers in professional development for STEM education suggest using alternative methods for assessing conceptual understanding within the complex areas of STEM content knowledge. In addition, researchers engaged in assessing conceptual understanding suggest using concept maps as authentic assessment tools that provide detailed information about learners' conceptual understanding, and opportunities for feedback and revision in complex and interdisciplinary STEM content knowledge (Cavlazoglu & Stuessy, 2013; Novak & Canas, 2008; Novak, 2010; NRC, 2014b). The use of concept maps may document changes in conceptual understanding of complex and interdisciplinary STEM content knowledge and provide a better understanding of how learners learn the STEM content knowledge. Therefore, concept maps should be used in today's learning environments including professional development to examine conceptual understanding of complex and interdisciplinary STEM content knowledge within new paradigms of teaching, learning, and assessment for effective STEM education.

CHAPTER III

IDENTIFYING AND VERIFYING EARTHQUAKE ENGINEERING

CONCEPTS TO CREATE A KNOWLEDGE BASE IN STEM EDUCATION:

A MODIFIED DELPHI STUDY

Introduction

STEM education in the last two decades has been a critical focus for stakeholders in public education (Lopez et al., 2011; Nathan, Atwood, Prevost, Phelps, & Tran, 2011; Wilson, 2011). Policymakers, researchers, and educators recognize the role of STEM education on the economic welfare and leadership status of the US (President’s Council of Advisors on Science and Technology, 2010), as well as students’ development of science literacy (Duschl, Schweingruber, & Shouse, 2007). Recent reports from leading stakeholders (i.e., NGSS, 2013; NRC, 2014b), furthermore, have stressed the need for improving and expanding STEM education and enhancing student readiness for future careers reliant on STEM content knowledge (NRC, 2012). In addition, new guidelines for K-12 science and engineering education stress STEM integration (NRC, 2014b) connecting science, technology, mathematics, and engineering content among, rather than within individual domains. As engineering knowledge “utilizes concepts in science and mathematics as well as technology tools” (NRC, 2014b, p. 14), some leading researchers have identified engineering as the likely catalyst for the integrating all STEM areas (Katehi, Pearson, & Feder, 2009). As a result, stakeholders in STEM

education have renewed the call to integrate engineering content knowledge into science, mathematics, and technology classrooms.

Background

Teachers have been encouraged to teach many STEM-related content areas through the integration of engineering rather than focusing on the specific content area. For example, the authors of the *Common Core State Standards for Mathematics* (CCSSM, 2010) announced the need for integrating mathematics with science and engineering. Similarly, the International Technology and Engineering Educators Association (ITEEA) stressed the necessity of understanding connections across science, technology, engineering, and mathematics (ITEEA, 2007). Moreover, important policy documents in science education, such as *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 2009), have announced the need for the integration of all STEM content areas, including engineering. Currently, however, most science teachers still restrict their content knowledge preparation to one specific content area (e.g., life science, chemistry, physics, and earth science) rather than broadening their knowledge to include engineering content areas that would facilitate successful integration. Although the need for integrating engineering to address the purpose of total STEM integration within the other three STEM content areas (i.e., science, mathematics, technology) has been stated, only recently and with limited implementation has engineering been integrated into science classrooms. Knowing this, NGSS (2013) announced a new framework with strong implications for enhancing STEM education. Specifically, this framework focuses on the integration of science and

engineering (S&E) in K-12 science education. A majority of US states have already proposed implementing this framework into their science curriculum (NRC, 2014b).

NGSS Framework

The NGSS framework (NGSS, 2013), based on *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC, 2012), called for deeper connections among STEM subjects (NGSS, 2013; NRC, 2014b). The framework was outlined around concepts for K-12 science education derived from existing documents including the *National Science Education Standards* (NRC, 1996), the *Benchmarks for Science Literacy* (AAAS, 2009), the *Atlas of Science Literacy* (AAAS, 2001), the *Science Framework for the 2009 National Assessment of Educational Progress* (National Assessment of Educational Progress, 2009), and the *Science College Board Standards for College Success* (College Board, 2009). Consequently, the NGSS framework reflects previous standards considered crucial for successful K-12 science education. The goal of the framework is as follows:

To ensure that by the end of 12th grade, *all* students have some appreciation of the beauty and wonder of science; possess sufficient knowledge of science and engineering to engage in public discussions on related issues; are careful consumers of scientific and technological information related to their everyday lives; are able to continue to learn about science outside school; and have the skills to enter careers of their choice, including (but not limited to) careers in science, engineering, and technology. (NRC, 2012, p. 1)

For successful K-12 science education, the NGSS framework outlines three dimensions: (a) Scientific and Engineering Practices, (b) Crosscutting Concepts, and (c) Disciplinary Core Ideas (Figure 3.1).

Scientific and Engineering Practices	<ul style="list-style-type: none"> Asking questions (for science) and defining problems (for engineering) Developing and using models Planning and carrying out investigations Analyzing and interpreting data Using mathematics and computational thinking Constructing explanations (for science) and designing solutions (for engineering) Engaging in argument from evidence Obtaining, evaluating, and communicating information
Crosscutting Concepts	<ul style="list-style-type: none"> Patterns Cause and effect: Mechanism and explanation Scale, proportion, and quantity Systems and system models Energy and matter: Flows, cycles, and conservation Structure and function Stability and change
Disciplinary Core Ideas	<ul style="list-style-type: none"> Physical Sciences (PS) 1: Matter and its interactions PS2: Motion and stability: Forces and interactions PS3: Energy PS4: Waves and their applications in technologies for information transfer Life Sciences (LS) 1: From molecules to organisms: Structures and processes LS2: Ecosystems: Interactions, energy, and dynamics LS3: Heredity: Inheritance and variation of traits LS4: Biological evolution: Unity and diversity Earth and Space Sciences (ESS) 1: Earth’s place in the universe ESS2: Earth’s systems ESS3: Earth and human activity Engineering, Technology, and Applications of Science (ETS)1: Engineering design ETS2: Links among engineering, technology, science, and society

Figure 3.1. The three dimensions of the NGSS framework with emphasis on practices, concepts, and core ideas.

The NGSS framework stresses meaningful learning in S&E through the integration of the three dimensions into standards, curriculum, instruction, and assessment (NRC, 2012). The first dimension, *Scientific and Engineering Practices*, emphasizes the essential role of practices for student learning of S&E in K-12 science classrooms. Mastering these practices helps students see similarities and differences between science and engineering. In addition, this dimension allows students to establish a better understanding of how scientific knowledge and engineering solutions are developed (NRC, 2012). The second dimension, *Crosscutting Concepts*, highlights critical concepts that “provide students with an organizational framework for connecting knowledge from the various disciplines into a coherent and scientifically based view of the world” (NRC, 2012, p. 83). Familiarity with these concepts in K-12 science classrooms supports student understanding of disciplines within S&E while providing a method to access information across these disciplines. The third dimension, *Disciplinary Core Ideas*, outlines core ideas for the focus of S&E education in K-12 science classrooms. Mastering these core ideas through learning progressions (Duschl et al., 2007) allows students to continually learn core ideas within S&E and develop deep understanding of multiple topics. This dimension, therefore, allows more time for teachers to teach and students to learn each topic over the course of students’ K-12 science education.

The three dimensions within the NGSS framework satisfy the overall goal of STEM integration by implementing engineering content knowledge in K-12 science

classrooms. However, additional challenges for successful STEM education must also be considered before successful integration can occur.

Identifying Knowledge Bases in Targeted Engineering Areas

Developing an understanding of engineering pedagogical content knowledge can be difficult for many K-12 science teachers. For successful STEM learning, teachers must recognize engineering knowledge with a consideration for student learning levels (e.g., elementary, middle, or high school). In doing so, identifying knowledge bases (i.e., key concepts identification; see Rossouw, Hacker, & de Vries, 2011; Wicklein, Smith, & Kim, 2009; Wooten, Rayfield, & Moore, 2013) for the targeted engineering knowledge becomes critical in facilitating student comprehension of the concepts associated with a level of understanding at an appropriate level. In addition, the identification of key concepts is essential for teachers to draft well-defined learning objectives, plan suitable teaching strategies, and create meaningful assessment strategies for measuring student understanding. Some researchers have noted a “fear of engineering” in STEM teachers, due to the complexity of engineering content knowledge (NRC, 2014b). Such a fear can result in a teacher’s lack of confidence in teaching engineering (Banilower et al., 2013). The prior identification of key concepts, therefore, has the potential to reduce the complexity of engineering content for STEM teachers while also increasing their understanding and confidence in teaching engineering.

Several researchers have noted that the identification of key concepts is important for developing valid and reliable assessment strategies (e.g., Darmofal, Soderholm, & Brodeur, 2002; Walshe, 2007), especially within the complex domains of

engineering knowledge (Darmofal et al., 2002; Martínez, Pérez, Suero, & Pardo, 2013; Wilson, 2011). Key concepts that have been previously identified can be used to develop measures for assessing knowledge. When key concepts have not been previously identified, the development of assessments becomes more difficult. Teachers must conduct their own research to identify key concepts in targeted engineering content areas. For example, Rossouw, Hacker, and de Vries (2011) conducted a Delphi study to identify key concepts in engineering and technology education. Similarly, Wooten et al. (2013) also used a Delphi study to identify 21 STEM concepts associated with a junior livestock project. Osborne, Ratcliffe, Collins, Millar, and Duschl (2003) also conducted a three-stage Delphi study to identify key concepts in the nature of science to provide students with a better understanding of the topic.

Similarly, the NGSS (2013) research team conducted an extensive analysis of related documents (e.g., National Science Education Standards, Benchmarks for Science Literacy, the Atlas, Science Framework for the 2009 National Assessment of Educational Progress, and Science College Board Standards for College Success) to identify the crosscutting concepts in the NGSS framework in science education. After the release of this framework, researchers from the National Association for Research in Science Teaching (NARST) suggested ways to develop new engineering lesson plans, which would include identified key concepts in the targeted engineering content area (Purzer, Moore, Baker, & Berland, 2014). This research group recognized key concepts as an essential element of the curriculum enabling science teachers to implement engineering into science classrooms. At this time, however, efforts to identify key

concepts for teaching engineering in K-12 science education are still limited. The earthquake engineering education professional development team at Texas A&M University learned this first hand as they attempted to develop a curriculum for science teachers who would be attending a summer professional development experience about earthquake engineering at Texas A&M University in College Station, Texas.

Earthquake Engineering as a Critical Content Area in Science Classrooms

The recent NGSS framework in science education suggests integrating critical engineering content areas into science classrooms (NGSS, 2013) and finding appropriate engineering areas that allow the implementation of the three dimensions of the NGSS (see Figure 3.1). Earthquake engineering fulfills the definition of a critical engineering content area in that the content domains of earthquake engineering cover most of the *Disciplinary Core Ideas* defined in the NGSS framework. Specifically, the three disciplinary core ideas (i.e., physical sciences; earth and space sciences; and engineering, technology, and applications of science) can be taught through earthquake engineering implementation. These three disciplinary core ideas represent approximately 75% of the disciplinary core ideas that have been a focus in the NGSS framework.

Furthermore, earthquake engineering has the potential to improve the literacy level of citizens about earthquake resilience. In 2011, the National Hazards Reduction Program announced a need in earthquake engineering education research to achieve an earthquake-resilient society and suggested improving understanding of earthquake engineering processes and impacts (NRC, 2011a). The NRC organized a community workshop with 37 researchers and practitioners from a wide range of earthquake

engineering disciplines to identify problems and high-priority research areas in earthquake engineering related research. This workshop revealed the need to focus on social systems as well as designed systems to improve community resilience in earthquake engineering research (NRC, 2011a). The researchers and practitioners in this workshop also noted the limited emphasis on social and designed systems in previous earthquake engineering research. As a result, stakeholders in earthquake engineering education had not yet achieved the goal of creating an earthquake-resilient society.

Earthquake engineering has the potential to be a critical content area for NGSS's recent call for significant engineering content. Currently, however, the key concepts necessary for science teachers and students in K-12 education to learn in order to understand earthquake engineering have yet to be identified. In this study, I propose to identify and verify the key concepts in earthquake engineering necessary for high school science teachers and students to understand earthquake engineering. These concepts will help science teachers, particularly those who have been traditionally prepared to teach a specific science content domain, and their students to understand the multifaceted content domain of earthquake engineering.

Methodology

Type of Research Design

In this study, I used a modified Delphi research design (Skulmoski, Hartman, & Krahn, 2007; see Figure 3.2). The purpose of the Delphi design is to obtain a consensus from a group of experts when there is insufficient knowledge about a phenomenon (Borg, Gall, & Gall, 2003; Wicklein et al., 2009). The Delphi design allows a group of

experts to share thoughts, exchange aspects, and ultimately reach consensus about a phenomenon (Osborne, Ratcliffe, Collins, Millar, & Duschl, 2003; Rossouw et al., 2011; Skulmoski et al., 2007; Wicklein et al., 2009; Wooten et al., 2013). Researchers using the Delphi design have indicated that this method is one of the best research strategies to ascertain a beginning knowledge base in topics that have no foundation in prior research (Delbeq, Van de Ven, & Gustafson, 1975; Skulmoski et al., 2007; Wicklein et al., 2009; Wooten et al., 2013). In addition, the Delphi design can be modified based on the purpose of the study, availability and type of data, and number of experts in the researched area (Skulmoski et al., 2007). When a sufficient number of experts is available (e.g., $n \geq 30$), the classic Delphi design procedures with three rounds of communication can be used. If participants in a classic Delphi design do not have a consensus after three rounds, additional rounds can be added until a sufficient level of consensus is reached among participants. Furthermore, different research methods (i.e., qualitative, quantitative, and mixed) can be used in Delphi studies based on the research questions and availability of data type. When the number of experts is limited in the researched area, further verification with another sample of experts should occur (Skulmoski et al., 2007).

In this study, the number of experts in earthquake engineering education was limited. As a result, I used a modified Delphi research design, implementing a two-phase process to identify and verify the knowledge base for earthquake engineering at the high school level. The goal was to assist science teachers in the summer work program in acquiring a sufficient understanding of earthquake engineering for them to implement

this content into their science classrooms. In addition, teachers can also use these concepts to develop strategies for assessing students' level of understanding, following recommended assessment practices by the NGSS framework developers and other stakeholders in science education (e.g., NRC, 2014a; Purzer et al., 2014).

Figure 3.2 displays the two phases of the modified Delphi study I employed in this study: The first phase- identification and the second phase- verification. The purpose of the first phase was to identify the essential key concepts in earthquake engineering for high school science teachers and students to learn. During this phase, the Earthquake Engineering Education Project (EEEP) researchers conducted intensive research from related literature in both science and earthquake engineering education. They participated in five panel meetings to deliberate, discuss, and negotiate the final list of key earthquake engineering concepts they felt were essential for high school teachers and students to know and understand.

The purpose of the second phase was to verify the key concepts from the original list with a larger panel of experts from varying disciplines. I used a one-round Delphi study via an online questionnaire to verify key concepts from the original list.

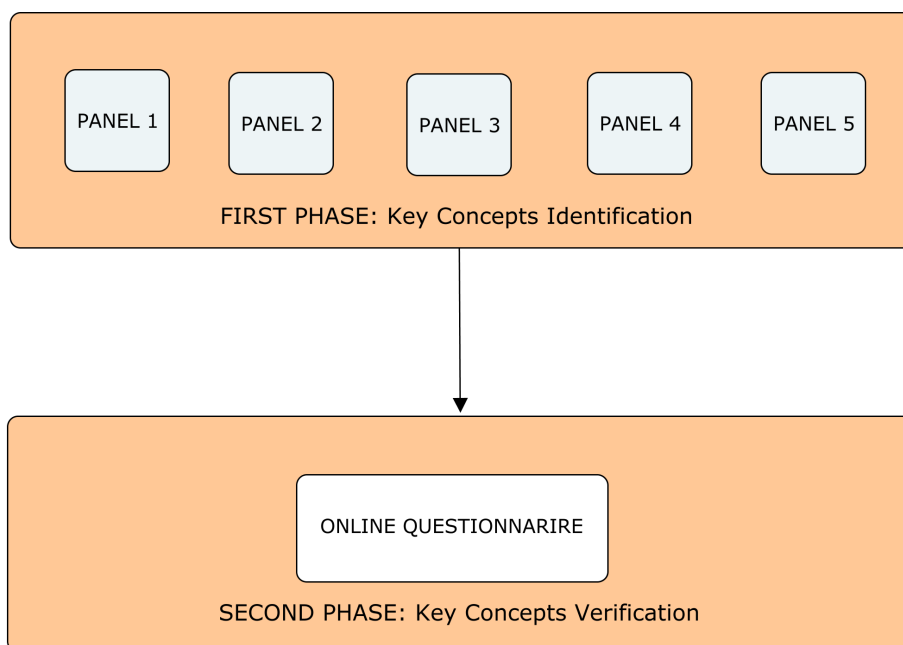


Figure 3.2. Modified Delphi research design used in this study.

Participants

The participants in the two phases of the study were nine experts in earthquake engineering education research. I used purposive sampling to gather experts' opinion (Skulmoski et al., 2007; Wooten et al., 2013) in order to generalize a list of key concepts in earthquake engineering. In the first phase of the modified Delphi study, three researchers identified the original key concepts list. They conducted intensive research from related literature to identify potential key concepts and convened five panel meetings over six months to discuss, deliberate, defend, and make decisions regarding the inclusion of earthquake engineering concepts. These researchers included an associate professor in science education who holds a PhD in science education. Her

research interests include broader impacts in science and engineering research, which led her to become an expert in developing effective STEM workshops for K-12 science teachers. The second researcher holds a master's degree in physics. Her research interests include social learning in teaching and learning science and earthquake engineering. The third researcher is a PhD student in science education who also holds a master's degree in science education. His research interests include developing authentic teaching, learning, and assessment strategies in earthquake engineering education. All researchers in the first phase were members of the Earthquake Engineering Education Project (EEEP) workshop development team.

The second phase of this Delphi study engaged six participants. These included three participants from science education and three participants from civil engineering with research interests and expertise in earthquake engineering. All participants were from tier-1 research universities in the US and met the four expertise criteria for Delphi studies as identified by Adler and Ziglio (1996): (1) sufficient knowledge and interest with the phenomena under investigation, (2) capacity and interest to participate, (3) available to spare sufficient time for participating and (4) efficient communication skills.

Data Collection and Analysis Procedures

For the first phase of the study, the data were collected using concept lists that the EEEP research team generated after each panel meeting. For the second phase of the study, the data were collected using an online questionnaire, and six experts were asked to verify the key concepts that had been identified in the first phase.

In the first phase of the study, I used descriptive statistics to report each panel's products resulting in a list of key concepts, using a criterion of 100% consensus for inclusion of the concept in the key concept list. In the second phase of the study, I again used descriptive statistics to report the results of respondents' ratings, including means, medians, and modes for each concept. For this phase, I established a criterion level of 80% consensus (Wooten et al., 2013) to verify the inclusion of a concept in the key concepts list.

Procedures and Results

This Delphi study consisted of two phases including first phase for key concepts identification and second phase for key concepts verification.

First Phase: Key Concepts Identification

This phase consisted of five face-to-face panel meetings of three researchers to identify and negotiate a final list of key concepts appropriate for learners at the high school level in developing a basic understanding of earthquake engineering. Each panel meeting focused on a particular phase of key concept identification, as follows: (1) Resource Document Identification, (2) Content Domain Identification, (3) Initial Key Concept Identification, (4) Key Concept List Completion, and (5) Key Concept List Confirmation.

Panel 1: Resource document identification. Three researchers convened to identify resource documents for identifying the key concepts appropriate for learners at the high school level in order to develop a basic understanding of earthquake engineering. Specifically, they asked, "What are the important documents I need to use

as references in identifying the key concepts necessary for high school learners to understand earthquake engineering?” The researchers discussed critical documents to use as resources, and all agreed on seven nationally published documents spanning a period of seventeen years (see Table 3.1).

Table 3.1

Source Documents for Identifying Key Concepts in Earthquake Engineering

Year	Name	Reference
2013	Next Generation Science Standards	NGSS
2011	Grand Challenges in Earthquake Engineering Research: A Community Workshop Report	NRC
2011	National Earthquake Resilience: Research, Implementation, and Outreach	NRC
2009	Benchmarks for Science Literacy	AAAS
2007	Atlas of Science literacy, Volume II	AAAS
2001	Atlas of Science literacy, Volume I	AAAS
1996	National Science Education Standards	NRC

At the end of the first panel meeting, researchers agreed that the next step would be to identify the domain areas in earthquake engineering. They also agreed to review the source documents on their own and bring ideas to discuss and finalize at the next

panel meeting. The researchers scheduled the second panel for approximately two months later.

Panel 2: Content domain identification. As earthquake engineering is an interdisciplinary content area, critical domains related with science, as well as its STEM connections, needed to be identified. In this panel, researchers identified the content domain areas subsuming the key concepts to include in high school earthquake engineering. After spending two months reviewing the documents (see Table 3.1), the participants discussed the identified five critical domains in earthquake engineering, with 100% agreement. These domains were: (1) Physical Systems, (2) Designed Systems, (3) Social Systems, (4) Earth Systems, and (5) STEM Proficiencies. At the end of the second panel meeting, participants agreed to identify key concepts representing the most essential ideas in earthquake engineering and to place them within each of the five critical domains areas. They scheduled the third panel meeting one month later. Each participant referred to the documents again, this time for the purpose of identifying key concepts and placing them into the related domain areas.

Panel 3: Initial key concept identification. In this panel, researchers focused on answering this question: “What domain-specific concepts are critical for high school science teachers and students to understand earthquake engineering?” Each researcher indicated concepts she/he found important in her/his individual review of decided literature (see Table 3.1) and discussed each concept in detail in the panel. At the end of this panel, the three researchers identified 23 key concepts (see Table 3.2), decided to

continue to identify any remaining key concepts, and scheduled the fourth panel meeting one month later.

Table 3.2

Identified Key Concepts List in Panel 3

Domain Area	Key Concepts
Physical Systems	Force, Energy, Motion, Transfer
Designed Systems	Efficacy, Cost, Safety, Constraints, Regulations, Risks, Resources
Social Systems	Social Response, Urban Infrastructure, Decision Making, Governance, Policy, Finance
Earth System	Earthquakes, Geographic Landforms, Plate Boundaries
STEM Proficiencies	Observation, Measuring, Prediction

Panel 4: Key concept list completion. In this panel, participants completed the key concepts list by adding 12 more concepts to the list. The added concepts were as follows: “disturbance” and “waves” in the Physical Systems domain; “reliability” and “resilience” in the Designed Systems domain; “oversight” and “prevention” in the Social Systems domain; “epicenter” and “worldwide patterns” in the Earth System domain; and “mathematical modeling,” “system thinking,” “theorizing,” and “tools” in the STEM Proficiencies domain. At the end of this meeting, participants decided to meet in another

panel to review the key concepts for a final time. The fifth panel was scheduled for three weeks later.

Panel 5: Key concept list confirmation. In this final panel meeting, all concepts were discussed and confirmed. In addition, two more concepts, “redundancy” and “trade-offs,” were added to the key concepts list. With two more concepts identified in this panel, the total came to 37 concepts distributed within the five domain areas (see Table 3.3).

Table 3.3

Final Version of Identified Key Concepts List

Domain area	Key concepts
Physical Systems	Force, Energy, Motion, Transfer, Disturbance, Waves
Designed Systems	Efficacy, Cost, Safety, Constraints, Regulations, Risks, Resources, Reliability, Resilience, Trade-offs, Redundancy
Social Systems	Social Response, Urban Infrastructure, Decision Making, Governance, Policy, Finance, Oversight, Prevention
Earth System	Earthquakes, Geographic Landforms, Plate Boundaries, Epicenter, Worldwide Patterns
STEM Proficiencies	Observation, Measuring, Prediction, Mathematical Modeling, System Thinking, Theorizing, Tools

Second Phase: Key Concepts Verification

In this phase, I asked six earthquake-engineering experts to indicate their level of agreement on each of the 37 concepts. I sent an online questionnaire to the experts via email, which was completed in three weeks. The questionnaire provided a brief summary of the previous concept identification process as well as rationale of the study. The 37 identified concepts were presented within the five domain areas listed in Table 3.3. To complete the verification process, each of the six experts indicated their level of agreement for each concept. My analysis of participant responses to the online questionnaire yielded statistics for each concept shown in Table 3.4. In Table 3.4, the first column indicates the domain areas for key concepts. The second column lists the concepts identified by experts in the phase one. The third and fourth columns contain measures of center, specifically the mean and mode values for experts' responses on the questionnaire. The fifth column contains a measure of spread, namely the range or difference between the highest and lowest response values. The sixth column contains a measure for the shape of experts' responses.

Table 3.4

Results for Key Concepts Verification

Domain area	Key concept	Mean	Mode	Range	% Rating with 4 or 5
Physical Systems	Force	5.00	5	0	100
	Energy	5.00	5	0	100
	Motion	5.00	5	0	100
	Waves	5.00	5	0	100
	Transfer	4.83	5	1	100
	Disturbance	4.17	5	2	67
Designed Systems	Cost	4.83	5	1	100
	Safety	4.83	5	1	100
	Risks	4.83	5	1	100
	Constraints	4.67	5	1	100
	Regulations	4.50	5	1	100
	Resources	4.50	5	1	100
	Resilience	4.50	5	1	100
	Efficacy	4.33	5	2	83
	Trade-offs	4.33	5	2	83
	Redundancy	4.33	5	2	83
	Reliability	4.33	5	2	67
Social Systems	Urban Infrastructure	4.67	5	1	100
	Governance	4.50	5	1	100
	Finance	4.50	5	1	100

Table 3.4 continued

Domain area	Key concept	Mean	Mode	Range	% Rating with 4 or 5
Earth Systems	Policy	4.33	4	1	100
	Social Response	4.33	4	1	100
	Decision Making	4.33	5	2	83
	Prevention	4.00	5	2	50
	Oversight	3.67	4	2	67
	Epicenter	5.00	5	0	100
	Earthquakes	4.83	5	1	100
	Plate Boundaries	4.83	5	1	100
	Geographic Landforms	4.50	5	1	100
	Worldwide Patterns	4.33	5	2	83
STEM Proficiencies	Mathematical Modeling	5.00	5	0	100
	Observation	4.50	5	1	100
	Measuring	4.50	5	2	83
	Prediction	4.50	5	2	83
	System Thinking	4.50	5	2	83
	Tools	4.17	5	3	83
	Theorizing	3.33	3	1	33

The concept verification process resulted in 35 concepts verified by six experts reaching the consensus criterion (i.e., 80% agreement; Wooten et al., 2013) with a minimum mean of 4.00. Only two concepts, “oversight” and “theorizing,” had a lower

mean (i.e., $M_{oversight}=3.67$ and $M_{theorizing}=3.33$). I dropped these concepts from the final key concepts list to yield a final list of 35 identified and verified concepts. Table 3.5 lists the 35 concepts considered essential for high school learners to understand earthquake engineering.

Table 3.5

Final Version of Key Concepts List

Domain area	Key concepts
Physical Systems	Force, Energy, Motion, Transfer, Disturbance, Waves
Designed Systems	Efficacy, Cost, Safety, Constraints, Regulations, Risks, Resources, Reliability, Resilience, Trade-offs, Redundancy
Social Systems	Social Response, Urban Infrastructure, Decision Making, Governance, Policy, Finance, Prevention
Earth System	Earthquakes, Geographic Landforms, Plate Boundaries, Epicenter, Worldwide Patterns
STEM Proficiencies	Observation, Measuring, Prediction, Mathematical Modeling, System Thinking, Tools

Furthermore, I created a strand map (see Figure 3.3) to facilitate high school teachers' use of the key concepts in teaching earthquake engineering. The strand map illustrates the key concepts in a visual form showing relationships among and across concepts in the five domains of earthquake engineering. The map indicates relationships

among concepts within a single strand (all of the same color, unbroken lines) and across strands (see dotted lines). The strand map follows conventions established by the AAAS (AAAS, 2001, 2007), in which they depict connections between and among strands for four grade level bands. My map, in contrast, indicates relationships between and among concepts within the strands for only high school (grades 9-12) learners. As with conventions established by Novak (2010), concepts are arranged hierarchically, arrows indicate the direction and connecting words indicate the nature of the relationship between the connected concepts.

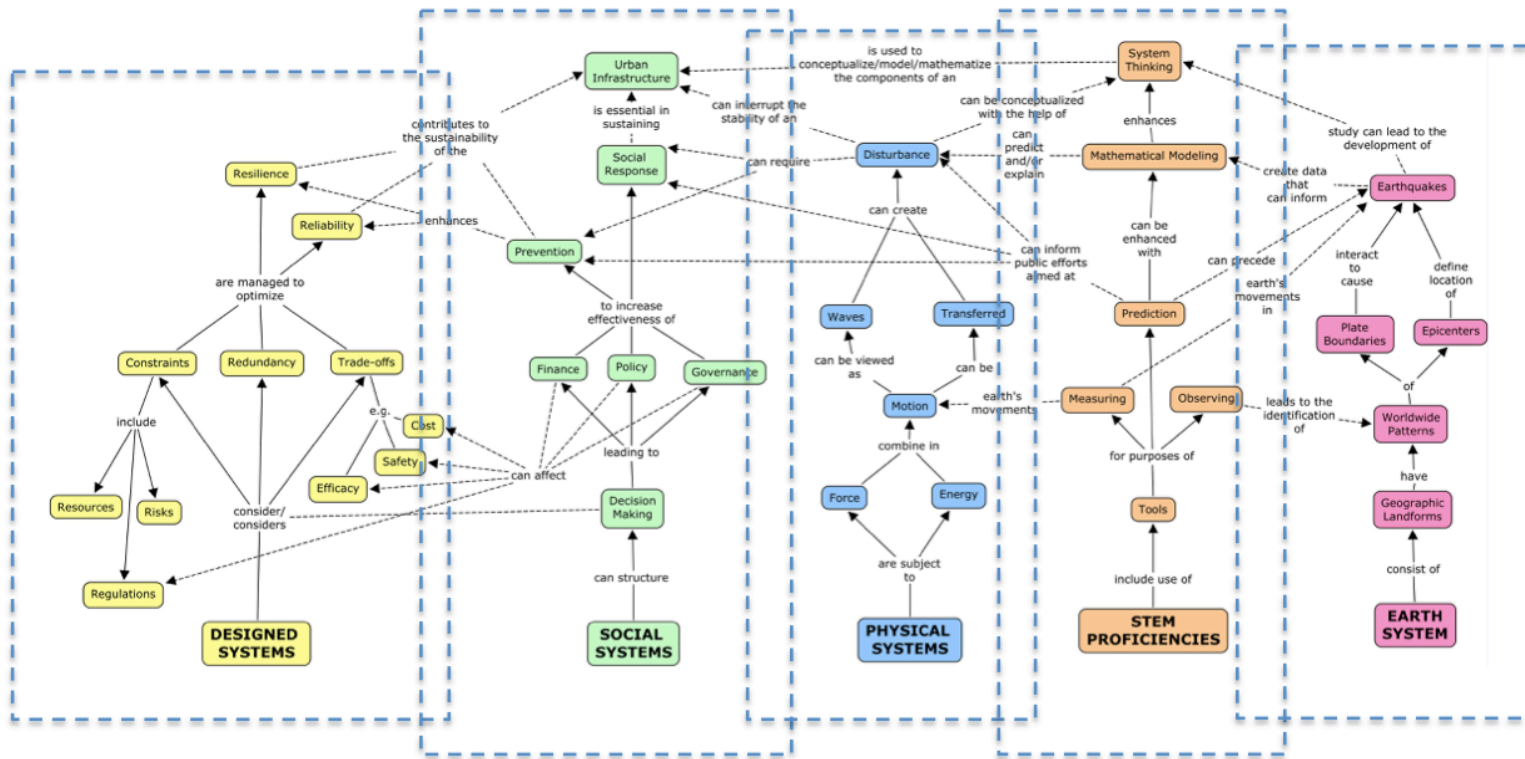


Figure 3.3. Strand map linking concepts identified within the five Domain Areas (i.e., “strands”) of Earthquake Engineering.

Conclusion

New K-12 STEM education guidelines emphasize integrating engineering knowledge in STEM-content classrooms, with engineering knowledge serving as a catalyst for the integration of STEM content areas. In addition, the recent NGSS framework (2013) stresses integration of science and engineering in K-12 science classrooms for successful STEM education. This framework has been purposed by a majority of US states to be implemented into their science curricula (NRC, 2014b). However, research continues to show that science teachers still have a “fear of engineering” because of their limited engineering content knowledge. Furthermore, most of these teachers do not have access to well-defined knowledge bases (e.g., key concepts) in critical engineering content areas. Currently, defined engineering knowledge bases at the high school level do not exist (NRC, 2014b). In this regard, researchers have suggested that new integrated STEM curricula contain a list of key concepts critical in understanding the specific engineering content area (e.g., earthquake engineering). My purpose in conducted this modified Delphi study was to identify and verify key concepts in earthquake engineering necessary for high school learners to acquire a basic understanding of earthquake engineering. I conducted the modified Delphi study in a two-phase process. In Phase 1, three researchers in earthquake engineering education identified 37 key concepts in five domains with 100% consensus; in Phase 2, I asked six experts in science education and civil engineering with research interests and expertise in earthquake engineering to verify the concepts identified in Phase 1. Phase 2 experts verified 35 of these concepts with at least 80% consensus. I

then created a key concepts list and strand map with 35 earthquake engineering key concepts to support high school science teachers' (and their students') development of an understanding about earthquake engineering. High school science teachers as well as other teachers in STEM content areas (i.e., mathematics, technology, and engineering) can use these key concepts to understand and teach earthquake engineering content in their STEM classrooms.

Implications

At least four implications exist in the results of this modified Delphi study. First, high school STEM teachers can use the engineering key concepts list for understanding and teaching earthquake engineering in their STEM classrooms. As research suggests, identifying key concepts is critical in engineering content areas for STEM teachers' better understanding and teaching of engineering content (Purzer et al., 2014; Rossouw et al., 2011; Wicklein et al., 2009; Wooten et al., 2013). STEM teachers can use the key concepts list to better understand and implement earthquake engineering (i.e., a critical engineering content area) into their classrooms. The strand map can help teachers see the key concepts in a visual form illustrating relationships among concepts within a single domain and across domains.

Second, this modified Delphi study can be a model for others to identify and verify key concepts in other engineering content areas. Stakeholders in STEM education suggest identification of key concepts in critical engineering content areas for high school STEM teachers to increase their engineering content knowledge and teach the engineering content confidently without a "fear of engineering" (NRC, 2014) due to the

complexity of engineering content. The identifications of key concepts can make complex and interdisciplinary engineering content areas more implementable for STEM classrooms.

Third, curriculum developers in science, or STEM education, can benefit from using key concepts in developing engineering integrated curricula for successful STEM education (Rossouw et al., 2011). The list can provide a reference for developing lesson plans, learning activities (Purzer et al., 2014), and assessments to measure complex and interdisciplinary engineering content areas (NRC, 2014a). As identified, key concepts in the list are related to nearly 75% of the disciplinary core ideas purposed in the NGSS framework. Implementing these earthquake-engineering concepts into science classrooms can be beneficial in the integration of the NGSS framework (NGSS, 2013) into science classrooms.

Finally, the implementation of earthquake engineering into STEM classrooms using these key concepts may result in achieving and enhancing students' earthquake resiliency literacy, as suggested by The National Hazards Reduction Program (NRC, 2011a). Implementing earthquake engineering into STEM classrooms can increase students' knowledge of earthquakes and result in improved awareness of earthquakes.

Limitations

I identified two limitations in this Delphi study. The first of these limitations was the small sample size for each phase of the study (e.g., n=3 researchers in the first phase and n=6 in the second phase). Even though some Delphi researchers (e.g., Lam, Petri, & Smith, 2000) explain that the number of participants can be limited due to limited

expertise in some areas (Skulmoski et al., 2007), a larger number of experts, if possible, could lead to greater population validity in terms of identifying the key concepts in earthquake engineering. The second of these limitations was the data source. In Delphi studies, the data comes from the experts' opinions rather than facts (Rossouw et al., 2011). In this study, the three researchers in the first phase conducted an intensive literature review to determine key concepts and therefore used both facts and opinion when identifying each concept. Expert opinion was asked in the second phase of the study.

CHAPTER IV

EXAMINING CHANGES IN SCIENCE TEACHERS' CONCEPTUAL UNDERSTANDING ABOUT EARTHQUAKE ENGINEERING

Introduction

Policy makers, researchers, and educators in science education have focused on STEM education because of its critical role on the economic welfare and leadership status of the country (Lopez et al., 2011; Nathan, Atwood, Prevost, Phelps, & Tran, 2011; National Science and Technology Council, 2011; Wilson, 2011). Furthermore, leading stakeholders in national educational policy (e.g., NGSS, 2013; NRC, 2014b) have reported the need for improving and expanding STEM education and enhancing students' readiness for future careers reliant on STEM content knowledge (NRC, 2012). In addition, recent calls (e.g., CCSSM, 2010; ITEEA, 2007; NGSS, 2013) stress the need for integration across all STEM content areas (NRC, 2014b). To do so, stakeholders suggest implementing engineering content knowledge into STEM classrooms since the nature of engineering content knowledge serves as a catalyst in the integration of all STEM areas (Katehi et al., 2009). Moreover, a recent framework in science education, the NGSS framework, emphasizes the integration of science and engineering (S&E) in K-12 science classrooms and indicates potential implications for enhancing STEM education (NGSS, 2013). Teachers with STEM connections (i.e., science teachers, technology teachers, mathematics teachers, and engineering teachers), especially science teachers in K-12 education, have had few opportunities to improve their conceptual

understanding of engineering content knowledge (Daugherty, 2009; Martínez, Pérez, Suero, & Pardo, 2013; Nathan et al., 2011) to increase students' conceptual understanding of engineering knowledge (Martínez, Pérez, Suero, & Pardo, 2013).

Background

The distinction between conceptual and procedural knowledge needs to be addressed in order to understand “conceptual understanding.” According to Star and Stylianides (2013), “conceptual knowledge would refer to knowledge of concepts, including principles and definitions; procedural knowledge would refer to knowledge of procedures, including action sequences and algorithms used in problem solving” (p. 171). Teachers must have a sufficient level of conceptual understanding to effectively teach the targeted content knowledge (Banilower et al., 2013; NRC, 2014b). However, some complex and interdisciplinary content areas (e.g., engineering) are far beyond teacher's experience or knowledge, and conceptual understanding of content knowledge can prove difficult.

Conceptual understanding of engineering content knowledge requires learners to become familiar with diverse knowledge domains and to make connections among those domains (NGSS, 2013; NRC, 2012, 2014a, 2014b). As stakeholders in science education stress integration of S&E (NGSS, 2013; NRC, 2012) as well as STEM integration in K-12 science classrooms (NRC, 2012, 2014a, 2014b), increasing science teachers' conceptual understanding of engineering content knowledge has become a matter of further concern among educators. Effective science teachers possess the ability to convert STEM content knowledge, including engineering content knowledge, into

meaningful learning for their students. Furthermore, new theories of learning have come into focus leading to very different ideas about teaching, learning, and assessment (Goldman et al., 1999; NGSS, 2013; Novak, 2010; NRC, 2000, 2014a, 2014b). These theories have emerged from research and practice in cognitive science, psychology, neuroscience, and learning (see NRC, 2000).

Science teachers are faced with new paradigms for teaching, learning, and assessment as they are confronted with new standards for integrating S&E content knowledge within STEM contexts (NGSS, 2013; NRC, 2014a, 2014b). While traditionally educated secondary school science teachers may possess a deep understanding of science content knowledge, these same teachers may have had no prior experiences or course work to support emerging STEM education needs for the integration of engineering content knowledge into their teaching. For example, a study of science teachers' college coursework shows that science teachers take courses within science disciplines (e.g., chemistry, life sciences, earth/space science, physics, and environmental science); however, engineering coursework is often limited (Banilower et al., 2013, see Table 4.1). Banilower's research indicated middle and high school science teachers take 7% and 14% of their college coursework in engineering, respectively, concluding science teachers' engineering content knowledge is limited when compared to their science content knowledge. With conclusions such as these, the NGSS announced the need for science teachers who are traditionally prepared to teach in one of the traditional domains of science to broaden their expertise and to increase their engineering content knowledge (NGSS, 2013; NRC, 2014a, 2014b). To achieve this

need, traditionally prepared science teachers must have opportunities to accommodate new goals familiarizing them with strategies to integrate engineering content into their traditionally structured science lessons. These opportunities are often found in STEM teacher education programs and professional development (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; NRC, 2014b; Wilson, 2011).

Table 4.1

Percent of Science Teachers Taking Coursework in Specific Science Disciplines by School Level

Discipline	Teacher school level		
	Elementary (%)	Middle (%)	High (%)
Engineering	1	7	14
Physics	32	61	86
Environmental science	33	57	56
Chemistry	47	72	93
Earth/Space science	65	75	61
Student teaching in science	70	73	72
Science education	89	89	85
Life sciences	90	96	91

STEM teacher education programs may provide opportunities to enhance science teachers' conceptual understanding of engineering. However, the number of engineering teacher education programs is very limited (Banilower et al., 2013; Katehi et al., 2009; NRC, 2014b) although a large number of science and mathematics teacher education programs and a small number of technology teacher education programs exist (NRC, 2014b). STEM teacher professional development may also provide critical opportunities for both pre- and in-service teachers to enhance their content knowledge (NRC, 2014b). According to results from a national survey (Banilower et al., 2013), more than 80% of science and mathematics teachers in STEM education participated in discipline-focused professional development within the last three years. This data supported the researchers' conclusion that current science and mathematics teachers in STEM education have a high interest in participating professional development and provides evidence that teachers perceive professional development as an appropriate way to enhance their knowledge of STEM education. Studies such as these substantiate the role of professional development as an appropriate and worthwhile venue for enhancing teacher quality in STEM education (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Greene et al., 2013; Katehi et al., 2009; Nathan et al., 2011; NRC, 2000, 2014b; Wilson, 2011).

Furthermore, research indicates STEM teachers' anxieties due to limited conceptual understanding of engineering content knowledge may lessen their effectiveness (Banilower et al., 2013) and STEM teacher professional development is likely essential in reducing teachers' anxiety with engineering content (NRC, 2014b). In

the national survey study conducted by Banilower et al. (2013), science teachers were asked how well they felt prepared to teach engineering content. Only 6% of science teachers in middle schools and 7% of science teachers in high schools responded as feeling very well prepared to teach engineering content. This study also revealed a high number of STEM teachers still have “the fear of engineering” and lack confidence in teaching engineering content (Banilower et al., 2013). The authors of this study concluded science teachers as well as other teachers in STEM should participate in engineering-oriented teacher professional development (EOTPD) to reduce their anxiety by increasing conceptual understanding of engineering content knowledge.

Engineering-Oriented Teacher Professional Development

Recent calls from interested organizations (e.g., American Association for the Advancement of Science [AAAS] and NRC) and research in the field (Daugherty, 2009; Nathan et al., 2011; Wilson, 2011) have recommended creating EOTPDs to enhance STEM teachers engineering content knowledge. In addition, stakeholders in both STEM education and science suggest integration of engineering into STEM content classrooms since the engineering content knowledge is suitable for integration across STEM content areas (NGSS, 2013; NRC, 2012, 2014b). Engineering, however, remains the least developed and implemented of the STEM areas at the K-12 level (NRC, 2014b).

Engineering knowledge for STEM integration. As previously mentioned, there is a need for the integration of engineering with other STEM content areas (NGSS, 2013; NRC, 2012, 2014b). In this sense, the nature of engineering knowledge may be appropriate for facilitating such integration (Katehi et al., 2009) as the nature of

engineering knowledge “utilizes concepts in science and mathematics as well as technology tools” (NRC, 2014b, p. 14). For example, a study by Katehi and others (2009) revealed students who had teachers with greater engineering content knowledge scored higher on science and mathematics than students from random comparison groups in a national level exam. Researchers have concluded engineering might serve as a catalyst for the integration of all STEM areas (Katehi et al., 2009).

Engineering integration efforts in science and mathematics content areas. In science and mathematics content areas, teachers have been encouraged to teach content through integration of engineering rather than focusing on specific STEM areas. For example, recent developments in science education have led to a renewed interest in the integration of science with engineering thus S&E are both embodied in the NGSS framework. The NGSS (2013) framework stresses active engagement in S&E practices to deepen understanding in both content areas as well as establishing meaningful connections between S&E concepts (NRC, 2012). In addition, the authors of the *Common Core State Standards for Mathematics* (CCSSM, 2010) announced the need for the integration of mathematics with science and engineering.

Design elements of leading EOTPDs. Daugherty (2009) explored design elements within five leading EOTPDs for STEM teachers in US high schools. The selected EOTPDs for this study were (a) *Engineering the Future Science Technology and the Design Process* (EtF), (b) *Project Lead the Way* (PLTW), (c) *Mathematics Across the Middle School MST Curriculum* (MSTP), (d) *The Infinity Project*, and (e) *The INSPIRES Project*. From Daugherty’s study, several design elements emerged in the

delivery of engineering content for STEM teachers, including: (a) philosophy towards engineering, (b) format in number of days, (c) an online component, (d) teacher recruitment, (e) design model, (f) instructional design, and (g) instructors.

Specific design elements of leading EOTPDs. Daugherty (2009) described seven design elements used in the delivery of engineering content knowledge. First, the philosophy of EtF and MSTP projects were oriented toward technological literacy for all students while the philosophy of PLWT, The Infinity, The INSPIRES projects were oriented towards developing students' aptitudes to pursue post-secondary engineering. Both of these types of philosophical thought might be necessary; while technological literacy for all students helps in developing STEM literacy, students' aptitudes to pursue post-secondary engineering is useful as a way to increase the engineering pipeline. Second, the number of days differed among the projects from two days to two weeks. Longer time periods support current research (Wilson, 2011) suggesting effective projects should go beyond the traditional one-day format found in most teacher professional development experiences. Wilson indicates longer time periods engage teachers more fully in activities, learning experiences, and effective collaborations. Moving beyond the one-day format also ensures teachers have sufficient time to process the complex engineering content within the projects (Daugherty, 2009). Third, all projects used an online component to provide support to teachers. Online components enhance the communication between project leaders and teachers as well as collaboration among teachers for sharing and discussing experiences during and after EOTPDs. Fourth, teacher recruitment was a design element that differed among projects.

The EtF, MSTP, and The INSPIRES projects used direct mailing for marketing workshops to targeted area schools while PLWT and The Infinity project used required agreements from school district administration for teachers' attendance. Fifth, all five projects used curriculum-linked instructional models. Each of these models focused on the desired knowledge, skills, and abilities for teachers' successful implementation of engineering content. However, leaders within the EOTPDs made different decisions regarding coverage of the curriculum provided to the teachers. Sixth, the instructional design was an important element within each project but one that also differed among projects. EtF, MSTP, and PLTW projects used a scaffolded problem solving approach while The Infinity and The INSPIRES projects used self-guided learning. Finally, the frequency of exposure to and types of instructors within projects was a design element that also varied among EOPTDs. For example, three of the five projects used two different instructor types whereas the remaining two used only one. It should also be noted that the type of instructors used in the projects varied to include master teachers, engineering faculty, and project leaders.

In addition to the design elements of leading EOTPDs, Daugherty (2009) noted that the leading EOTPDs' assessment strategies were insufficient to evaluate effectiveness. For example, the leading EOTPDs used the strategies of surveys and/or informal discussions. By contrast, Daugherty (2009) suggested "projects should incorporate rigorous evaluation into the design of their professional development so that they can provide a better understanding of how teachers learn engineering, change, and impact student learning" (p. 21). Instead of superficial assessments (e.g., short surveys or

informal discussions), comprehensive assessments should be considered in EOTPDs. Overall, Daugherty (2009) suggested more research examining how teachers learn different engineering content knowledge as important in the design of future EOTPDs. An examination of this sort may result in better understanding of how effective EOTPDs can be designed (NRC, 2014b) for meaningful conceptual understanding in the engineering content knowledge of STEM teachers.

Design criteria for effective EOTPDs. The idea of EOTPD is new to the literature. Few studies exist examining the nature of quality EOTPDs for teachers. Cunningham and Carlsen (2014), however, recently attempted to create a “design criteria” for effective EOTPDs. According to these authors, an effective design for teachers in K-12 engineering education should:

- engage teachers in engineering practices,
- model pedagogies that support those practices,
- give teachers experience as both learners and teachers,
- develop teachers’ understanding of the fundamentals of and interconnections between science and engineering, and
- help teachers to understand engineering as a social practice. (p. 207)

Research, therefore, is currently under way to develop and test design criteria for effective EOTPDs to increase teachers’ conceptual understanding of engineering content knowledge and their familiarity with new paradigms of teaching, learning, and assessment. Cunningham and Carlsen’s recent work provides structural guidelines for developing effective EOTPDs. Currently lacking in their list, however, is mention of any

assessment strategies, formative or summative, to inform teachers about their learning and EOTPD designers about the effectiveness of their designs. In conducting the research I report here, I found it necessary to develop a new conceptual framework that describes crucial components for an effective EOTPD including an authentic assessment strategy.

Meaningful Conceptual Learning

The conceptual framework of this study, *Meaningful Conceptual Learning* (MCL; see Figure 4.1), is bounded by the literature describing components needed to improve learners' conceptual understanding of complex and interdisciplinary content knowledge within new paradigms of teaching, learning, and assessment. To enhance and sustain change in learners' conceptual understanding of complex and interdisciplinary content knowledge, researchers recommend four components: (1) use of cognitive scaffolds (O. Kaya, 2008; Novak, 2002; Novak & Canas, 2008; Novak, 2010; NRC, 2014b), (2) inclusion of collaboration (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Katehi et al., 2009; NRC, 2014b), (3) provisions for argumentation discourse (Duschl, Schweingruber, & Shouse, 2007; E. Kaya, 2013; NRC, 2014b), and (4) use of authentic assessment strategies (Ingec, 2009; Katehi et al., 2009; O. Kaya, 2008; Lopez et al., 2011) for meaningful conceptual learning (Ausubel, 2000; Martínez et al., 2013; Novak, 2002; 2010; Novak & Canas, 2008).

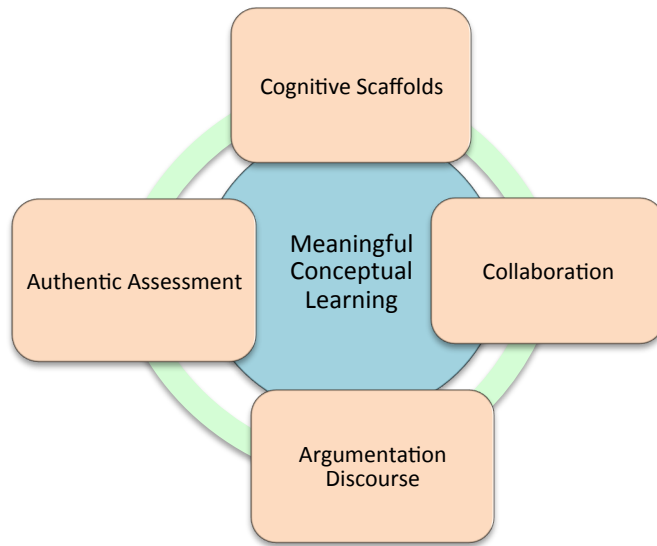


Figure 4.1. An illustration of the Meaningful Conceptual Learning framework developed to guide the research in this study.

A distinction between meaningful and rote learning is necessary to understand the MCL framework. Meaningful learning occurs when learners conscientiously choose to integrate new knowledge into existing knowledge structures (Ausubel, 2000; Novak, 2002; 2010; Novak & Canas, 2008). New knowledge gained through meaningful learning is retained longer and results in a well-organized knowledge structure (Novak, 2002, 2010; Novak & Canas, 2008). This well-organized structure helps learners acquire related materials as well as make connections across interdisciplinary content areas (Novak, 2002, 2010). Furthermore, meaningful learning results in a high commitment for learners to seek relationships between new and existing knowledge (Novak & Canas,

2008). With meaningful learning, this acquired knowledge “can be applied in a variety of new problems or contexts” (Novak, 2010, p. 68). On the other hand, rote learning occurs when learners make no conscious effort to integrate new knowledge into existing knowledge structures. With rote learning, new knowledge is retained in short-term memory and results in poorly organized or unorganized knowledge structure. Thus, meaningful learning should be considered superior to rote learning in frameworks designed to improve conceptual understanding of complex and interdisciplinary content knowledge. As the MCL framework targets meaningful learning in complex and interdisciplinary content areas within new paradigms of teaching, learning, and assessment, using this framework can be beneficial in learning complex and interdisciplinary engineering content knowledge.

Cognitive scaffolds. Cognitive scaffolds are learning tools providing support in the organization of knowledge structures. The analogy of physical scaffolds can be useful in understanding the role of cognitive scaffolds. Physical scaffolds around a building provide a temporary framework in building construction. These scaffolds are temporary supports removed as the building is completed (Goldman et al., 1999). Similarly, cognitive scaffolds serve as temporary frameworks to support the process of knowledge construction. In learning complex and interdisciplinary content knowledge (e.g., engineering content knowledge), cognitive scaffolds (e.g., concept maps and Vee diagrams) can be vital for facilitating learners’ conceptual understanding (Novak, 2002; 2010; Novak & Canas, 2008; NRC, 2014b).

Conceptual understanding in some content areas can be difficult to acquire (Custer & Daugherty, 2009; Wilson, 2011). For example, the current view of STEM education in K-12 education proposes integrating engineering into all STEM areas (CCSSM, 2010; ITEEA, 2007; NGSS, 2013). However, learning complex content knowledge in engineering can be quite challenging (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Katehi et al., 2009; Nathan et al., 2011; Wilson, 2011), especially for novice learners (NRC, 2000, 2014b). In addition, cognitive scaffolds can be crucial tools for rote learners to transition into meaningful learning (Novak, 2002). Use of cognitive scaffolds, therefore, assists learners in organizing the cognitive learning process for meaningful learning (Ausubel, 2000; Novak, 2002, 2010; Novak & Canas, 2008).

Collaboration. Collaboration describes how learners work together to accomplish common goals (Goldman et al., 1999; NRC, 2000, 2014b). Collaboration is vital in engaging learners through social interactions for meaningful learning (Good & Brophy, 2008). Social interactions via collaboration facilitate learning from others (NRC, 2000, 2014b; Vygotsky, 1978), enhance conceptual understanding (Bilgin & Geban, 2006; Miyake, 2013) and scaffold learning complex and interdisciplinary content knowledge (Cunningham & Carlsen, 2014; Daugherty, 2009; Katehi et al., 2009).

Collaboration provides social interaction opportunities for learners. These opportunities establish learning environments in which social dialogs support learning. In this regard, the Zone of Proximal Development (ZPD) is defined as “the distance between the actual developmental level as determined by independent problem solving

and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” (Vygotsky 1978, p. 86). Social interaction with more knowledgeable others (e.g., peers or experts) is, therefore, a method for closing the distance that exists between novice learners and more knowledgeable peers.

Research findings have demonstrated appropriate social supports within collaboration helps learners engage meaningfully in learning activities (NRC, 2000), while suitable cognitive supports within collaboration results in better conceptual understanding of subject content knowledge (Novak & Canas, 2008). For example, Bilgin and Geban (2006) conducted a quasi-experimental designed study to examine the effects of collaborative learning approaches on high school students’ conceptual understanding of chemical equilibrium. The study provided evidence collaborative learning approaches increases conceptual understanding. Similarly, collaboration in EOTPDs can establish a format for social dialogue and enhance STEM teachers’ conceptual understanding of complex content knowledge in engineering (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Katehi et al., 2009; Nathan et al., 2011; Wilson, 2011). However, research has shown that in designing today’s collaborative learning environments, a careful arrangement is necessary by considering complexity and learners’ needs (NRC, 2014b). Research suggests collaboration among learners in small group structures with peer interaction opportunities and collaborative learning tools (e.g., concept mapping) to organize and scaffold complex content learning processes leads to increased content knowledge (Novak, 2010; NRC, 2000, 2014b).

In learning complex and interdisciplinary content knowledge, researchers suggest creating small learning groups with peer interaction opportunities (NRC, 2014b). Gauvain (2001) indicates large groups obstruct active participation, hinder monitoring of the collaborative learning process, and obscure scaffolding the learning process in learning complex and interdisciplinary content knowledge. On the other, small groups encourage learners to be active and contributing members, and allow for instructors to monitor collaborative learning process and scaffold learners if they stray from the goal (Gauvain, 2001; NRC, 2014b) of learning the complex and interdisciplinary content knowledge. Furthermore, peer interaction is superior to interaction with adults (NRC, 2014b) as peer interaction is more open and gives equal opportunities for all learners to participate in the learning process (Piaget, 1952). Ellis and Guavin (2013) argue peer interactions (e.g., tutoring, discussion, negotiation, and argumentation discourse) serve different learning opportunities because defining and structuring problems are mutually accessible for peers (as cited in NRC, 2014b, p. 87). Also, different perspectives of learners can be available via peer interaction so that peers can better conceptualize knowledge through peer interactions (NRC, 2014b). As small group structure is useful and peer interaction is more beneficial in today's learning environments, creating small groups with peer interaction opportunities in learning complex and interdisciplinary content knowledge should take place.

Argumentation discourse. Argumentation discourse is “the substance of any meaningful discourse that seeks to generate improved knowledge and understanding” (Duschl & Osborne, 2002, p. 51). A primary goal for argumentation discourse is the

establishment of dialogue in which learners participate in social interactions and collaboration opportunities leading to enhanced knowledge and understanding about content. As new learning theories emphasize the importance of social interactions and collaboration opportunities to enhance cognitive learning (NRC, 2000, 2014b), argumentation discourse has become a critical component in effective learning environments. Some researchers in learning theory believe argumentation discourse; (a) increases conceptual understanding (Duschl et al., 2007; Duschl & Osborne, 2002; E. Kaya, 2013), (b) improves learners' argumentation skills (Duschl & Osborne, 2002; E. Kaya, 2013; Simon, Erduran, & Osborne, 2006), and (c) fosters active participation in learning processes (Duschl & Osborne, 2002; E. Kaya, 2013; NRC, 2014b; Simon et al., 2006).

According to recent research, argumentation discourse among learners supports the development of conceptual understanding (E. Kaya, 2013) and facilitates cognitive development of content knowledge (Erduran, Simon, & Osborne, 2004; Jimenez-Alexandre & Erduran, 2008; E. Kaya, 2013; Simon et al., 2006). For example, a quasi-experimental research intervention initiated by E. Kaya (2013) delivered chemical equilibrium content to pre-service teachers using argumentation discourse with an experimental group and traditional lecture with a control group. She found argumentation discourse increased pre-service teachers' conceptual understanding of chemical equilibrium content, as well as their argumentation skills.

As teachers are still at the center of educational practices and dominate argumentation discourse in classrooms (Duschl & Osborne, 2002), students need

opportunities to involve learning with active participation (Duschl et al., 2007) for meaningful learning of complex and interdisciplinary content knowledge to occur (Cavlazoglu et al., 2013; Cavlazoglu & Stuessy, 2013). Classroom discourse, as described by Duschl and Osborne (2002), more often occurs as whole class discourse led by teachers in which students have limited opportunities for argumentation discourse. Furthermore, students rarely have opportunities for active engagement in whole class argumentation discourse. When active argumentation discourse has been provided for students in small groups, students have opportunities to reason and reflect on their own learning as well as construct and evaluate their own knowledge (Duschl & Osborne, 2002; NRC, 2000). In addition, research indicates limitations in teachers' pedagogical skills in argumentation discourse (E. Kaya, 2013). These limitations may further prevent teachers from using argumentation discourse in classrooms. E. Kaya suggests that teachers should be provided with opportunities to improve their pedagogical skills in argumentation discourse to overcome these deficiencies.

Effective teachers encourage students “to question, to justify and to evaluate their own, and others' reasoning, enculturating the students as learners into discourse processes that support personal knowledge construction and student metacognition” (Duschl & Osborne, 2002, p. 43). In doing so, teachers' roles include; (a) creating classroom environments to engage students for active participation in argumentation discourse and (b) fostering discourse processes in small groups rather than whole classrooms. To accomplish these roles, a distributed learning approach may prove useful.

A distributed learning approach gives meaningful roles for members of small groups (i.e., two to four members). These roles allow members to actively participate in collaborative learning (NRC, 2014b). In this approach, all members have equal opportunities and are kept active within the group. To do so, creating a guideline for argumentation discourse can be helpful. Cohen and others (1994) note that the absence of guidelines may result in poor or unsuccessful argumentation discourse within small groups (as cited in Duschl & Osborne, 2002, p. 57). Structured guidelines are likely to be most important for learners having no prior experience with argumentation discourse and/or complex content. Effective argumentation discourse is more likely to occur when teachers create guidelines based upon their learners' prior experiences in argumentation discourse and their levels of content knowledge.

Authentic assessment. Authentic assessment is a form of assessment directly linked to student learning, allowing learners opportunities to improve their knowledge structures by receiving feedback and revising for conceptual understanding (Goldman et al., 1999; Ingec, 2009; O. Kaya, 2008; NRC, 2000, 2014b). As today's learning environments become more challenging to learners (NGSS, 2013; NRC, 2014b), the use of authentic assessments has become essential (O. Kaya, 2008; NRC, 2000, 2014b). Research on strategies for assessing learners' conceptual understanding of complex and interdisciplinary content knowledge (NRC, 2014a, 2014b) suggests using authentic assessments over traditional assessments (Ingec, 2009). The structure of traditional assessments (e.g., multiple choice tests and short answer tests) makes them incapable of measuring or providing detailed information about learners' conceptual understanding of

content knowledge. Additionally, these assessments are not sufficient to assess learners' content knowledge within an interdisciplinary context, as they are incapable of linking relationships among the content areas. Also, these assessments do not give sufficient opportunities for learners to revise understanding and receive feedback. In contrast, the structure of authentic assessments, such as concept maps, are capable in assessing learners' conceptual understanding of complex and interdisciplinary content knowledge and giving these same learners feedback to revise their understanding (Darmofal et al., 2002; Goldman et al., 1999; Ingec, 2008; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013; Novak & Canas, 2008; Novak, 2010; NRC, 2000, 2014a, 2014b).

Concept Maps as Essential Tools for the MCL

Concept maps may serve as essential, multi-purpose tools in each component of the MCL framework (i.e., cognitive scaffolds, collaboration, argumentation discourse, and authentic assessment). Literature, therefore, on concepts maps explaining critical roles in each component of the MCL framework needs to be explored.

Concept maps. The idea of concept maps was first developed in Novak's research program to better understand how children develop and organize knowledge in science (Novak & Gowin, 1984). Concept maps are two-dimensional diagrams representing conceptual knowledge in a visual format (Martínez et al., 2013). A concept map consists of concepts, connection lines, and linking-words/prepositions (see Figure 4.2). Used properly, the use of valid concepts and meaningful connections about a topic in these maps represent learners' extant knowledge. A growing body of cognitive research in the last four decades has indicated concept maps are powerful learning tools

(Darmofal et al., 2002; Ingec, 2008, 2009; O. Kaya, 2008; Lopez et al., 2011; Miller et al., 2009; Novak, 2002, 2010; Novak & Canas, 2008; Novak & Gowin, 1984) serving as cognitive scaffolds (Novak, 2002; 2010; Novak & Canas, 2008), collaborative learning tools (Bilgin & Geban, 2006; Darmofal et al., 2002; O. Kaya, 2008; Miller et al., 2009; Miyake, 2013; Novak & Canas, 2008; Novak, 2010; Preszler, 2004), facilitator in argumentation discourse (Duschl & Osborne, 2002; E. Kaya, 2013; NRC, 2014b), and authentic assessment tools to assess conceptual knowledge (Darmofal et al., 2002; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013; Novak, 2010; Walshe, 2007).

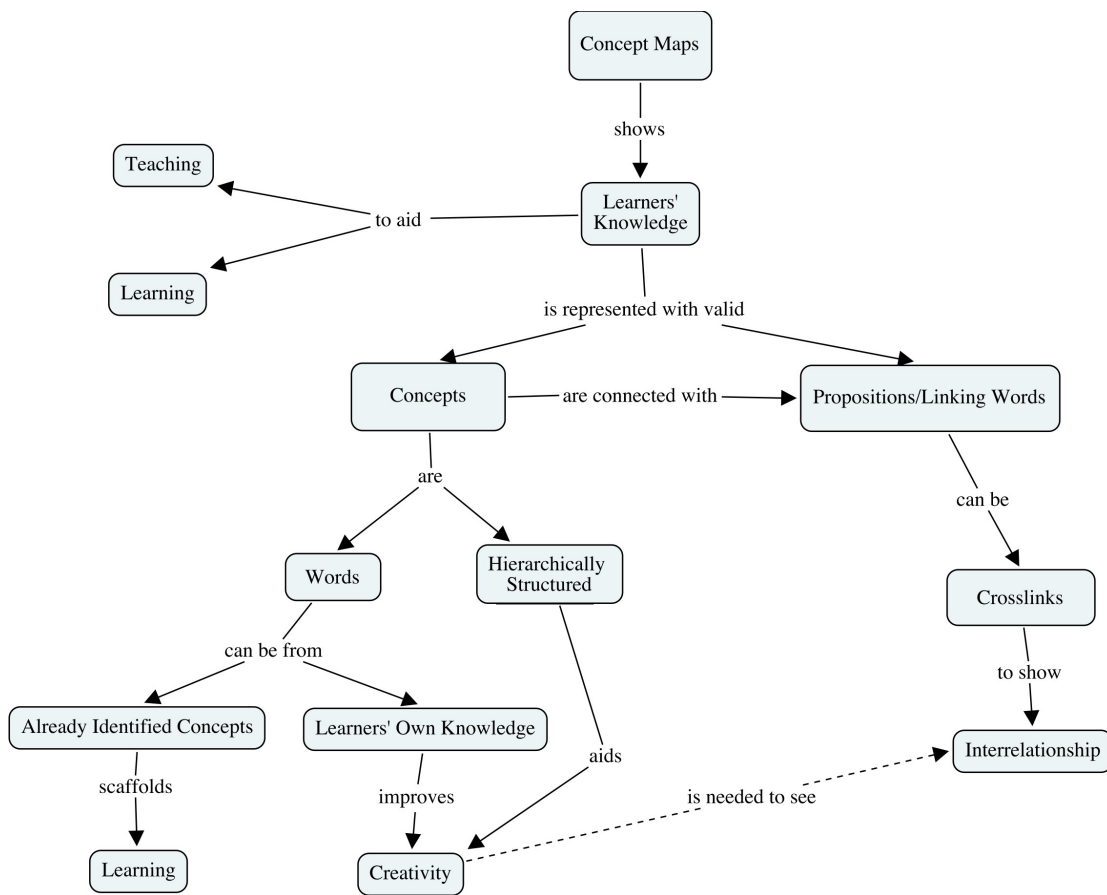


Figure 4.2. A concept map showing the key ideas and principles in a “good concept map” (adapted from Novak, 2010).

Concept maps as cognitive scaffolds. Research has shown concept maps serve as effective cognitive scaffolds (Novak, 2010). As cognitive scaffolds, concept maps help learners think, analyze, solve problems, and deepen their conceptual understanding (Goldman et al., 1999). Moreover, concept maps are suitable in establishing a “road map” for connections among content knowledge areas (Novak, 2010) in learning complex and interdisciplinary content areas. For example, concept maps in learning and

teaching engineering content knowledge, requiring expertise across multiple content areas (Duschl et al., 2007), can act as effective cognitive scaffolds for meaningful learning. Concept maps have been used in various content areas (e.g., science and mathematics) to assess changes in learners' conceptual understanding of content knowledge (Lopez et al., 2011; Walshe, 2007), but their usage as cognitive scaffolds is limited in engineering content (Darmofal et al., 2002; Lopez et al., 2011; Martínez et al., 2013; Wilson, 2011). Some recent research findings indicate cognitive scaffolds can improve learners' conceptual understanding and facilitate meaningful learning in engineering content knowledge (Darmofal et al., 2002; Martínez et al., 2013). Recent calls highlight the need for increasing STEM teachers' engineering content knowledge (e.g., CCSSM, 2010; ITEEA, 2007; and NGSS, 2013) and integrating this knowledge with other STEM areas (NGSS, 2013; NRC, 2012, 2014b). With these calls in mind, concept maps are promising tools to use as cognitive scaffolds to facilitate students' development of conceptual understanding of complex content knowledge in engineering as well as establishing integration between/among STEM areas.

Concept maps as collaborative learning tools. A growing body of research indicates collaborative concept map activities in small groups are useful for conceptual understanding of this knowledge (Bilgin & Geban, 2006; Darmofal et al., 2002; O. Kaya, 2008; Miller et al., 2009; Miyake, 2013; Novak & Canas, 2008; Novak, 2010; Preszler, 2004). Collaborative concept map activities often establish a format for social dialog in which learners find opportunities for social interactions (e.g., discussion, negotiation, and argumentation discourse). When appropriately designed, these activities

also encourage learners to be active and contributing members. For example, having discussions about what concepts to include and how to construct group concept maps, negotiations about which concepts to use, and argumentation discourses about each members point of view on topics makes learners more active and helps them clarify their understanding.

Furthermore, while collaborative concept map activities allow monitoring of learners' conceptual understanding, observations of other members' conceptualization and knowledge structures may increase learners' understanding and result in well-organized knowledge structures. Allowing learners to construct their own concept maps about topics and sharing them to the group helps learners identify what and how others think about the topics (Cavlazoglu, Akgun, & Stuessy, 2013; Cavlazoglu & Stuessy, 2013). Doing so also may scaffold learners' conceptual understanding of complex and interdisciplinary content knowledge. Using concept maps as collaborative learning tools, therefore, can establish a unique collaboration opportunity for meaningful learning and be critical for better conceptual understanding in learning complex and interdisciplinary content knowledge (Cavlazoglu et al., 2013; Cavlazoglu & Stuessy, 2013).

Concept maps as argumentation discourse tools. Concept maps in small groups may provide learners with unique opportunities in argumentation discourse. Research suggests using tools, such as concept maps, facilitate learners' use of argumentation discourse (Duschl & Osborne, 2002; E. Kaya, 2013; NRC, 2014b). Although little research exists on understanding the influence of argumentation discourse in a single content area, even less research exists on the influence of

argumentation discourse across interdisciplinary content areas. However, having small groups of learners construct individual concept maps about a topic and then organizing those learners into other small groups may facilitate argumentation discourse.

Furthermore, having multiple concept maps as visual aids for developing individual members' knowledge about a topic may increase learners' active participation in argumentation discourse.

Concept maps as authentic assessment tools. The use of concept maps as authentic assessment tools has many advantages in today's learning environments. Concept maps as authentic assessment tools (a) assess conceptual knowledge (Darmofal et al., 2002; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013; Novak, 2010; Walshe, 2007), (b) help learners make thinking visible to themselves and others (Darmofal et al., 2002; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Novak, 2010; Novak & Canas, 2008), (c) provide feedback and revision opportunities to improve learners' thinking and learning (Goldman et al., 1999; Greene et al., 2013; Novak, 2010; NRC, 2000, 2014b), and (d) allow monitoring of learners' progress (Bilgin & Geban, 2006; Darmofal et al., 2002; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013; Novak, 2002; 2010; Novak & Canas, 2008). When used properly, these maps are valid and reliable tools for assessing learners' meaningful conceptual understanding rather than factual memory (Lopez et al., 2011), and are capable for assessing complex and interdisciplinary content knowledge (Katahi, 2009; NGSS, 2013; NRC, 2014a, 2014b).

Assessing conceptual knowledge. Assessing conceptual knowledge requires appropriate assessment methods (Ingec, 2008, 2009; Lopez et al., 2011). Research on methods for assessing conceptual knowledge (Ingec, 2008, 2009; NRC, 2014a; Ozdemir, 2005) indicates some traditional methods (e.g., multiple-choice tests) are not capable in assessing conceptual knowledge. For example, Ozdemir (2005) pointed out multiple-choice exams and written exams are not appropriate for assessing conceptual understanding of mathematics content.

Using concept maps assessing conceptual understanding. Researchers engaged in assessing learners' conceptual understanding suggest the use of concept maps (Cavlazoglu et al., 2013; Darmofal et al., 2002; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013; Novak, 2010; Walshe, 2007). Concept maps are designed to provide detailed information about learners' conceptual understanding (Cavlazoglu et al., 2013; Cavlazoglu & Stuessy, 2013; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013). Results of studies on assessing conceptual knowledge (Ingec, 2009; Lopez et al., 2011; O. Kaya, 2007) revealed concept maps are powerful tools for assessing learners' conceptual understanding in various content areas (e.g., chemistry, materials processing, aerospace, and algebra).

Making learners' thinking visible. Concept maps provide concrete information about learners' knowledge structures in a visual form (Darmofal et al., 2002; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Novak, 2010; Novak & Canas, 2008). Learners can therefore display their conceptual understanding via concept maps. This display of

conceptual understanding is also useful for identifying learners' misconceptions (Greenet et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013; Novak, 2010).

Opportunities for feedback and revision via concept maps. According to new learning theories (Goldman et al., 1999; NRC, 2000, 2014b), learners should have opportunities for feedback and revision as these opportunities are critical for learners to modify and refine their knowledge. Concept maps, as an authentic assessment tolls, provide feedback to learners about targeted content knowledge and offer opportunities to revise their knowledge (Cavlazoglu & Stuessy, 2013; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013). Learners' concept maps visually document what knowledge learners have and how they think about the knowledge (Novak, 2010). Instructors may use these maps to determine learners' (a) levels of content mastery, (b) knowledge structures for content, and (c) responses to the instructor's teaching (O. Kaya, 2008). Ultimately, these maps provide instructors with opportunities to modify their instruction upon learners' needs in learning content and resulting in improved teaching.

Validity and reliability of concept maps. Researchers in prior studies have used concept maps as tools for assessing conceptual knowledge (Cavlazoglu et al., 2013; Darmofal et al., 2002; Greene et al., 2013; Ingec, 2009; O. Kaya, 2008; Lopez et al., 2011; Martínez et al., 2013; Novak, 2010; Walshe, 2007). Lopez et al. (2011) reported these maps as valid and reliable instruments in assessing that knowledge. Two concept map construction techniques (i.e., fill-in-the-map and construct-a-map-from-scratch)

have been used most often (Ingec, 2009; Lopez et al., 2011). In the construct-a-map-from-scratch technique, learners are asked to construct a concept map by using concepts from a key concept list and identifying prepositions (i.e., linking verbs to make meaningful connections between concepts; Novak, 2010). The fill-in-the-map technique, on the other hand, requires learners to fill in missing information in a pre-constructed concept map (Lopez et al., 2011). Ruiz-Primo, Schultz, Li, and Shavelson (2001) examined the validity and reliability of both techniques and concluded the construct-a-map-from-scratch technique better reflects learners' knowledge structures.

Assessing complex and interdisciplinary content knowledge with concept maps.

Concept maps can be used as authentic assessment tools to assess learners' conceptual understanding of the complex and interdisciplinary content knowledge existing in today's learning environments. Current research suggests using concept maps for assessing conceptual understanding of this knowledge leads to positive outcomes for learners (Cavlazoglu et al., 2013; Darmofal et al., 2002; Greene et al., 2013; Martínez et al., 2013). In addition, concept maps provide information about conceptual understanding in interdisciplinary content areas and their connections across the areas (Cavlazoglu & Stuessy, 2013; Novak & Canas, 2008; Novak, 2010; NRC, 2014b). As learning in today's environments has become challenging with the need for conceptual understanding of complex and interdisciplinary content knowledge (e.g., engineering content knowledge; NGSS, 2013; NRC, 2014b), use of concept maps as authentic tools for assessing conceptual understanding has become indispensable (NRC, 2014a). For example, recent calls by stakeholders in STEM education emphasize establishing deeper

connections among the STEM content areas (NGSS, 2013; NRC, 2014b) and developing new tools for assessing conceptual understanding in complex and interdisciplinary content areas (NRC, 2014a). Furthermore, the aim of these calls is both the designing of learning experiences with coherent progression over years and the assessing of that progression (NRC, 2014a). Concept maps as authentic tools for assessing conceptual knowledge may answer these calls because concept maps provide information regarding learners' conceptual understanding while assessing learners' progression over time. Concept maps, therefore, should be considered as authentic tools in assessing learners' conceptual understanding of complex and interdisciplinary content knowledge.

As described in the MCL framework, cognitive scaffolds, collaboration, argumentation discourse, and authentic assessment are critical components for meaningful conceptual understanding of complex and interdisciplinary content knowledge in today's learning environments. In addition, research has shown concept maps serve as tools for cognitive scaffolds, collaboration, argumentation discourse, and authentic assessment (Cavlazoglu & Stuessy, 2013). The use of concept maps may document changes in conceptual understanding of complex and interdisciplinary content knowledge (e.g., engineering content knowledge) and provide a better understanding of how learners learn the complex and interdisciplinary content knowledge. Therefore, concept maps should be used in today's learning environments including EOTPDs to examine conceptual understanding of complex and interdisciplinary content knowledge within new paradigms of teaching, learning, and assessment.

In this study, I examined changes in science teachers' conceptual understanding of earthquake engineering after their participation in the EEEP teacher workshop. Earthquake engineering is a critical engineering knowledge base (Cavlazoglu & Stuessy, 2015b) for the integration of engineering into science classrooms as well as other STEM classrooms. In addition, teaching earthquake engineering in K-12 classrooms is critical for increasing national earthquake resilience. In this regard, stakeholders in earthquake engineering have identified citizens' knowledge in social systems and designed systems domain of earthquake engineering as very limited (NRC, 2011a; 2011b).

As previously mentioned, using concept maps as an assessment strategy may provide an authentic assessment to document changes in teachers' (e.g., learners) conceptual understanding of earthquake engineering content knowledge. As such, the strategy has potential in revealing ways that teachers' conceptual understanding of earthquake engineering knowledge change in an EOTPD learning environment. Moreover, although conceptual change for learners in many traditional science content areas has been investigated (Bilgin & Geban, 2006; Ingec, 2009; E. Kaya, 2013; O. Kaya, 2008; Walshe, 2007), conceptual change for learners in the earthquake engineering content area has yet to be explored. Additionally, this study provides the first to examine changes in learners' conceptual understanding of earthquake engineering in individual and collaborative group levels via concept maps as a result of an EOTPD. Specifically, in this study I addressed the following three questions:

1. What differences in individual workshop science teachers' conceptual understanding of earthquake engineering were observed in their pre- and post-concept maps?
2. What differences in science teacher groups' conceptual understanding of earthquake engineering were observed in their pre- and post-concept maps?
3. What differences between individual and group conceptual understanding of earthquake engineering were observed in pre- and post-concept maps?

Methodology

Context of the Study

The EEEP was a STEM education research project supported by the National Science Foundation to increase high school teachers' understanding about earthquake engineering. To achieve the designed goals, EEEP researchers organized a six-day teacher workshop for high school science teachers in June 2013 at Texas A&M University in College Station, Texas/USA. This workshop provided the context for this study.

The EEEP teacher workshop was an EOTPD designed using EOTPD design criteria from related literature and crucial components of the MCL conceptual framework. Research on crucial components of effective EOTPDs has suggested (a) providing better subject content and pedagogical content knowledge preparation (Custer & Daugherty, 2009; Darmofal et al., 2002; Martínez et al., 2013; NRC, 2014b; Wilson, 2011); (b) developing opportunities to deepen teacher knowledge and practice on engineering topics (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009;

Daugherty, 2009; Wilson, 2011); (c) using learner-centered instructional strategies (Cunningham & Carlsen, 2014; Goldman et al., 1999; O. Kaya, 2008; NRC, 2000; 2014b; Wilson, 2011); (d) including hands-on activities for collaboration (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Katehi et al., 2009); (d) integrating social, environmental, and other impacts of engineering design (Cunningham & Carlsen, 2014; Katehi et al., 2009; NRC, 2011a, 2011b); (e) defining an engineering conceptual base (Custer & Daugherty, 2009; NRC, 2014b); (f) using credible instructors to deliver engineering content and pedagogy (Custer & Daugherty, 2009; Daugherty, 2009); and (g) using authentic assessment strategies to assess conceptual understanding of engineering subjects (Daugherty, 2009; Katehi et al., 2009; Wilson, 2011).

Overall, the EEEP teacher workshop provided hands-on, minds-on experiences and background information about what earthquake engineers do, how earthquake engineers work within social systems to solve complex problems related to earthquake engineering, how the STEM-related domains of science, technology, engineering, and mathematics come together in solving complex real-world problems, and how the use of models (including simulations and modeling software) assist individuals in understanding complex and interdisciplinary problems. Activities in the workshop included using concept maps as pre- and post-assessment strategies individually and in groups as well as using them as cognitive scaffolds, collaboration tools, and argumentation discourse tools. Additional educational activities included: (a) educational board games, (b) background readings, (c) presentations and discussions led by earthquake engineers, (d) earthquake simulations and demonstrations, and (e) group

projects. The EEEP workshop was designed to provide: (a) better earthquake engineering content knowledge within new paradigms of teaching, learning, and assessment (e.g., earthquake engineering key concepts list, group projects, concept maps as cognitive scaffolds, collaboration and argumentation discourse tools, and authentic assessment strategy); (b) opportunities to deepen teacher knowledge and practice on earthquake engineering (e.g., background readings, educational board game, group concept map, group projects, presentations, discussions, simulations, and demonstrations); (c) hands-on activities for collaboration (e.g., group concept maps and educational board game); (d) integration of social, environmental, and other impacts of earthquake engineering design (e.g., background readings, presentations, discussions, simulations, and demonstrations); (e) well-defined engineering conceptual base (e.g., earthquake engineering key concepts list); (f) credible instructors to deliver engineering content and pedagogy (e.g., professors from earthquake engineering and science education departments); and (g) authentic assessment methods to measure conceptual understanding of earthquake engineering (e.g., concept maps).

Type of Research Design

In this study, I used a one-group, pre-test/post-test research design that “includes a pre-test measure followed by a treatment and a post-test for a single group” (Creswell, 2009, p. 160). I proposed to examine changes in science teachers’ conceptual understanding of earthquake engineering content after their participation in the EEEP teacher workshop. Specifically, I aimed to describe differences in science teachers’ pre- and post- concept map development at two levels: individual and group.

Participants

The participants in this study were 12 high school science teachers (9 female, 3 male) electing to attend a summer workshop focusing on the integration of earthquake engineering education into their traditional science curricula. The science teachers were “traditionally prepared,” specializing in biology, physics, chemistry, and earth science content areas. They had neither professional development nor teaching experiences in integrating STEM content into their specialty area classrooms. Teacher recruitment occurred via brochures at national conferences, applications on the EEEP website (<http://eeep.tamu.edu>), and invitations on the EEEP Facebook page. Classroom experience for the science teachers ranged from one to 33 years. Eight of the 12 science teachers had completed or were pursuing an advanced degree in Education. Four of the science teachers were from Texas, while the remaining teachers lived in Alaska, Florida, Indiana, Louisiana, Maryland, North Carolina, South Carolina, and Ohio. Ethnic representation among science teachers included White (50%), Hispanic (25%), African-American (17%), and Asian (8%).

Data Collection Procedures

The data for this study were collected using individual and group pre- and post-concept maps during pre- and post-workshop activities. In the first day morning sessions of the EEEP workshop, a concept mapping activity was held as one of the “pre-workshop activities.” First, I familiarized science teacher participants with the procedures for constructing individual concept maps and for engaging in group concept mapping activities. In the first part of the presentation, science teachers received a short

training about general principles of constructing concept maps and discussed some good example of concept maps. Although 10 of 12 teachers indicated some familiarity with concept map construction, the training was held to make sure that all science teachers were familiar with concept map construction process. After the training session, EEEP researchers explained details of pre-workshop activities and distributed a pre-workshop activity sheet. They also received a key concepts list detailing key concepts for earthquake engineering. This list was generated as the result of a Delphi study for high school science teachers and students (Cavlazoglu & Stuessy, 2015b). In total, the list held 35 earthquake engineering key concepts within 5 domain areas (i.e., Physical Systems, Designed Systems, Social Systems, Earth Systems, and STEM Proficiencies; see Table 4.2). Teachers received the list in alphabetical order with no indication of the interdisciplinary domains or connections between them. They also received the necessary materials for hands-on concept maps construction: large pieces of poster paper, post-it notes in different colors, scissors, and markers.

Table 4.2

Earthquake Engineering Key Concepts

Domain area	Key concepts
Physical systems	Force, Energy, Motion, Transfer, Disturbance, Waves
Designed systems	Efficacy, Cost, Safety, Constraints, Regulations, Risks, Resources, Reliability, Resilience, Trade-offs, Redundancy
Social systems	Social Response, Urban Infrastructure, Decision Making, Governance, Policy, Finance, Prevention
Earth systems	Earthquakes, Geographic Landforms, Plate Boundaries, Epicenter, Worldwide Patterns
STEM Proficiencies	Observation, Measuring, Prediction, Mathematical Modeling, System Thinking, Tools

After all questions were clarified about the concept mapping activity, teachers began to individually construct their concept maps about their understanding of earthquake engineering using concepts from the earthquake engineering key concepts list and/or any other concepts not on the list they thought important to indicate their understanding of earthquake engineering. After completing their individual concept maps, science teachers were randomly assigned to small groups (i.e., groups with 2 members and 3 members) to collaboratively construct a concept map for their group. This procedure began with each group member presenting her/his individually constructed concept maps to other group member/s; then the science teachers within each group discussed similarities and differences of their individual concept maps as well as other ideas they thought important for their groups' understanding of earthquake

engineering. Finally, each group negotiated their group map by making decisions for any concepts and connections.

I used pictures of the individual and group maps as the data set for this study (see Figure 4.3). On the last day of the EEEP teacher workshop, the science teachers used the same procedures to construct individual and group concept maps to indicate their understanding of earthquake engineering.

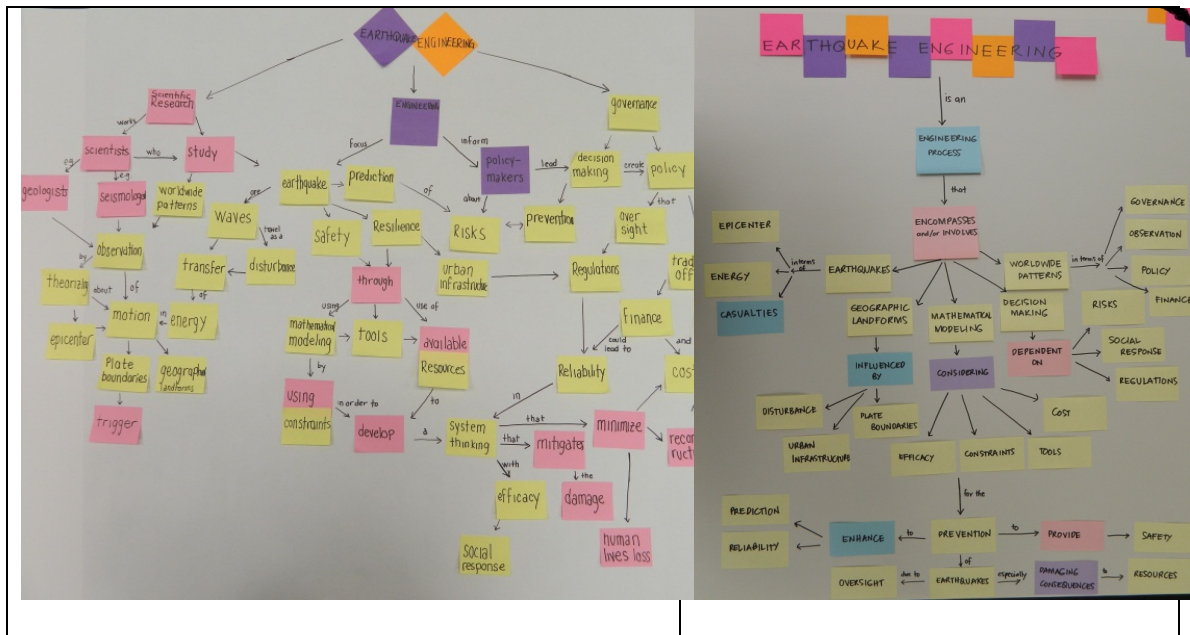


Figure 4.3. Pictures of two science teachers' individual concept maps.

Data Analysis Procedures

In this study, the Wilcoxon-Sign Test was used to determine significance of differences occurred between science teachers' individual and group pre- and post-workshop concept maps scores. Descriptive statistics were used to describe differences

between individual and group concept maps as well as changes in science teachers' conceptual understanding on each domain area of earthquake engineering. Two experts in earthquake engineering education served as scorers to score each constructed concept map. Before beginning scoring, scorers participated in a training section in which they scored three different concept maps, compared, and discussed their scores. Then, scorers individually scored all concept maps. Inter-scorer correlations were found as significant, positive, and higher than .82 (Table 4.3). Scorers also met face-to-face, compared their decisions for each concept, discussed differences, and ultimately came to 100% agreement. For each different decision of concepts used in science teachers' concept maps, the scorers made final decisions on the proper use of the concepts. At the end of the scoring procedure, thus, all concepts science teachers used in their concepts maps were indicated as valid or invalid.

Table 4.3

Results of Inter-Scorer Analysis

Individual concept map [†]		Group concept map [‡]	
Pre	Post	Pre	Post
.95	.93	.82	.90

[†]Pearson, [‡]Spearman-Brown.

Furthermore, I examined changes in each domain area of earthquake engineering content knowledge (i.e., Physical Systems [PS], Designed Systems [DS], Social Systems [SS], Earth Systems [ES], and STEM Proficiencies [STEMP]; refer to Table 4.2).

Examinations of concepts maps revealed that science teachers used a majority of concepts (77%) from the key concepts list.

I performed frequency analyses of the valid usage from the key concepts list in pre- and post-workshop concept maps both in individual and group levels to document changes in each domain area of earthquake engineering content knowledge. I determined the results of these analyses based on percentage of valid usage of generated earthquake engineering key concepts. In each domain area, I identified science teachers' valid usage of concepts from the key concepts list in each specific domain area and calculated averages of valid usage of key concepts in each domain for all individual and group concept maps. I then converted averages to percentages. For example, in the DS domain area, there were 11 key concepts from the earthquake engineering key concept list and teachers' valid usage average was 2.75 in individuals' pre-workshop concept maps. When this average number was converted to percentages ($(2.75/11)*100$), the percentage found as 25%. This number showed that valid usage average in the DS domain was 25% at the beginning of the workshop.

In calculating scores of concept maps, I used a modified version of O. Kaya's (2008) concept map scoring method. O. Kaya considered (a) valid concepts, (b) valid propositions, (c) valid cross-links, and (d) valid examples. He assigned 1 point for each valid concept, 2 points for each valid proposition, 5 points for each valid cross-link, and

1 point for each valid example. In this study, I modified O. Kaya's method to accommodate my procedures of (a) providing the earthquake engineering key concepts list and (b) allowing teachers to use any other concepts. In this study, therefore, I considered (a) valid concepts from key concepts list, (b) valid concepts from science teachers, (c) valid propositions, (d) valid cross-links, and (e) valid examples. I assigned scores so that I awarded 1 point for each valid concept from the key concepts list, 2 points for each valid concept generated by the science teacher on his or her own, 2 points for each valid proposition, 5 points for each valid cross-link, and 1 point for each valid example. It is important to note that in counting concepts as valid concepts in concept maps, the concepts had to be used with a valid proposition and connected to another valid concept/s as stated in meaningful learning theory (Novak, 2010). In other words, writing concepts meaninglessly into concept maps without propositions and accurate connections were not considered as valid usage of concepts. When scorers finished scoring all ($n = 34$) pre- and post-workshop concept maps, I used Pearson product-moment correlation to calculate correlation between Kaya's original scoring method and my modified scoring method, which yielded a positive and significant correlation between O. Kaya's my modified scoring method ($r = 0.997$, $n = 34$, $p = 0.000$).

Results

Research Question #1: What differences in individual workshop science teachers' conceptual understanding of earthquake engineering were observed in their pre- and post-concept maps?

I used the Wilcoxon-Sign Test was used to identify significant differences between science teachers' individual pre- and post-concept maps scores. The results of Wilcoxon-Sign Test indicated science teachers' individual post-concept maps scores were significantly higher than individual pre-concept maps scores (Table 4.4), indicating a significant increase in teachers' conceptual understanding of earthquake engineering in the EEEP teacher workshop.

Table 4.4

Results of Wilcoxon-Sign Test between Pre and Post Scores on Individual Concept Maps

	N	Mean Rank	Sum of Ranks	z	p
Negative Ranks	0 ^a	.00	.00		
Positive Ranks	12 ^b	6.50	78.00		
Ties	0 ^c				
Total	12				
Ind_Post – Ind_Pre				-3.062 ^b	.002

^aInd_Post < ^aInd_Pre.

^bInd_Post > ^bInd_Pre.

^cInd_Post = ^cInd_Pre.

A frequency analysis of individual teachers' valid usage indicated overall science teachers' post-workshop conceptual understanding was higher than their pre-workshop conceptual understanding. Pre-workshop conceptual understanding in ES and PS domains were relatively higher than DS, SS, and STEMP domains. Post-conceptual

understanding in ES and STEMP domains were relatively greater than DS, PS, and SS domains. The growth of conceptual understanding in SS, DS, and STEMP domains were superior to ES and PS domains at individual level (see Table 4.5).

Table 4.5

Results of Science Teachers' Pre- and Post-Conceptual Understanding within Each Domain Area of Earthquake Engineering

Domain Area	Individual			Group		
	Pre (%)	Post (%)	Growth (%)	Pre (%)	Post (%)	Growth (%)
Physical Systems	49	68	19	40	67	27
Designed Systems	25	67	42	16	69	53
Social Systems	26	70	44	30	78	48
Earth Systems	57	75	18	44	84	40
STEM Proficiencies	37	74	37	49	80	31
Overall	36	70	34	33	75	42

Research Question #2: What differences in science teacher groups' conceptual understanding of earthquake engineering were observed in their pre- and post-concept maps?

I used the Wilcoxon-Sign Test was employed to identify statistically significant differences between group pre- and post-workshop concept maps scores. The results of Wilcoxon-Sign Test showed that group post-concept maps scores were significantly

higher than group pre-concept maps scores (see Table 4.6). These results indicated significant increases in teachers' conceptual understanding of earthquake engineering at the end of the EEEP teacher workshop.

Table 4.6

Results of Wilcoxon-Sign Test between Pre and Post Scores on Group Concept Maps

	N	Mean Rank	Sum of Ranks	z	p
Negative Ranks	0 ^a	.00	.00		
Positive Ranks	5 ^b	3.00	15.00	2.023	.043
Ties	0 ^c				
Total	5				

^aG_Post < ^aG_Pre.

^bG_Post > ^bG_Pre.

^cG_Post = ^cG_Pre.

A frequency analysis of groups' valid usage of concepts in their concept maps revealed overall science teachers' post-workshop conceptual understanding was higher than their pre-workshop conceptual understanding at group level. Pre-workshop conceptual understanding in STEMP, ES, and PS domains were relatively higher than DS and SS domains. Post-workshop conceptual understanding in ES, STEMP, and SS domains were comparatively greater than PS, and DS domains. The growth of conceptual understanding in DS and SS domains were superior to PS, STEMP, and ES domains at group level (see Table 4.5).

Research Question #3: What differences between individual and group conceptual understanding of earthquake engineering were observed in pre and post-concept maps?

Descriptive statistics of individual and group pre- and post-concept maps scores showed that science teachers enhanced their conceptual understanding of earthquake engineering in the EEEP teacher workshop in both individual and group levels. Pre-workshop concept maps mean scores at the individual level were higher than pre-workshop concept maps mean scores at group level; whereas post-workshop concept maps mean scores at group level were greater than post-concept map mean scores at individual level. Scores of pre-concept maps revealed that science teachers showed better conceptual understanding in their individual concept maps than group concept maps at the beginning of the EEEP teacher workshop. However, scores of post-concept maps indicated that science teachers in groups showed better conceptual understanding than their individual concept maps at the end of the EEEP teacher workshop. While scores of individual and group concept maps were close at the beginning of the workshop, group concept map scores were relatively higher than individual concept map scores at the end of the workshop (see Figure 4.4).

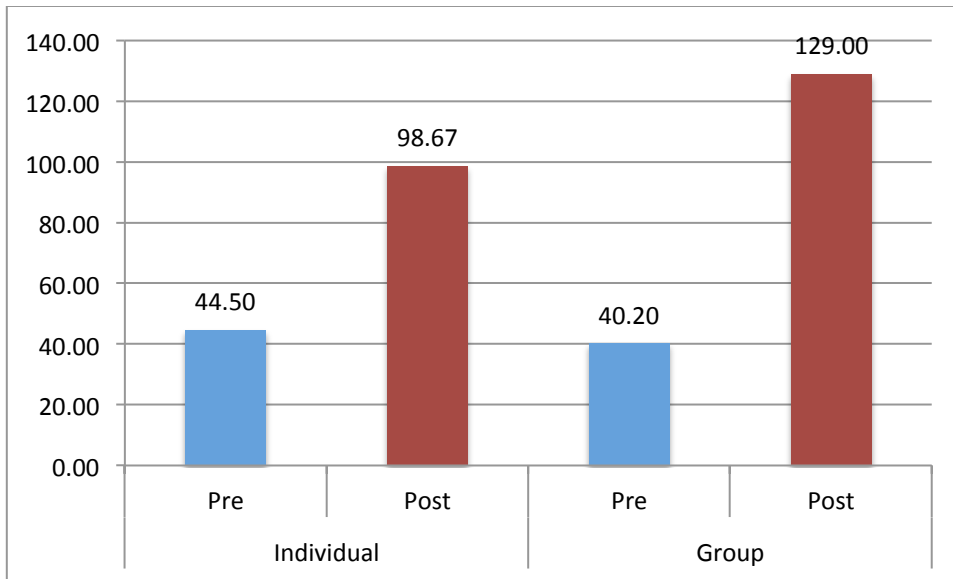


Figure 4.4. Mean scores of teachers' pre- and post-concept maps in individual and group levels.

Frequency analyses of both individual and group concept map results showed that teachers' conceptual understanding in all knowledge domain areas of earthquake engineering improved (see Table 4.5). Overall, teachers increased their conceptual understanding by 34% at the individual level and 42% at group level. While science teachers' pre-workshop conceptual understanding at the individual level (36%) was higher than their groups' pre-workshop conceptual understanding (33%), the group post-workshop conceptual understanding scores (75%) were higher than post-workshop conceptual understanding at individual level (70%).

Discussion and Conclusion

In this study, I examined the changes in science teachers' conceptual understanding of earthquake engineering as result of their participation in the EEEP teacher workshop. I analyzed science teachers' individual and group pre- and post-workshop concept maps, determined science teachers' valid usage of concepts from the earthquake engineering key concepts list, and described the changes in science teachers' conceptual understanding of earthquake engineering. Results of Wilcoxon-Sign Tests for both individual and group concept maps revealed significant increases in conceptual understanding of earthquake engineering from the beginning to the end of teachers' participation in the EEEP teacher workshop. In addition, results from frequency analyses of science teachers' valid concept usage percentages indicated science teachers enhanced their conceptual understanding in all knowledge domain areas of earthquake engineering (see Table 4.5). Overall, results provided evidence that EEEP workshop teachers' conceptual understanding of earthquake engineering content knowledge increased after their participation in the EEEP workshop.

Conceptual Understanding of Engineering Content Knowledge and Effectiveness of the EOTPD

As STEM teachers have been encouraged to participate in effective EOTPDs to increase their conceptual understanding of engineering content knowledge (Daugherty, 2009; Nathan et al., 2011; NGSS, 2013; NRC, 2014a, 2014b Wilson, 2011), the results in this study provide promising evidence that the EEEP teacher workshop was useful for increasing STEM teachers' conceptual understanding of engineering content knowledge

(Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Darmofal et al., 2002; Katehi et al., 2009; Martínez et al., 2013; NRC, 2014b; Wilson, 2011).

Stakeholders in STEM education suggest integrating engineering into STEM classrooms as the engineering content knowledge is suitable for integration across all STEM content areas (NRC, 2014b) and stakeholders in science education stress integration of S&E in K-12 science classrooms (NGSS, 2013), science teachers, especially for those traditionally prepared, need opportunities to improve their conceptual understanding in critical engineering areas for successful science education as well as STEM education. For both stakeholders in STEM education and science education, this study can be valuable because the context of study, EEEP teacher workshop, aimed to meet needs indicated by stakeholders in both STEM education and science education by increasing science teachers' conceptual understanding of engineering content knowledge. I observed traditionally prepared science teachers, participants in this study, broadened their expertise in earthquake engineering and enhanced their conceptual understanding of the earthquake engineering content knowledge to effectively teach the content to their students in science classrooms as well as other STEM classrooms.

MCL Conceptual Framework and Concept Mapping

The conceptual framework of this study, the MCL framework, implied cognitive scaffolds, collaboration, argumentation discourse, and authentic assessment as critical components for conceptual understanding of complex and interdisciplinary content knowledge in today's learning environments. Additionally, previous research efforts

have indicated that concept maps can serve as tools for cognitive scaffolds, collaboration, argumentation discourse, and authentic assessment (Cavlazoglu & Stuessy, 2013), which led to my suggestions regarding the use of concepts maps in the design of today's EOPTD learning environments. In this study, I thought concept maps were useful to use in each component of the MCL framework.

Cognitive scaffolds. I observed concept maps' use as cognitive scaffolds facilitated teachers' conceptual understanding of complex content knowledge in the EEEP teacher workshop. Science teachers were able to show their understanding by establishing connections in each domain of earthquake engineering as well as cross-links between/among domains. In addition, I observed concept maps helping teachers to visualize their individual knowledge and supporting their cognitive learning processes for meaningful learning (Ausubel, 2000; Novak, 2002, 2010; Novak & Canas, 2008). Parallel to previous studies on using cognitive scaffolds in learning engineering content knowledge (Darmofal et al., 2002; Martínez et al., 2013), I use evidence from this study to support the use of concept maps as appropriate cognitive scaffolds for learning engineering content knowledge.

Collaboration. Collaborative group concept map activities in small groups were found useful in enhancing science teachers' conceptual understanding of earthquake engineering content knowledge. Results of both descriptive statistics (see Figure 4.4) and frequency analyses (see Table 4.5) of concept maps showed that while science teachers' individual pre-conceptual understanding was higher than group pre-conceptual understanding, post-conceptual understanding in groups was much higher than post-

conceptual understanding at individual level. This is an interesting result showing that teachers with limited conceptual understanding were not able to develop better understanding in group concept maps at the beginning of the workshop. However, as they increased their conceptual understanding throughout the workshop they showed much better conceptual understanding in the post-group concept maps than individual concept maps at the end of the workshop. This result indicated that as science teachers improved their conceptual knowledge through the EEEP teacher workshop, at the end of the workshop with better knowledge they were able to close the distance between/among group members conceptual knowledge in group concept maps as defined in Vygotsky's social development theory (1978). Interaction with more knowledgeable peers allowed them to better increase their conceptual understanding in post-group concept maps. In addition, participants' socialization during the workshop may have increased interactions over the workshop.

I conceived that small groups of two or three members encouraged science teachers' learning of earthquake engineering content knowledge. In these small groups, teachers were able to find opportunities to interact with one or two other teachers and involve themselves in group learning processes. For example, I saw that teachers' discussions about what concepts to include and how to construct group concept maps, negotiations about which concepts to use, and argumentation discourses about members point of view on topics made teachers more active and contributing members in groups.

Argumentation discourse. Furthermore, argumentation discourse with distributed learning approaches in the collaborative group concept mapping activities

were useful in keeping teachers in small groups active while giving equal opportunities to become involved in argumentation discourse. I used distributed learning approach by providing structured guidelines for the argumentation discourse in group concept map activities as related research suggested (Duschl & Osborne, 2002) for learners with no prior experience in argumentation discourse and/or complex content. The guideline included presenting each group member's individually constructed concept maps to other group member/s, discussing similarities and differences of teachers' individual concept maps as well as other ideas they thought important for conceptual understanding earthquake engineering, and constructing group concept maps with group members by making decisions for any concepts and connections to include in group concept maps with all group members' agreement. During the argumentation discourse, although some other factors in group collaboration (e.g., discussants' dominant personality in group decisions) may have affected on group concept maps, I observed that structured guideline was crucial in keeping teachers active and giving equal opportunities to involve in group concept map activities. Overall, I detected that group concept map activities facilitated teachers' use of argumentation discourse as found in related studies (e.g., Duschl & Osborne, 2002; E. Kaya, 2013).

Authentic assessment. In this study, I also observed using concept maps as authentic assessment strategies to assess changes in science teachers' conceptual understanding of earthquake engineering knowledge was indispensable. Concept maps successfully assessed teachers' conceptual understanding of complex and interdisciplinary earthquake engineering content knowledge. As stakeholders in science

education (e.g., NRC, 2014a; Purzer et al., 2014) and STEM education (NRC, 2012; 2014b) seek capable assessment strategies to assess the complex and interdisciplinary engineering content knowledge, results in this study indicated concept maps were capable in assessing the targeted complex and interdisciplinary engineering knowledge.

In addition to assessing conceptual knowledge in complex and interdisciplinary content area, concept maps as authentic assessment strategies also provided other advantages. These advantages included making thinking visible to teachers themselves and other peers in groups to scaffold understanding of complex and interdisciplinary engineering content knowledge (Darmofal et al., 2002; Greene et al., 2013; Novak & Canas, 2008; Novak, 2010), receiving feedback and revision opportunities to improve thinking and learning (Goldman et al., 1999; Greene et al., 2013; Novak, 2010; NRC, 2000, 2014b), and monitoring teachers' progresses both individually and in groups. In addition, I observed that providing earthquake engineering key concepts list to teachers in concept map construction helped them to start constructing their concept maps to indicate their conceptual understanding in the complex and interdisciplinary content area of earthquake engineering.

Finally, results of conceptual understanding in DS and SS domains indicated science teachers conceptual understanding in these domains were two of the lowest ones both in individual and group pre-concept maps. Stakeholders in earthquake engineering research have emphasized these two domains need more attention in teaching earthquake engineering (NRC, 2011a, 2011b). In this study, parallel to stakeholders' emphasize I found these two domains were two lowest domains in the pre-concept maps. However,

results of frequency analyses in DS and SS domains were two of highest growths both in individual and group pre-concept maps. These results revealed EEEP teacher workshop was effective in enhancing science teachers' domain knowledge in these two critical earthquake engineering domain areas as emphasized by earthquake engineering stakeholders. The results are promising for increasing national earthquake resilience in the near future, if science teachers as well as other teachers can implement earthquake engineering into their classrooms.

Implications

The results of this study are encouraging as they provided evidence that science teachers' conceptual understanding of earthquake engineering significantly increased as result of their participation in the EEEP teacher workshop. The design criteria of EEEP teacher workshop, therefore, can be used in other EOTPDs as an effective design that resulted in significant improvement in teachers' conceptual understanding of engineering. Additionally, the conceptual framework of MCL can be used in designing future EOTPDs or in any similar learning environment. Furthermore, in this study concept maps served multiple roles; including cognitive scaffolds, collaboration and argumentation discourse tools, and authentic assessment strategy. In learning and teaching other engineering content areas, concept maps can be used as in this study.

Results of collaborative group concept maps in small groups were interesting. Pre-conceptual understanding in groups was lower than pre-conceptual understanding at individual level, but post-conceptual understanding in groups was much higher than post-conceptual understanding at individual level. Teachers in groups involved in

argumentation discourse with a structured guideline and built their group concept maps by sharing their individual concept maps, discussing about their ideas, negotiating on concepts and connections to include/use in group concept maps, and making decisions with all group members' agreement. I thought future research on discourses and negotiation processes during these group concept maps activities need to be explored. I recommend future research on examining concept negotiation process, factors and/or characteristics influencing group decision, and associations between learners' conceptual understanding and argumentation discourse levels in collaborative group concept maps in learning engineering content knowledge. Doing so may provide a better understanding of how teacher learning occurs in groups and help EOTPD developers designing new learning environments with more effective components.

In this study, using concept maps as authentic assessment strategy to assess teachers' conceptual understanding of earthquake engineering knowledge was vital both individually and in groups. After my experience with concept maps in this study, I saw that concept maps were capable in assessing complex and interdisciplinary earthquake engineering content knowledge. Therefore, I suggest stakeholders in science education as well as STEM education to consider concept maps in assessing complex and interdisciplinary engineering knowledge as they look for new assessment strategies to assess complex and interdisciplinary engineering knowledge (Daugherty, 2009; NGSS, 2013; NRC, 2014a; Purzer et al., 2014). Additionally, I thought providing the key concept list was essential for teachers. Although I gave teachers the opportunity to use any concepts they wished, most preferred to use concepts from the list. As these teachers

were unfamiliar with earthquake engineering knowledge, and the targeted knowledge was complex and had multiple domains to consider I thought the key concept list scaffolded their thinking. In addition, teachers' high preference of the concepts from the list allowed us to track how their conceptual understanding changed overall and in earthquake engineering domain. I know that generating key concepts requires an additional research study if it is not available, but for effective conceptual knowledge assessment as well as teaching and learning I found key concept lists are critical. Thus, I suggest inclusion of more concept maps with generated key concepts as authentic assessment strategy in today's learning environments.

For future research related to this study, I also suggest conducting studies on (a) changes of teachers' beliefs and expectations about integrating engineering content into their science or STEM classrooms, (b) teachers' implementation of engineering content into their classrooms after their EOTPD experiences and its effects on students' engineering learning and interest, (c) students' earthquake engineering learning, and its effect on their success in STEM education and future interest in STEM related areas, (d) use of concept maps as tools for cognitive scaffolds, collaboration, argumentation discourse, and authentic assessment in classrooms with students, and (e) use of different types of cognitive scaffolds, collaboration and argumentations tools, and authentic assessments for teachers in EOTPDs.

Limitations

In this study, I identified two limitations. First, a small sample size in the number of workshop teachers (n=12) was a limitation in this study. A larger sample (n>30)

would lead to greater population validity in terms of claims about changes in teachers' conceptual understanding. Second, the research design of this study (i.e., one-group, pre-test/post-test research design) was another limitation. An improved design (e.g., true experimental design with separate control and intervention groups) would be more beneficial in terms of understanding the effects of the EEEP teacher workshop on science teachers' conceptual understanding of earthquake engineering content knowledge.

CHAPTER V

EXAMINING SCIENCE TEACHERS' ARGUMENTATION DISCOURSE IN AN ENGINEERING-ORIENTED TEACHER PROFESSIONAL DEVELOPMENT

Introduction

Scientists embarking on new frontiers to explain how the world works rely on their abilities to construct arguments based on evidence. In line with the way scientists use argumentation to advance scientific knowledge, the current focus in science education has recently shifted from “what I know” to “how I know and why I believe” (Duschl, 2008, p. 269). In that light, students’ active participation in scientific discussions in learning science has led to a focus on implementing argumentation into science classrooms (Duschl & Osborne, 2002; Erduran, Simon, & Osborne, 2004; Jimenez-Aleixandre & Erduran, 2008; Kaya, 2013; Simon, Erduran, & Osborne, 2006). Additionally, national reports in science education (e.g., NGSS, 2013; NRC, 2007) point to the need for students’ participation in scientific practices and discourse, involvement in scientific discussions, and creation and evaluation of scientific explanations to understand the natural world. A wide range of stakeholders in science education, therefore, suggest that goals for proficiency in science must include the development of sufficient levels of argumentation while actively participating in science learning processes.

Furthermore, recent calls by stakeholders also support greater integration of science and engineering in science classrooms (NGSS, 2013). New guidelines for STEM

education emphasize the need for teaching each content area within STEM through an integration approach in K-12 education (NRC, 2014). This approach connects science, technology, mathematics, and engineering content areas among rather than within individual domains in STEM teaching. Researchers in STEM education have noted engineering knowledge has the potential to be a catalyst for this integration (Katehi, Pearson, & Feder, 2009) because engineering knowledge “utilizes concepts in science and mathematics as well as technology tools” (NRC, 2014, p. 14). With recent calls by science reformers to also address the need of engineering integration in science classrooms, a new skill set for science teachers is needed to enable the teaching of science content through the integration of engineering content, rather than more traditional curriculum frameworks focusing on specific science content areas (e.g., life science, chemistry, physics, and earth science).

Recent researchers have revealed, however, that science teachers possess limited pedagogical skills in teaching engineering content (Banilower et al., 2013) and in teaching argumentation (Passmore & Svoboda, 2012). Development of pedagogical approaches stressing content integration and argumentation may result in teachers’ development of better understanding about complex and interdisciplinary engineering content knowledge and successful teaching of the engineering knowledge in their science classrooms (Cavlazoglu, 2015; Cavlazoglu & Stuessy, 2015a).

Background

Theoretical Background of Argumentation

Argumentation is defined as “the substance of any meaningful discourse that seeks to generate improved knowledge and understanding” (Duschl & Osborne, 2002, p. 51). Researchers have noted the philosophical and cognitive bases of argumentation have a critical role to shape the meaning of “argumentation” in science education contexts (Duschl & Osborne, 2002). According to current perspectives for philosophy of science (e.g., Giere, 1991), science is not just accumulating facts about how the world is; rather, “science involves the construction of theories that provide explanations for how the world may be” (Erduran et al., 2004, p. 917). To provide explanations for causes of the scientific events, theories are open to challenges and contradictions (Popper, 1959). Thus, scientific processes often include disputations, conflictions, and argumentations rather than general agreement as explained by some leading philosophers in science (e.g., Kuhn, 1962; Latour & Woolgar, 1986).

In addition to contemporary philosophies of science, cognitive processes of argumentation require understanding (Erduran et al., 2004). According to these processes, learners involved in argumentation externalize their thinking to others (Billig, 1987; Kuhn, 1992). Vygotsky (1978) noted that this externalization process requires a shift from “*intra*-psychological plane and rhetorical argument to *inter*-psychological and dialogic argument” (as cited in Erduran et al., 2004, p. 917). Adoption of these ideas can lead to the creation of learning environments in which learners create high-quality arguments with others through social interaction.

Argumentation Discourse in Learning and Teaching

An argumentation-discourse focused learning environment centers on social interactions and collaboration. In these learning environments, learners are able to enhance their knowledge and understanding about the world (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt., 1999). The contemporary learning theories highlight the critical role of social interactions and collaboration opportunities to enhance cognitive learning (NRC, 2000, 2014). For example, Vygotsky (1978) introduced the *Zone of Proximal Development* (ZPD), defined as “the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers” (p. 86). In this regard, argumentation discourse could provide unique opportunities for social interaction with more knowledgeable individuals (e.g., peers or experts). Moreover, argumentation discourse allows learners to be more active in the learning process by giving opportunities to share, reflect, and revise their ideas with others (Goldman et al., 1999; Passmore & Svoboda, 2012). Thus, stakeholders (e.g., Duschl, 2008; Erduran et al., 2004; Jimenez-Aleixandre & Erduran, 2008; NRC, 2007; Simon et al., 2006; Von Aufschnaiter, Erduran, Osborne, & Simon, 2008) suggest the need to enhance students’ argumentation skills.

To enhance students’ argumentation skills, teachers’ roles in argumentation discourse should be considered (Cavlazoglu & Stuessy, 2015a). Duschl and Osborne (2002) observe teachers are still at the center of educational practices dominating whole-

class argumentation discourse. In whole-class discourse, students rarely have opportunities to actively initiate their participation in the discourse. Teachers are unable to encourage students “to question, to justify and to evaluate their own, and others' reasoning, enculturating the students as learners into discourse processes that support personal knowledge construction and student metacognition” (Duschl & Osborne, 2002, p. 43). A more appropriate and effective learning environment would engage students in small groups with less teacher-driven activity. To accomplish these roles, distributed learning approaches may prove effective. Ann Brown (2003) discusses practical implications of how teachers orchestrate learning environments to allow for “learners of all ages and levels of expertise and interests [to] seed the environment with ideas and knowledge that are appropriated by different learners at different rates, according to the current state of the zoned of proximal development in which they are engaged” (p. 193).

Distributed Learning Approaches for Effective Argumentation Discourse

The purpose of distributed learning approaches is to give equal opportunities to all members in small groups (i.e., two to four members) to actively participate (NRC, 2014b) in the exploration, expression, reflection, and revision of ideas as they develop within an active community of learners.

... Participation in practice is the main activity in which learning occurs:

Conceiving of learning in terms of participation focuses attention on ways in which it is an evolving, continuously renewed set of relations ... Participation is always based on situated negotiation and renegotiation of meaning in the world.

This implies that understanding and experience are in constant interaction –

indeed, are mutually constitutive. (Lave & Wenger (1991), pp. 49-52 in Brown (2003), p. 189)

While argumentation discourse is effective when all participants make active contributions to the discourse, novice participants in argumentation discourse may need help in understanding how argumentation discourse can occur within the structure of the group. Cohen (1994) noted poor or unsuccessful argumentation discourse resulted when no procedural guidelines or highly structured guidelines were provided (as cited in Duschl & Osborne, 2002, p. 57). Creating procedural guidelines for novice participants, in particular, can be necessary to keep learners active and involved in the argumentation discourse. Procedural guidelines should clearly explain the steps and roles for participants in completing assigned tasks (Herrenkohl, Palincsar, DeWater, & Kawasaki, 1999).

Teachers' pedagogical skills to effectively implement argumentation discourse are often insufficient; they need opportunities to improve their pedagogical skills in argumentation discourse (Kaya, 2013), just as novice learners may also need opportunities to practice their skills to become effective within argumentation discourse contexts. While these opportunities can be found in teacher professional development activities, methods for examining the quality of teachers' argumentation are needed to provide useful insights for enhancing teachers' skills in argumentation discourse.

Toulmin's Argumentation Model

To examine the quality of argumentation, Toulmin (1958, 2003) developed a model of argumentation to qualify arguments based on components. According to his

model, the components of an effective argument include *claims, data, warrants, backings, qualifiers, and rebuttals*. Figure 5.1 shows components of Toulmin’s argument model with descriptions.

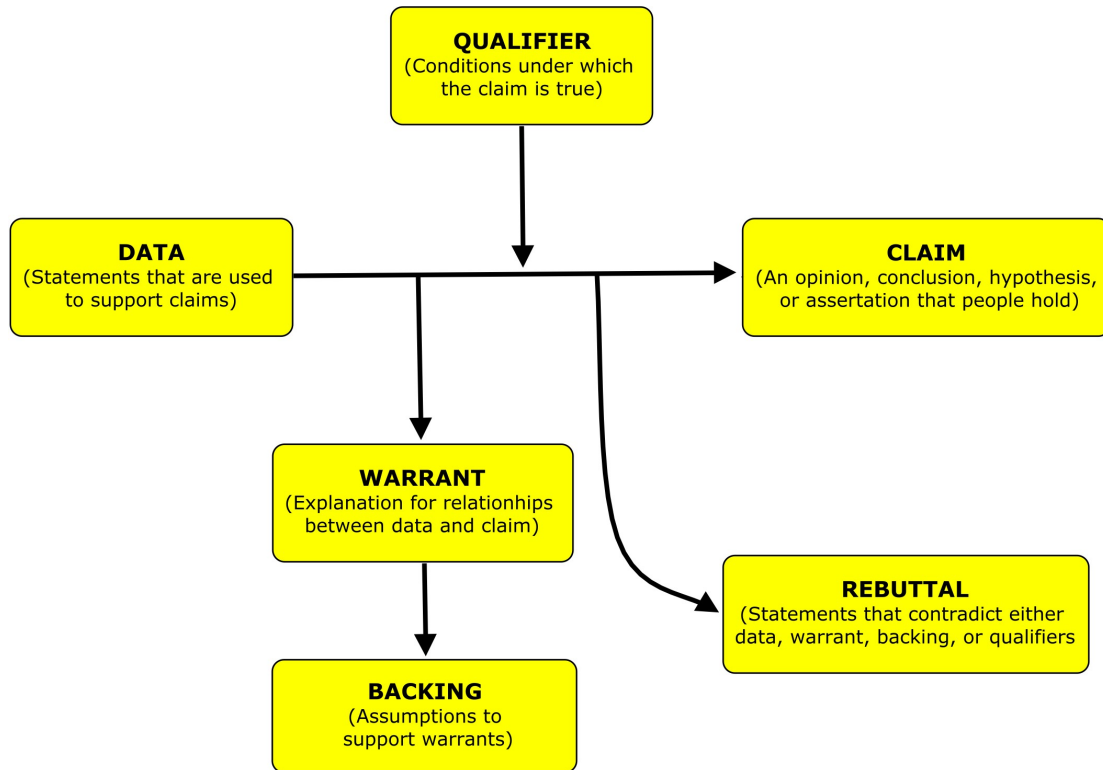


Figure 5.1. Toulmin’s argumentation model with descriptions for each component.

A high number of researchers have used this model (Dawson & Venville, 2009; Erduran et al., 2004; Kaya, 2013; Simon et al., 2006; Venville & Dawson, 2010) as an analytical framework to evaluate the quality of arguments. Difficulties in differentiating the components of arguments have led to the development of specific methodologies by

some researchers (e.g., Erduran et al., 2004; Kaya, 2013; Sadler & Fowler, 2006; Venville & Dawson, 2010). For example, Erduran et al. (2004) created two methodologies to assess whole-class argumentation and small-group argumentation in evaluating the quality of middle school science teachers' argumentation. Using Toulmin's argumentation model, Venville and Dawson (2010) used a previously developed schema by Dawson and Venville (2009) consisting of numerical scores from zero to four, collected data via written forms from high school students, and evaluated the quality of students' arguments. Similarly, Kaya (2013) modified Dawson and Venville's work to develop a schema for the evaluation of pre-service science teachers' arguments. In doing so, she classified the quality of arguments from one to four by considering no written response as zero and collected data via written argumentation surveys from pre-service science teachers in order to evaluate pre-service teachers' arguments about chemical equilibrium.

Argumentation Discourse in Contemporary Science Education

As mentioned, in recent years the focus in science education has shifted from “what one needs *to know* to do science” to “what students need *to do* to learn science.” Researchers have found student development of argumentation skills useful for learning science (Duschl & Osborne, 2002; Jimenez-Aleixandre & Erduran, 2008; Osborne, 2010; Simon et al., 2006; Venville & Dawson, 2010; Zohar & Nemet, 2002). This supports researchers' conclusions that argumentation discourse (a) helps students understand how the science works (Jimenez-Aleixandre & Erduran, 2008; NRC, 2007; 2014b; Simon et al., 2006), (b) fosters students' active participation in learning process

(Duschl & Osborne, 2002; NRC, 2014; Simon et al., 2006), (c) improves students' critical thinking and argumentation skills (Kaya, 2013; Venville & Dawson, 2010; Zohar, 2007), and (d) supports students' development of conceptual understanding (Jimenez-Aleixandre & Erduran, 2008; Kaya, 2013; Von Aufschnaiter et al., 2008).

Researchers in science education have noted teaching argumentation discourse and improving student argumentation skills have a positive impact on students' understanding of how the science works (Duschl & Osborne, 2002; Erduran et al., 2004; Osborne, Erduran, & Simon, 2004; Simon et al., 2006). Through integrating argumentation into teaching, students increase their use of scientific theory, data, and evidence (Simon et al., 2006) and make better connections between data and claims (Jimenez-Aleixandre & Erduran, 2008). Students empower their abilities to talk and write with scientific language (Duschl & Osborne, 2002; Osborne, 2010). This process also encourages students to engage actively in scientific discussions and to create and evaluate scientific explanations to understand the natural world (NRC, 2007, 2014b).

Furthermore, engaging students into argumentation-based instructions enhances their argumentation and critical thinking skills (Kaya, 2013; Venville & Dawson, 2010; Zohar, 2007). For example, Venville and Dawson (2010) indicated that high students' argumentation and critical thinking skills were improved when their teachers had participated in professional development focusing on argumentation discourse. In addition, many research studies have revealed that argumentation practices support students' conceptual development and increase conceptual understanding in science (Jimenez-Aleixandre & Erduran, 2008; Kaya, 2013; Von Aufschnaiter et al., 2008). In

an experimental study conducted by Kaya (2013), pre-service teachers were taught chemical equilibrium with argumentative practices in the experimental group and traditional lecturing in the control group. The result of the study showed that pre-service teachers' conceptual understanding and argumentation skill significantly increased after teaching chemical equilibrium with argumentation practices in the experimental group. However, pre-service teachers' conceptual understanding and argumentation skill in the control group indicated no significant difference after teaching chemical equilibrium with traditional lecturing.

As mentioned previously, recent calls from NGSS (2013) in science education and NRC (2014b) in STEM education focus on integrating engineering into science and other STEM classrooms in K-12 education. However, researchers have noted that the integration of engineering content can be difficult for some teachers due to their limited engineering content knowledge and pedagogic content knowledge for teaching engineering in their classrooms. In a national survey study, Banilower et al. (2013) found science teachers' engineering content knowledge is insufficient and they lack confidence in teaching engineering. Researchers have noted also that understanding engineering content can be difficult for teachers due to complexity of engineering content areas. Thus, for science teachers learning and teaching engineering aspects in the curriculum can be challenging (Cunningham & Carlsen, 2014; Daugherty, 2009; Katehi et al., 2009). In addition, the complexity may require teachers to have additional pedagogical skills (which could include argumentation) to successfully integrate their content areas (NRC, 2014b) with engineering concepts and skills. Therefore, science

teachers, especially those who are traditionally prepared to teach in only one science domain, need opportunities to broaden their pedagogical skills and enhance their engineering content knowledge. Engineering-oriented teacher professional development (EOTPD) has been found to be useful in providing these opportunities to the teachers (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Katehi et al., 2009; NRC, 2000, 2014b; Wilson, 2011). Stakeholders, therefore, suggest that EOTPDs be designed to consider the complexity of engineering content and additional pedagogical skills necessary for them to be effective (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009).

Meaningful Conceptual Learning

Cavlazoglu (2015) created a conceptual framework, *Meaningful Conceptual Learning* (MCL), identifying necessary components to improve learners' conceptual understanding of complex content knowledge. The MCL framework consists of four critical components: (1) cognitive scaffolds, (2) collaboration, (3) argumentation discourse, and (4) authentic assessment (Cavlazoglu, 2015). The framework includes cognitive scaffolds as learning tools providing support to learners in organizing knowledge structures. *Cognitive scaffolds*, such as concept maps, Vee diagrams, computer simulations, and models can be crucial in facilitating learners' conceptual understanding of complex knowledge. *Collaboration* engages learners through social interactions. These interactions facilitate learning construction and elaboration from others. *Argumentation discourse* provides learners with opportunities to develop, share, reflect, and revise their ideas within a community of their peers and with knowledgeable

others who provide feedback through discourse. Finally, use of *authentic assessments* within the contexts of learning provides detailed feedback about learners' understanding, which allows learners to receive timely feedback and revise their understanding of complex ideas naturally and continuously during the learning process.

Traditionally prepared science teachers enrolled in an Earthquake Engineering Education Project (EEEEP) summer workshop had no previous professional development nor teaching experiences in integrating engineering content into their science classrooms. The EEEEEP summer workshop was an EOTPD with the goal of increasing high schools science teachers' understanding about earthquake engineering while also improving their pedagogical skills, including argumentation discourse. As a result of the EEEEEP workshop, science teachers were expected to understand the earthquake engineering content knowledge and successfully implement the engineering knowledge into their science classrooms. My previous research examining changes in science teachers' conceptual understanding of earthquake engineering content at the conclusion of their participation to the EEEEEP workshop found teachers significantly increased their conceptual understanding of earthquake engineering (Cavlazoglu & Stuessy, 2015a).

In the current study, I proposed to examine changes in science teachers' argumentation discourse quality as a result of their participation to the EEEEEP workshop. My intent was to add to the literature in two major ways: (1) introducing research in a context not previously studied and (2) examining monologic discourse using the different medium of concept maps. First, previous studies examining argumentation discourse were often in the context of biology (Venville & Dawson, 2010; Zohar &

Nemet, 2002; Zohar, 2007) chemistry (Kaya, 2013), and socio-scientific issues (Von Aufschnaiter et al., 2008). However, argumentation discourse in any engineering context has yet to be examined. This study, therefore, provides a first examination of argumentation discourse within an earthquake engineering professional development context. Second, prior research often used monologic discourse (e.g., Kaya, 2013; Venville & Dawson, 2010; Von Aufschnaiter et al., 2008; Zohar, 2007). Monologic discourse occurs when individuals are asked to answer a question and justify their ideas in written form. In this study, I also used a monologic discourse approach but in a different form. I required participants to individually construct a concept map to answer a question about earthquake engineering and explain their ideas to others in small groups. Using a modified monologic discourse approach via concept maps, this study provides a different form in which to collect and analyze participants' argumentations.

Method

Context of the Study

The context of this study was an EOTPD organized by EEEP researchers for high school science teachers in June 2013. EEEP was a STEM education research project supported by the National Science Foundation. The goal of the project was to increase high school teachers' and students' understanding about earthquake engineering by integrating appropriate knowledge, skills, and tools into STEM classrooms. To achieve the targeted goals, EEEP researchers organized the six-day workshop for high school science teachers at a tier-one university in Texas, USA. The EEEP workshop provided hands-on, minds-on experiences and background information about what earthquake

engineers do, how earthquake engineers work within social systems to solve complex problems related to earthquake engineering, how the STEM-related domains of science, technology, engineering, and mathematics come together in solving complex real-world problems, and how the use of models (including simulations and modeling software) assist individuals (including scientists) in understanding complex and interdisciplinary problems.

I embedded pre- and post-workshop argumentation discourse activities within the workshop format. Argumentation discourse with a distributed learning approach using procedural guidelines was implemented (see Appendix). The procedural guideline consisted of four parts: (a) individual concept-mapping, (b) individual argumentation discourse, (c) group discourse and group concept mapping, and (d) group discussion.

In the individual concept-mapping part, I explained how teachers would use hands-on materials for their concept mapping and what steps they would follow in constructing their individual concept maps. The steps in this phase included preparation for individual concept mapping (e.g., the use of stickers in different colors and where to write their names for identification), thinking about essential concepts to be used in the individual concept maps (e.g., making a selection for essential concepts from the provided list of 35 concepts and/or from their own additional concepts), and constructing concept maps (e.g., how to draw lines between concepts and write connection words). As a result, teachers were required to construct individual concept maps about their understanding of earthquake engineering.

In the second part, I provided instructions about the requirement that teachers would participate in monologic argumentation discourse about their concept maps with other members of their small group of two or three participating members. All in the group were required to present an argumentation discourse in which the individual argued/defended her/his understanding of earthquake engineering to the other group members.

In the third part of the guideline, I provided steps for the group discussion and group concept mapping. For this part, first, teachers were supposed to have a conversation about their earthquake engineering concept maps in which they discussed the similarities, differences, and other ideas thought important about earthquake engineering with their group members. Second, teachers were required to construct a group concept map through a decision-making process involving all group members as equal participants in the discussion.

In the fourth part, I provided several argumentation discourse questions about earthquake engineering and asked for each group to discuss these questions and giving each teacher an opportunity to speak. (I created the discussion questions to facilitate teachers' argumentation discourse learning process)

During the third and fourth parts, I scaffolded each group's argumentation discourse learning process by visiting each group, becoming involved in the discussions, and facilitating discussions about ways to improve the effectiveness of the argumentation discourse. Based on each group's needs, I scaffolded teachers'

understanding of argumentation discourse and provided feedback to improve the quality of their argumentation discourse.

Research Design

I employed a one-group pre-test/post-test research design in which a single group of teachers received a pre-test measure, treatment, and a post-test measure (Creswell, 2009, p. 160). I proposed to examine changes in the levels of science teachers' argumentation discourse before and after their participation in the EEEP workshop. To do so, I examined teachers' argumentations in pre- and post-argumentation discourse activities. This allowed us to report how science teachers' argumentation levels in earthquake engineering changed in the EEEP workshop.

Participants

The participants in this study were ten high school science teachers (7 female, 3 male) electing to attend the EEEP workshop. Teachers were recruited via brochures at national conferences, applications on the project website, and invitations on the project Facebook page. Teachers' classroom experience ranged from one to 33 years. Seven of the ten science teachers had completed or were pursuing an advanced degree in Education. Three of the science teachers were from Texas, while the remaining teachers lived in Alaska, Florida, Indiana, Louisiana, Maryland, South Carolina, and Ohio. Ethnic representation among science teachers included White (40%), Hispanic (30%), African-American (20%), and Asian (10%).

Data Collection Procedures

To collect data for this study, I audio-recorded teachers' monologic pre- and post-workshop argumentation discourse. In the first day morning sessions of the EEEP workshop, I held pre-assessment activities that included pre-workshop argumentation discourse. Before workshop teachers' active participation in the activity, I familiarized science teachers with the procedures for constructing concept maps and instructions for accomplishing the argumentation discourse activity. First, I gave a short training about the general principles of constructing concept maps. Although nine of ten teachers expressed their familiarity with concept map construction, I did this training to make sure that all science teachers were familiar with the same concept map construction process. Then, I explained details of the argumentation discourse activity. Finally, I provided the rationale for integrating concept-mapping approaches with the argumentation discourse activity.

I provided teachers with necessary concept mapping materials, including large papers, post-it notes in different colors, scissors, markers, and a printed list of concepts previously developed by a modified Delphi technique engaging expert focus groups. After all questions were clarified about activities, I asked each teacher to construct a concept map about her/his understanding of earthquake engineering to be used in her/his argumentation discourse. When all teachers finished constructing their concept maps, I randomly assigned them into small groups (i.e., groups with two or three members) and asked that each teacher present his/her map to the group via argumentation discourse. Specifically, they were asked "How would you argue/defend your understanding of

earthquake engineering to your group?” as a main question. In addition, to facilitate teachers’ argumentation process sub questions were asked such as “Please explain why students need to know the concepts you indicated in your concept map in learning earthquake engineering at high school level.” Teachers used their concept maps as tools to organize their arguments.

The complexity of earthquake engineering content required a tool to assist learners in organizing knowledge structures and improving learners’ thinking, analyzing, and problem solving skills (Goldman et al., 1999; Novak & Canas, 2008; Novak, 2010) to scaffold teachers’ argumentation discourse environment about earthquake engineering. Figure 5.2 shows examples of concept maps constructed and used by teachers during their argumentation discourse in the EEEP workshop. In both pre- and post-argumentation discourse activities, I audio-recorded all discourse processes to examine the patterns in the arguments of the teachers.

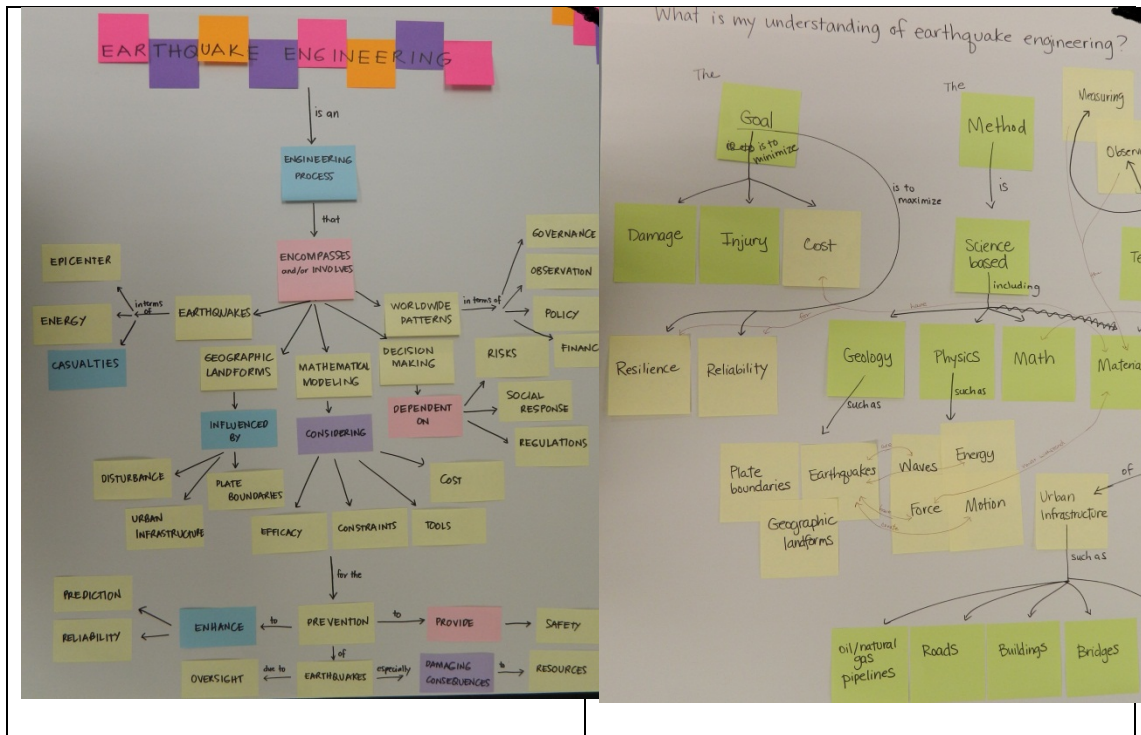


Figure 5.2. Pictures of two constructed concept maps teachers used for argumentation discourse in the EEPP workshop.

I chose concept mapping rather than a written argumentation survey method commonly used by researchers for data collection (Kaya, 2013; Venville & Dawson, 2010). In the survey method, participants are asked a specific question in the targeted content area (e.g., biology and chemistry) and are expected to indicate their level of argument within their response. I argue that asking one question about a specific part of the targeted content area may not be a reasonable method to qualify individuals' argumentation levels due to the limitation the method imposed on participants' responses about a "specific" part of the content, whether the participant is familiar with the content or not. A concept mapping approach provides the research with more options. First,

participants can be asked to make open-ended responses about content they have targeted on their concept maps. Second, participants can be asked a broad argumentation question that allows participants to talk or write about any part of the content on the map. In this research, I asked a broad argumentation question to workshop teachers about earthquake engineering and gave them opportunity to talk about any part of earthquake engineering content they had indicated on the map.

Data Analysis Procedures

Previous researchers have developed a classification schema based on Toulmin's (1958) argumentation pattern to qualify science teachers' argumentation levels (Erduran et al., 2004; Kaya, 2013; Osborne et al., 2004; Venville & Dawson, 2010). In addition, researchers have used different classification schemas corresponding to argumentation discourse type (i.e., monologic discourse and/or dialogic discourse). Monologic discourse refers to argumentation discourse performed by one individual, with no interaction of others. However, dialogic discourse corresponds to instances in which multiple participants interact in the discourse. In dialogic discourse, multiple participants share their knowledge with others orally, which may lead to a group decision or agreement about an issue. A five-level classification schema includes all components of Toulmin's argumentation model and has commonly been used (e.g., Erduran et al., 2004; Osborne et al., 2004). When the goal was to analyze monologic discourse, the component of rebuttal was excluded from the schema (e.g., Dawson & Venville, 2009; Kaya, 2013; Venville & Dawson, 2010), as rebuttals only occur in dialogic discourse. Researchers analyzing monologic discourses, therefore, have used a four-level

classification schema. For example, Kaya (2013) developed a four-level classification schema to qualify pre-service teachers' written arguments about chemical equilibrium. In her research, pre-service teachers were taught the content via argumentative practices. Results showed pre-service teachers significantly increased their argumentation skills as a result of their argumentative practices in learning chemical equilibrium. In another study, Venville and Dawson (2010) used a four-level classification schema to evaluate high school students' argumentation levels in learning genetics. For their embedded case study, these researchers first provided a short professional development to teachers about how to teach argumentation skills to students. Venville and Dawson's study employed an experimental design in which two teachers were assigned to teach genetics with argumentation skills for students in the experimental group and another two teachers were assigned to teach genetics with traditional lecture for students in the control groups. Analysis of students' written arguments showed that students in the experimental group significantly improved the complexity and quality of their arguments, whereas no significant improvement occurred among students in the control group. Venville and Dawson (2010) concluded that even a short professional development on argumentation skills for teachers can enhance students' argumentation skills.

In this study, I aimed to analyze science teachers' monologic arguments about earthquake engineering. To do so, I developed a classification schema modifying Venville and Dawson's (2010) classification schema. I transcribed audio recordings of each science teachers' pre- and post-workshop argumentation discourse and analyzed their argumentative statements. The schema consisted of four levels from 1 to 4,

indicating the quality of arguments. Table 5.1 provides details about each level and examples of arguments at different levels, sourced from the arguments presented by science teachers when they presented their concept maps to the individuals in their groups.

Table 5.1

Argumentation Levels and Examples from Teachers' Arguments

Levels	Examples from Teachers' Arguments
Level 1 (claim)	Earthquakes cause damage to urban infrastructure (claim).
Level 2 (claim + data and/or warrant)	Earthquakes are a transfer of energy at plate boundaries caused by force and motion (claim) resulting in formation or destruction of geographic landforms (data).
Level 3 (claim + data and/or warrant + backing or qualifier)	Earthquakes are gonna happen regardless (data), I can't predict when they are gonna happen (claim). Therefore, I must have preparing approaches for an earthquake that is going to happen (backing), maybe now, maybe two hundred years later. It is gonna happen. That is the key.
Level 4 (claim + data/warrant + backing + qualifier)	To understand earthquake engineering, I should know all the basic science concepts behind earthquakes (claim) including energy, waves, motion, epicenter, plate boundaries, and geologic landforms. Understanding all the basic science allows us to create knowledge about possible prediction and prevention strategies (data). This knowledge should be used by governance to study and maintain urban infrastructure (backing). All these governing things I found so important so come up with that without the social component, I may not able to understand earthquake engineering (qualifier).

To identify each science teacher's argumentation levels, two experts in argumentation research served as coders. One coder was a doctoral student in science

education and other coder was an assistant professor in science education. The two coders participated in a training session before they began to code in which they read, individually coded, and discussed differences and similarities of their coding on a set of randomly selected argument statements. Both coders then individually coded all randomly selected argument statements to engage in a two-stage process of determining “the extent to which independent coders evaluate a characteristic of a message or artifact and reach the same conclusion” (Lombard, Snyder-Duch, & Bracken, 2002, p. 589). In the first, pilot stage, coders used an online inter-rater reliability calculator (<http://justusrandolph.net/kappa>) developed by Randolph (2008) to reveal strong agreement, Kappa = 0.76. In the second, clarifying stage after Kappa was calculated, coders met a final time face-to-face to compare their decisions for each statement, discussed differences, and ultimately came to 100% agreement.

The coding procedure included two parts: (1) identification of argument statements and (2) identification of each argument’s level according to the adopted classification schema. To identify argument statements, the coders individually read all transcripts. In this identification process, unrelated teacher talks (e.g., procedural talks, technical talks) were excluded from the analysis. Coders then analyzed each identified argument statement to assign the level for each statement (i.e., 1, 2, 3, and 4; see Table 5.1). Then, I calculated the mean score for each teacher’s arguments in the pre- and post-workshop argumentation activities. Descriptive statistics were used to describe differences between teachers’ pre- and post-workshop argumentation discourse.

Wilcoxon signed-rank tests (related samples, repeated measures) were used to determine significant difference between pre- and post- workshop argumentation discourse levels.

Research Questions

Specifically, in this study I addressed two questions regarding science teachers' argumentation discourse:

1. What differences in science teachers' argumentation discourse were observed in their pre- and post-workshop argumentation discourse assessments?
2. Were there significant differences between science teachers' pre- workshop argumentation discourse levels and post-workshop argumentation discourse levels?

Results

Research Question #1: What differences in science teachers' argumentation discourse were observed in their pre- and post-workshop argumentation discourse assessments?

Descriptive statistics of teachers' arguments showed that number of argument statements decreased. In total, science teachers used 64 argument statements in the pre-argumentation discourse and 52 argument statements in the post-argumentation discourse. However, the results of the Wilcoxon signed-test indicated there was no statistical difference between number of science teachers' argument statements before and after the workshop (See Table 5.2).

Table 5.2

Results of Wilcoxon Signed-Test between Number of Argument Statements Before and After the Workshop

	N	Mean Rank	Sum of Ranks	z	p
Post AD Counts – Negative Ranks	6 ^a	6.83	41.00		
Pre AD Counts					
Positive Ranks	4 ^b	3.50	14.00		
Ties	0 ^c			-1.384 ^b	.166
Total	10				

^aPost AD Counts < Pre AD Counts.

^bPost AD Counts > Pre AD Counts.

^cPost AD Counts = Pre AD Counts.

However, argument levels were found to differ before and after the workshop. Level 1 was the most frequent argument level before the workshop, whereas Level 2 was the most frequent argument level after the workshop (See Figure 5.3). However, numbers of Level 2 argument statements were almost same in both assessments. While the initial number of Level 1 argument statements was much higher than those after the workshop, numbers of Level 2, Level 3, and Level 4 argument statements were higher after the workshop. The largest increase occurred at Level 3. My analysis indicated the presence of only one Level 3 argument statement before the workshop, which increased to 15 statements after the workshop. Similarly, while I recorded no Level 4 argument statements in the initial activity, seven Level 4 argument statements were recorded after the workshop.

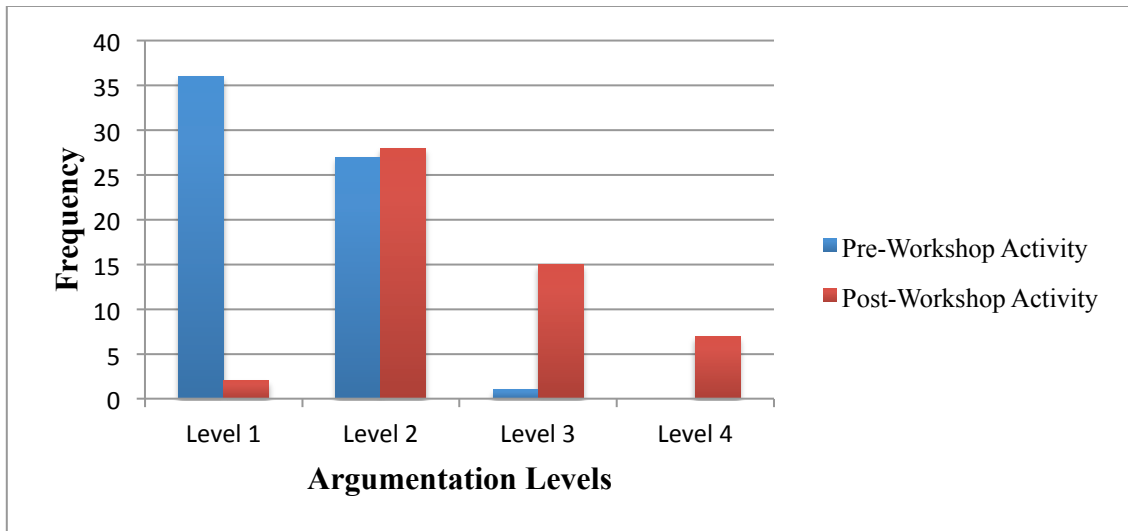


Figure 5.3. Frequency of pre-workshop and post-workshop argumentation levels for ten engineering education science teachers.

Research Question #2: Were there significant difference between science teachers’ pre-workshop argumentation discourse levels and pre-workshop argumentation discourse levels?

I identified each teacher’s argumentation discourse level by calculating her/his average of argument statements. For example, one teacher made two Level 1 and three Level 3 argument statements in her pre-workshop argumentation discourse; the calculated average pre-workshop argumentation discourse level, therefore, was calculated to be at the level of 1.6. The same teacher made two Level 2 and one Level 4 argument statements in her post-workshop argumentation discourse; her post-

argumentation discourse level was calculated at the level of 2.6. Figure 5.4 shows ten teachers' (A-L) levels of argumentation discourse levels before and after the workshop.

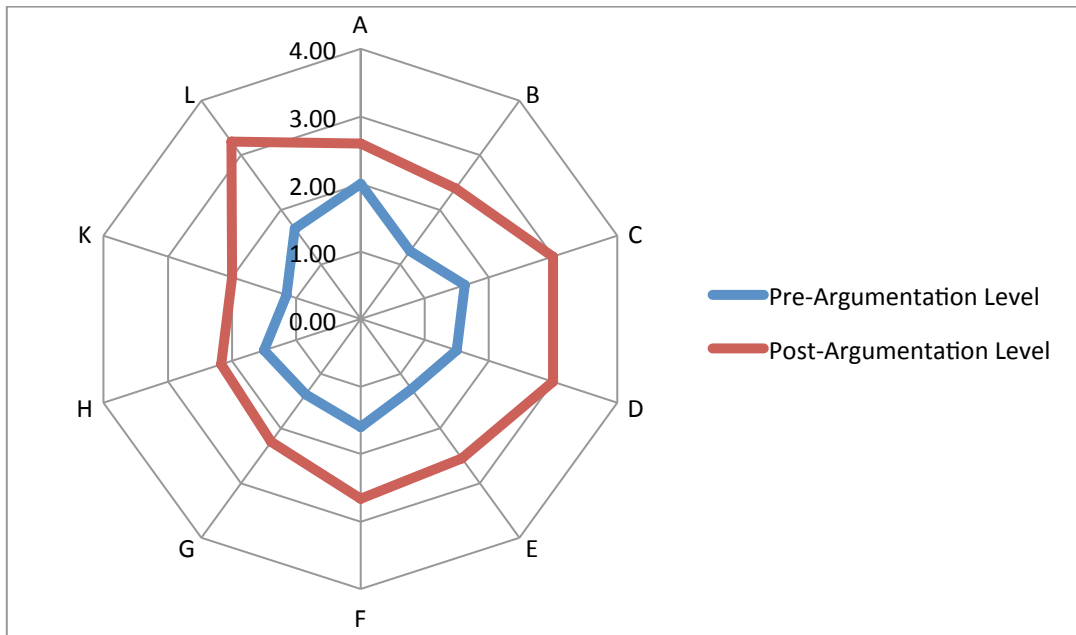


Figure 5.4. Ten teachers' (indicated as A-L) levels of argumentation discourse before and after the EEEP workshop.

I applied the Wilcoxon signed-test to identify statistically significant difference between science teachers' pre- and post-workshop argumentation discourse levels. The results of the Wilcoxon signed-test revealed that science teachers' post-workshop argumentation discourse levels were significantly higher than pre-workshop argumentation discourse levels (see Table 5.3).

Table 5.3

Results of Wilcoxon Signed-Test between Pre and Post Argumentation Discourse Levels

		N	Mean Rank	Sum of Ranks	z	p
Post Argumentation Level – Pre Argumentation Level	Negative Ranks	0 ^a	.00	.00		
	Positive Ranks	10 ^b	5.50	55.00	-2.803 ^b	.005
	Ties	0 ^c				
	Total	10				

^aPost Argumentation Level < Pre Argumentation Level.

^bPost Argumentation Level > Pre Argumentation Level.

^cPost Argumentation Level = Pre Argumentation Level.

Conclusion and Discussion

In this study, I examined changes in science teachers' argumentation discourse as a result of their participation in an EOTPD, EEEP workshop, about earthquake engineering. Results support the conclusion that although the number of total argumentation statements by science teachers did not change significantly, the level of their argumentation discourse did increase significantly. Science teachers have been encouraged to enhance their pedagogical skills to develop their students' argumentation skills (Duschl & Osborne, 2002; Erduran et al., 2004; Jimenez-Aleixandre & Erduran, 2008; Osborne et al., 2004; Osborne, 2010; Zohar & Nemet, 2002; Zohar, 2007) and active participation in integrating engineering into their science learning (Katehi et al., 2009; NGSS, 2013; NRC, 2014b; Purzer, Moore, Baker, & Berland, 2014). Results of this study provide promising evidence that the EEEP workshop was useful in enhancing

science teachers' argumentation discourse levels within an earthquake engineering context. As indicated in the previous research (e.g., Venville & Dawson, 2010), a short teacher professional development on argumentation discourse can enhance quality of arguments, I also found that the workshop teachers' short immersion in the EEEP workshop resulted in significant improvement in the quality of their arguments.

For the first research question of this study, I examined changes in science teachers' argument statements in pre- and post-workshop argumentation discourse. Results indicated that as a result of argumentation discourse intervention via distributed learning approach in the EEEP workshop, the number of argument statements in Level 1 decreased while the number of Level 2, Level 3, and Level 4 argument statements increased. Especially noteworthy is the highest increase in Level 3 argument statements. This result is consistent with previous argumentation discourse intervention studies (e.g., Kaya, 2013; Venville & Dawson, 2010; Zohar & Nemet, 2002) in which researchers found highest increase in Level 3 as a result of their argumentation intervention.

For the second research question, I employed Wilcoxon signed-test to identify significant difference between the ten science teachers' pre-workshop argumentation discourse levels and post-workshop argumentation discourse levels. Results showed that science teachers' post-workshop argumentation discourse levels were significantly higher than pre-workshop argumentation discourse levels. This result is parallel to many previous argumentation discourse intervention studies on argumentation discourse in various contexts including biology (Venville & Dawson, 2010; Zohar & Nemet, 2002;

Zohar, 2007) chemistry (Kaya, 2013) and socio-scientific issues (Von Aufschnaiter et al., 2008).

The results also support my conclusion that an argumentation intervention via distributed learning approach (NRC, 2014b) in the context of engineering (i.e., earthquake engineering) was successful in improving science teachers' argumentation discourse levels. Further, I developed a procedural guideline (Herrenkohl et al., 1999) based on the distributed learning approach (NRC, 2014b) to science teachers for improving argumentation discourse and scaffolding the learning process in their own classrooms. During the group activities (i.e., third and fourth parts of the guideline), EEEP workshop researchers involved EEEP workshop organizers in the group discussion and facilitated each group's argumentation discourse learning process. In small groups, researchers provided feedback to science teachers about quality of their argumentation discourse and discussed how they could improve quality of their arguments. As explained by Vygotsky (1978) I believed this involvement provided unique opportunities for social interaction with more knowledgeable others (e.g., peers or experts) as a method for closing the distance between novice learners and more knowledgeable peers. The results suggest social interaction among group members and experts as enabling science teachers to improve their argumentation discourse levels. Additionally, distributed learning within the procedural guideline allowed teachers to become more active in the learning process and provided opportunities for them to share, reflect, and revise their ideas with others (Goldman et al., 1999; Passmore & Svoboda, 2012).

I also modified a data collection method used in previous research (Dawson & Venville, 2009; Kaya, 2013; Venville & Dawson, 2010) by substituting specific questions covering a part of the targeted context with broad questions providing flexibility for teachers to target the earthquake engineering content about which they would argue. This method allowed an open-ended approach rather than the more restricted approaches in other research contexts. I contend the use of broad questions to collect data in research centering on monologic argumentation discourse. My approach also differed in that my participants were not expected to indicate the level of argumentation discourse within their responses. My belief is that specific questions in which participants are also required to identify their argumentation level is not helpful in reflecting participants' actual argumentation discourse levels, particularly in cognitively complex contexts such as those integrating engineering into science learning. For example, earthquake engineering is a multidisciplinary context that contains physical systems, designed systems, social systems, and earth systems (Cavlazoglu & Stuessy, 2015b). If specific argumentation questions were asked of participants about one of these systems, participants' argumentation discourse may be limited when the participants are not familiar with the specific discipline. By using broad, open-ended questions about earthquake engineering, however, I allowed participants to engage in discourse about any part of the context with which they were familiar. My use of broad questions allowed us to focus on the change in teachers' argumentation discourse within the multidisciplinary context of earthquake engineering, which not specifying the content about which they were to construct an argument.

In this study, concept maps were used as cognitive scaffolds and argumentation tools. Before argumentation discourse implementation, I asked teachers to construct concept maps concerning their understanding of earthquake engineering. Due to the complexity in the targeted engineering context, I used concept maps as cognitive scaffolds in organizing their knowledge structures and scaffolding tools in facilitating their argumentation discourse process. I conclude constructing individual concept maps prior to the argumentation discourse in small groups was useful for teachers to organize and visualize their understanding of the targeted engineering context. Furthermore, the concept mapping exercise itself may have facilitated the teachers' thinking about relationships among systems of ideas, thus providing them with additional motivation to share their new thinking with others in their group (i.e., constructing arguments in the monologic argumentation discourse). Moreover, the concept mapping exercise was appropriate in the activities because it provided participants with opportunities to socially interact with others.

Furthermore, in a related investigation, I found that increases in science teachers' conceptual understanding of earthquake engineering in the EEEP workshop impacted the quality of their argumentation discourse. In the previous investigation, I found statistically significant increases in teachers' conceptual understanding of earthquake engineering before and after the EEEP workshop (Cavlazoglu & Stuessy, 2015a). These findings lead us to assume positive impacts of improved conceptual understanding on the quality of teachers' argumentation discourse quality. Mine would be a similar case to prior research supports teaching content via argumentation practices improves students'

conceptual understanding in different content areas, including biology and chemistry (e.g., Kaya, 2013; Venville & Dawson, 2010). Extending my thoughts, I could also design a study testing the effects of enhancing conceptual understanding not only on the quality of teachers' arguments but also on increased confidence in teaching (Banilower et al., 2013).

For future research, I recommend examining argumentation discourse in other engineering content areas, following recommendations for integrating engineering into science classrooms (NGSS, 2013; NRC, 2014b). In addition, research on science teachers' argumentation discourse implementation in engineering contexts would be critical for understanding how teachers' argumentation experiences impact the quality of students' argumentation. Moreover, I suggest more research on use of concept mapping as an argumentation discourse tool to scaffold argumentation discourse process in complex contexts, such as engineering. Finally, I recommend conducting future research on changes in argumentation discourse with distributed learning approaches in dialogic discourse of small groups in diverse engineering contexts.

Limitations

In this study, I identify two limitations. First, I was limited to a small sample size ($n=10$) in this study. A larger sample ($n>30$) could lead to greater population validity for claims about changes in teachers' argumentation discourse in earthquake engineering contexts. Second, the research design for this exploratory study used a one-group pre-test/post-test design. An improved design, such as a true experimental design with separate control and intervention groups, could be more beneficial in understanding the

effects of the procedural guidelines with distributed learning approaches on science teachers' argumentation discourse in earthquake engineering context.

CHAPTER VI

SUMMARY OF RESULTS AND RECOMMENDATIONS FOR STAKEHOLDERS

Policy makers, researchers, and educators in science education have focused on STEM education because of its critical role on the economic welfare and leadership status of the country (Lopez et al., 2011; Nathan, Atwood, Prevost, Phelps, & Tran, 2011; Wilson, 2011). Furthermore, leading stakeholders in national educational policy (e.g., NGSS, 2013; NRC, 2014b) have reported the need for improving and expanding STEM education and enhancing students' readiness for future careers reliant on STEM content knowledge (NRC, 2012). In addition, recent calls (e.g., CCSSM, 2010; ITEEA, 2007; NGSS, 2013) stress the need for integration across all STEM content areas (NRC, 2014). To do so, stakeholders suggest implementing engineering content knowledge into STEM classrooms since the nature of engineering content knowledge serves as a catalyst in the integration of all STEM areas (Katehi, Pearson, & Feder, 2009).

Furthermore, a recent framework in science education, the NGSS framework, emphasizes the integration of science and engineering in K-12 science classrooms and indicates potential implications for enhancing STEM education (NGSS, 2013). Teachers with STEM connections including science teachers in K-12 education have had few opportunities to improve their conceptual understanding of engineering content knowledge (Daugherty, 2009; Nathan et al., 2011) and pedagogical skills to teach engineering (Banilower et al., 2013). Therefore, science teachers need opportunities to

enhance their conceptual understanding of engineering content knowledge and pedagogical skills for successful engineering implementation in science classrooms. These opportunities can be often found in EOTPDs.

As the idea of EOTPD is new to the literature, few studies exist examining the effectiveness of EOTPDs for teachers. Research is currently under way to develop and test design criteria for effective EOTPDs to increase teachers' conceptual understanding of engineering content knowledge and their familiarity with new paradigms of teaching, learning, and assessment (NGSS, 2013; NRC, 2014a, 2014b). Therefore, there is a need for a new conceptual framework that describes crucial components for an effective EOTPD including new paradigms of teaching, learning, and assessment. Examining changes in teachers' conceptual understanding of engineering content knowledge and pedagogical skills as a result of EOTPDs has become critical to understand the effectiveness of the purposed EOTPDs. In addition, researchers suggest creating new knowledge bases (Purzer, Moore, Baker, & Berland, 2014) in critical engineering content areas that can be used in learning and teaching engineering at targeted learner levels in STEM classrooms.

The purpose of this summary chapter is fourfold. First, I describe a modified Delphi study in which I created a knowledge base in earthquake engineering. Second, I report my examination for changes in science teachers' conceptual understanding of earthquake engineering content knowledge as a result of their participation to an EOTPD. Third, I explain my examination for changes in science teachers' argumentation discourse quality as a result of their participation to an EOTPD. Finally, I link the three

studies together to make specific recommendations for stakeholders, which should help in designing EOTPDs to increase science teachers' conceptual understanding of engineering content knowledge and enhance science teachers' necessary pedagogical skills for integrating engineering knowledge into their science classrooms.

Identifying and Verifying Earthquake Engineering Concepts

The first paper for this dissertation was a modified Delphi study to identify and verify earthquake engineering concepts to create a knowledge base in STEM education, appearing as Chapter III in this dissertation. Stakeholders in both STEM education and science education have called integrating engineering content knowledge into STEM-content classrooms (NGSS, 2013; NRC, 2014b). However, research indicates many science teachers, particularly those traditionally prepared to teach within a specific science content domain, need to broaden their knowledge in engineering content areas for successful integration. Furthermore, most of these traditionally prepared teachers do not have access to well-defined knowledge bases (e.g., key concepts) in critical engineering content areas. Currently, defined engineering knowledge bases at the high school level do not exist. In this regard, researchers have suggested that new integrated STEM curricula contain a list of key concepts critical in understanding the specific engineering content area (e.g., earthquake engineering). Therefore, there is a need for generating key concepts in critical engineering areas enabling science teachers to implement engineering into science classrooms.

Using a modified Delphi research design, I identified and verified key concepts in earthquake engineering necessary for high school learners to acquire a basic

understanding of earthquake engineering. Through a two-stage process, (1) three researchers in earthquake engineering education identified 37 key concepts and (2) six experts in science education and civil engineering with research interests and expertise in earthquake engineering verified 35 of these concepts. A key concepts list and strand map with 35 earthquake engineering key concepts were created to support high school students' development of understanding about earthquake engineering. High school science teachers as well as other teachers in STEM content areas (i.e., mathematics, technology, and engineering) can use these key concepts to understand and teach earthquake engineering content in their STEM classrooms.

Examining Changes in Science Teachers' Conceptual Understanding about Earthquake Engineering

The second paper for this dissertation consisted of two parts, MCL conceptual framework and examination of changes in science teachers' conceptual understanding of earthquake engineering as a result of their participation to the EEEP teacher workshop, appearing as Chapter IV in this dissertation. Current calls in science education suggests designing effective EOTPDs to increase science teachers' conceptual understanding of complex engineering content knowledge as well as improve their pedagogic content knowledge to successfully integrate engineering into science classrooms (NGSS, 2013; NRC, 2014b). However, research is still under way to develop and test design criteria for effective EOTPDs. Therefore, I found important to develop a new conceptual framework that describes crucial components for effective learning environments such as EOTPDs that requires conceptual understanding of complex targeted knowledge.

I created the MCL framework based on the literature describing components needed to improve learners' conceptual understanding of complex content knowledge within new paradigms of teaching, learning, and assessment (See Figure 4.1). To enhance and sustain change in learners' conceptual understanding of complex content knowledge, researchers suggest four components: (a) use of cognitive scaffolds (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt., 1999; Novak, 2010; NRC, 2014b), (b) inclusion of collaboration (Cunningham & Carlsen, 2014; Custer & Daugherty, 2009; Daugherty, 2009; Katehi et al., 2009; NRC, 2000, 2014), (c) provisions for argumentation discourse (Duschl, Schweingruber, & Shouse, 2007; NRC, 2014; Osborne, 2010; Venville & Dawson, 2010; Zohar & Nemet, 2002), and (d) use of authentic assessment strategies (Ingec, 2009; Katehi et al., 2009; O. Kaya, 2008; Lopez et al., 2011). Thus, I included these four components in the framework and the EEEP workshop as an EOTPD was designed based on the MCL conceptual framework. Additionally, I proposed using concept maps as tools within each component of the MCL framework including an authentic assessment strategy to assess changes in science teachers' conceptual understanding of earthquake engineering.

Science teachers participated in a six-day long EOTPD that was designed based on the MCL framework components. Specifically, the EOTPD was designed to provide (a) better earthquake engineering content knowledge within new paradigms of teaching, learning, and assessment, (b) opportunities to deepen teacher knowledge and practice on earthquake engineering, (c) hands-on activities for collaboration, (d) integration of social, environmental, and other impacts of earthquake engineering design, (e) well-

defined engineering conceptual base, (f) credible instructors to deliver engineering content and pedagogy, and (g) authentic assessment methods to measure conceptual understanding of earthquake engineering. Results provided evidence that science teachers' conceptual understanding of earthquake engineering significantly increased as result of their participation in the EOTPD. Overall, results provided evidence that the EOTPD significantly increased science teachers' conceptual understanding of earthquake engineering content knowledge. As STEM teachers have been encouraged to participate in effective EOTPDs to increase their conceptual understanding of engineering content knowledge (Banilower et al., 2013; Daugherty, 2009; Nathan et al., 2011; NGSS, 2013; NRC, 2014b; Purzer et al., 2014; Wilson, 2011), the results in this study provide promising evidence that the EEEP teacher workshop as an EOTPD designed within crucial components of MCL conceptual framework, was useful for enhancing science teachers' conceptual understanding of engineering content knowledge. Science teachers with better understanding of engineering content knowledge as a result of effective EOTPDs may have sufficient level of confidence to implement the engineering content into their science classrooms.

Examination of Science Teachers' Argumentation Discourse in an Engineering-Oriented Teacher Professional Development

This third paper for this dissertation was an examination of changes in science teachers' argumentation discourse quality as a result of their participation to an EOTPD. As argumentation has become a critical component in today's learning environments, many science educators have focused on implementing argumentation into science

classrooms (Duschl & Osborne, 2002; Erduran, Simon, & Osborne, 2004; Jimenez-Alexandre & Erduran, 2008; E. Kaya, 2013; Simon, Erduran, & Osborne, 2006)

Additionally, national reports in science education (e.g., NRC, 2007) point to the need for students' participation in scientific practices and discourse, involvement in scientific discussions, and creation and evaluation of scientific explanations to understand the natural world. Stakeholders (i.e., policy makers, researchers, and educators) in science education, therefore, suggest students possessing sufficient levels of argumentation skills to actively participate in science learning processes are more likely to meet goals for proficiency in science.

Furthermore, recent calls have addressed the need of engineering integration into science classrooms. Stakeholders in science education, therefore, have encouraged science teachers to teach science content through integration of engineering content rather than focusing on specific science content areas (e.g., life science, chemistry, physics, and earth science). However, researchers reveal science teachers possess limited pedagogical skills in teaching engineering content (Banilower et al., 2013). Therefore, science teachers need opportunities to enhance their pedagogical skills (e.g., argumentation discourse; Passmore & Svoboda, 2012) for successful engineering integration in science classrooms. These opportunities may result in better understanding of complex and interdisciplinary engineering content knowledge and successful teaching of the engineering knowledge in their science classrooms (Cavlazoglu, 2015; Cavlazoglu & Stuessy, 2015a).

For this study, I implemented argumentation discourse into an EOTPD via distributed learning approach in the context of earthquake engineering to enhance science teachers argumentation discourse levels. Then, I examined changes in the levels of science teachers' argumentation discourse as a result of their participation in the EOTPD. In doing so, I examined teachers' argumentations in pre- and post-argumentation discourse activities. I modified a data collection method that used in the previous research for collecting data in monologic argumentation discourse as explained in Chapter V. Results support the conclusion that although the number of total argumentation statements by science teachers did not change significantly, their level of argumentation discourse did increase significantly. As science teachers have been encouraged to enhance their pedagogical skills in argumentation discourse to be able to improve their students' argumentation skills (Erduran et al., 2004; Osborne, Erduran, & Simon, 2004; Osborne, 2010; Zohar, 2007) for active participation in learning science with engineering integration (Katehi et al., 2009; NGSS, 2013; NRC, 2014b; Purzer et al., 2014), the results of this study provide promising evidence that the EOTPD was useful for enhancing science teachers' argumentation discourse levels in earthquake engineering context.

Final Summary and Recommendations

In my dissertation, I addressed three gaps that I found during my literature review on learners' conceptual understanding of complex and interdisciplinary content knowledge. To address these gaps, I (a) conducted a modified Delphi study to create a key concepts list as a knowledge base in earthquake engineering that can be used in

learning and teaching earthquake engineering at high school level (b) examined changes in science teachers' conceptual understanding of earthquake engineering as a result of their participation to an EOTPD and increased stakeholders' understanding of how learners acquire earthquake engineering knowledge in an EOTPD learning environment, and (c) investigated changes in science teachers' argumentation discourse quality as a result of their participation to an EOTPD in the context of earthquake engineering. In addition, as a part of my second paper I created a new conceptual framework, MCL, which describes critical components to improve learners' conceptual understanding of complex content knowledge.

Researchers in science education suggest identification of key concepts in critical engineering content areas for high school science teachers to increase their engineering content knowledge and confidently teach the engineering content in their classrooms. My first paper is one of the first studies identifying knowledge base in a critical engineering content area; therefore, more studies identifying knowledge bases in other critical engineering areas would be useful. Doing so may provide more opportunities to implement engineering in science as well as other STEM related classrooms. Therefore, I recommend stakeholders taking actions to conduct more studies for creating knowledge bases in other potential engineering areas at high school level.

Furthermore, stakeholders in STEM education and science education suggest providing opportunities for STEM teachers, especially for those traditionally prepared, to improve their conceptual understanding in critical engineering areas as research reports. In my second study, I observed traditionally prepared science teachers

broadened their expertise in earthquake engineering and enhanced their conceptual understanding of the earthquake engineering content knowledge to effectively teach the content to their students in science classrooms as well as other STEM classrooms. Thus, for both stakeholders in STEM education and science education, my second study is valuable because the context of study, EEEP teacher workshop as an EOTPD, aimed to meet needs indicated by the stakeholders by increasing STEM teachers' conceptual understanding of engineering content knowledge. The design of the EOTPD based on the conceptual framework (i.e., MCL) that I developed, was effective in enhancing teachers' conceptual understanding of engineering content; therefore, I recommend my framework to be implemented in other learning environments requiring understanding of complex and interdisciplinary knowledge.

Finally, stakeholders in science education emphasize the critical role of using argumentation discourse in teaching science and indicate most science teachers still lack of pedagogical skills in argumentation discourse. In my third study, I implemented argumentation discourse via distributed learning approach with a procedural guideline, used a modified method for data collection and analyses, found significant enhancement in teachers' argumentation discourse levels after the implementation. As previous research revealed science teachers need opportunities to improve their pedagogical skills in argumentation discourse within various contexts including engineering and researchers found even short immersions of argumentation discourse can improve quality of arguments, this study provided evidence that the workshop teachers' short immersion in the EEEP workshop resulted in significant improvement in the quality of

their arguments. This study was one of the first examinations of argumentation in engineering context; therefore, I recommend more examination of argumentation discourse in other engineering content areas.

REFERENCES

- Adler, M., & Ziglio, E. (Eds.). (1996). *Gazing into the oracle: The Delphi method and its application to social policy and public health*. London: Jessica Kingsley Publishers.
- American Association for the Advancement of Science. (2001). *Atlas of science literacy. Volume 1*. Washington, DC: Author.
- American Association for the Advancement of Science. (2007). *Atlas of science literacy. Volume 2*. Washington, DC: Author.
- American Association for the Advancement of Science. (2009). *Benchmarks for science literacy*. New York, NY: Oxford University Press.
- Ausubel, D. P. (1968). *Educational psychology: A cognitive view*. New York: Holt, Rinehart and Winston.
- Ausubel, D. P. (2000). *The acquisition and retention of knowledge: A cognitive view*. Dordrecht, Boston: Kluwer Academic Publishers.
- Banilower, E. R., Smith, P. S., Weiss, I. R., Malzahn, K. A., Campbell, K. M., & Weis, A. M. (2013). *Report of the 2012 national survey of science and mathematics education*. Chapel Hill, NC: Horizon Research, Inc.
- Bilgin, I., & Geban, O. (2006). The effect of cooperative learning approach based on conceptual change condition on students' understanding of chemical equilibrium concepts. *Journal of Science Education and Technology*, 15(1), 31-46.
doi:10.1007/s10956-006-0354-z

- Borg, W., Gall, J., & Gall, M. (2003). *Educational research: An introduction (7th ed.)*. Boston: Allyn and Bacon.
- Brown, A. L., Ash, D., Rutherford, M., Nakagawa, K., Gordon, A., & Campione, J. C. (2003). In Salomon, G. (eds.), *Distributed cognitions: Psychological and educational considerations*, pp. 188-228. New York, NY: Cambridge University Press.
- Cavlazoglu, B. (2015). *Meaningful conceptual learning in engineering-oriented teacher professional development: A conceptual framework*. Paper presented at the annual conference of National Association for Research in Science Teaching (NARST), Chicago, IL.
- Cavlazoglu, B., & Stuessy, C. (2013). *An investigation of STEM teachers' mental frameworks changes via concept maps*. Paper presented at the annual meeting of School Science and Mathematics Association (SSMA), San Antonio, TX.
- Cavlazoglu, B., & Stuessy, C. (2015a). *Becoming STEM teachers: Examining changes in science teachers' conceptual understanding about earthquake engineering*. Manuscript submitted for publication.
- Cavlazoglu, B., & Stuessy, C. (2015b). *Identifying and verifying earthquake engineering concepts to create a knowledge base in STEM education: A modified Delphi study*. Manuscript submitted for publication.
- Cavlazoglu, B., Akgun, O. E., & Stuessy, C. L. (2013). *An innovative use of concept mapping for improving and assessing STEM teachers' conceptual understanding*.

Paper Presented at the Annual Conference of Society for Information
Technology and Teacher Education (SITE), New Orleans, LA.

- Chinn, C. A., Duncan, R. G., Dianevesky, M., & Rinehart, R. (2013). Promoting conceptual change through inquiry. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (2nd ed., pp. 539-559). Florence, KY: Routledge.
- Cohen, E. G. (1994). Restructuring the classroom: Conditions for productive small groups. *Review of Educational Research*, 64(1), 1-35.
- Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches*. Thousand Oaks, CA: Sage Publications.
- Cunningham, C. M., & Carlsen, W. S. (2014). Teaching engineering practices. *Journal of Science Teacher Education*, 25, 197-210.
- Custer, R. L., & Daugherty, J. L. (2009). Professional development for teachers of engineering: Research and related activities. *The Bridge: Linking Engineering and Society*, 39(3), 18-24.
- Darmofal, D. L., Soderholm, D. H., & Brodeur, D. R. (2002). Using concept maps and concept questions to enhance conceptual understanding. *Proceedings of the 2002 American Society for Engineering Education Annual Conference and Exposition*. Montreal, Canada.
- Daugherty, J. L. (2009). Engineering professional development design for secondary school teachers: A multiple case study. *Journal of Technology Education*, 21(1), 10-24.

- Dawson, V., & Venville, G. J. (2009). High-school students' informal reasoning and argumentation about biotechnology: An indicator of scientific literacy? *International Journal of Science Education, 31*(11), 1421-1445.
- Delbeq, A., Van de Ven, A., & Gustafson, D. H. (1975). *Group techniques for program planning: A guide to nominal group and delphi processes*. Glenview: Scott, Foresman and Company.
- Dierking, L. D., Falk, J. H., Rennie, L., Anderson, D., & Ellenbogen, K. (2003). Policy statement of the "informal science education" ad hoc committee. *Journal of Research in Science Teaching, 40*(2), 108-111. doi:10.1002/tea.10066
- Duschl, R., Schweingruber, H., & Shouse, A. (Eds.). (2007). *Taking science to school: Learning and teaching science in grades K-8*. Washington, DC: The National Academies Press.
- Duschl, R. (2008). Science education in three-part harmony: Balancing conceptual, epistemic, and social learning goals. *Review of Research in Education, 32*(1), 268-291.
- Duschl, R., & Osborne, J. (2002). Supporting and promoting argumentation discourse in science education. *Studies in Science Education, 38*(1), 39-72.
doi:10.1080/03057260208560187
- Dyke, S., & Truman, K. Z. (2011). Earthquake engineering modules for K-12 learning. Retrieved from <https://nees.org/resources/927>

- Ellis, S., & Gauvain, M. (2013). Social and cultural influences on children's collaborative interactions. *Children's Development within Social Context*, 2, 155-180.
- Erduran, S., Simon, S., & Osborne, J. (2004). TAPping into argumentation: Developments in the application of Toulmin's argument pattern for studying science discourse. *Science Education*, 88(6), 915-933. doi:10.1002/sce.20012
- Gall, M., Borg, W., & Gall, J. (2003). Case study research. *Educational Research: An Introduction*, 123-163.
- Gilbert, J. K., Boulter, C. J., & Elmer, R. (2000). Positioning models in science education and in design and technology education. In J. K. Gilbert, & C. J. Boulter (Eds.), *Developing models in science education* (pp. 3-17). Norwell, MA: Kluwer Academic Publishers.
- Goldman, S. R., Petrosino, A. J., & Cognition and Technology Group at Vanderbilt. (1999). Design principles for instruction in content domains: Lessons from research on expertise and learning. In F. T. Durso, R. S. Nickerson, R. W. Schvaneveldt, S. T. Dumais, D. S. Lindsay & M. T. H. Chi (Eds.), *Handbook of applied cognition* (pp. 595-627). New York: Wiley.
- Good, T. L., & Brophy, J. E. (2008). *Looking in classrooms*. Boston: Pearson/Allyn and Bacon.
- Greene, B. A., Lubin, I. A., Slater, J. L., & Walden, S. E. (2013). Mapping changes in science teachers' content knowledge: Concept maps and authentic professional

- development. *Journal of Science Education and Technology*, 22(3), 287-299.
doi:10.1007/s10956-012-9393-9
- Gauvain, M. 2001. The social context of cognitive development. New York: Guilford.
- Herrenkohl, L. R., Palincsar, A. S., DeWater, L. S., & Kawasaki, K. (1999). Developing scientific communities in classrooms: A sociocognitive approach. *Journal of the Learning Sciences*, 8(3-4), 451-493.
- Ingec, S. K. (2008). Using concept maps as an assessment tool in physics education. *Hacettepe University Journal of Education*, 35, 195-206.
- Ingec, S. K. (2009). Analysing concept maps as an assessment tool in teaching physics and comparison with the achievement tests. *International Journal of Science Education*, 31(14), 1897-1915. doi:10.1080/09500690802275820
- Jimenez-Aleixandre, M. P., & Erduran, S. (2008). Argumentation in science education: An overview. In S. Erduran, & M. P. Jimenez-Aleixandre (Eds.), *Argumentation in science education: Perspectives from classroom-based research* (pp. 3-27). Dordrecht: Springer.
- Jonassen, D., & Easter, M. A. (2013). Model building for conceptual change. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (2nd ed., pp. 580-600). Florence, KY: Routledge.
- Katehi, L., Pearson, G., & Feder, M. (2009). The status and nature of K-12 engineering education in the united states. *The Bridge: Linking Engineering and Society*, 39(3), 5-10.

- Kaya, E. (2013). Argumentation practices in classroom: Pre-service teachers' conceptual understanding of chemical equilibrium. *International Journal of Science Education, 35*(7), 1139-1158.
- Kaya, O. (2008). A student-centered approach: Assessing the changes in prospective science teachers' conceptual understanding by concept mapping in a general chemistry laboratory. *Research in Science Education, 38*, 91-110.
doi:10.1007/s11165-007-9048-7
- Kwon, S. Y. (2006). *The comparative effect of individually-generated vs. collaboratively-generated computer-based concept mapping on science concept learning* (Doctoral dissertation). Retrieved from Texas A&M University Library.
- Lam, S. S., Petri, K. L., & Smith, A. E. (2000). Prediction and optimization of a ceramic casting process using a hierarchical hybrid system of neural networks and fuzzy logic. *Iie Transactions, 32*(1), 83-91.
- Lombard, M., Snyder-Duch, J., & Bracken, C. C. (2002). Content analysis in mass communication. *Human Communication Research, 28*(4), 587-604.
- Lopez, E., Kim, J., Nandagopal, K., Cardin, N., Shavelson, R. J., & Penn, J. H. (2011). Validating the use of concept-mapping as a diagnostic assessment tool in organic chemistry: Implications for teaching. *Chemistry Education Research and Practice, 12*, 133-141.
- Martínez, G., Pérez, Á L., Suero, M. I., & Pardo, P. J. (2013). The effectiveness of concept maps in teaching physics concepts applied to engineering education: Experimental comparison of the amount of learning achieved with and without

concept maps. *Journal of Science Education and Technology*, 22(2), 204-214.

doi:10.1007/s10956-012-9386-8

Miller, K. J., Koury, K. A., Fitzgerald, G. E., Hollingsead, C., Mitchem, K. J., Tsai, H.,

& Meeaeng, K. P. (2009). Concept mapping as a research tool to evaluate

conceptual change related to instructional methods. *Teacher Education and*

Special Education: The Journal of the Teacher Education Division of the Council

for Exceptional Children, 32(4), 365-378. doi:10.1177/0888406409346149

Miyake, N. (2013). Conceptual change through collaboration. In S. Vosniadou (Ed.),

International handbook of research on conceptual change (2nd ed., pp. 466-

483). Florence, KY: Routledge.

Nathan, M. J., Atwood, A. K., Prevost, A., Phelps, L. A., & Tran, N. A. (2011). How

professional development in project lead the way changes high school STEM

teachers' beliefs about engineering education. *Journal of Pre-College*

Engineering Education Research, 1(1), 15-17.

National Science and Technology Council. (2011). The federal science, technology,

engineering, and mathematics (STEM) education portfolio. Retrieved from

http://www.whitehouse.gov/sites/default/files/microsites/ostp/costem__federal_stem_education_portfolio_report.pdf

NGSS. (2013). NGSS release: Appendix A - conceptual shifts. Retrieved from

www.nextgenscience.org/next-generation-science-standards

- Novak, J. D. (2002). Meaningful learning: The essential factor for conceptual change in limited or inappropriate propositional hierarchies leading to empowerment of learners. *Science Education*, 86(4), 548-571. doi:10.1002/sce.10032
- Novak, J. D. (2010). *Learning, creating, and using knowledge: Concept maps as facilitative tools in schools and corporations*. New York, NY: Routledge.
- Novak, J. D., & Canas, A. J. (2008). The theory underlying concept maps and how to construct and use them. Retrieved from <http://cmap.ihmc.us/publications/researchpapers/theorycmaps/theoryunderlyingconceptmaps.htm>
- Novak, J. D., & Gowin, D. B. (1984). *Learning how to learn*. New York, NY: Cambridge University Press.
- National Research Council. (2000). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.
- National Research Council. (2007). *Taking science to school: Learning and teaching science in grades K–8*. Washington, DC: National Academy Press.
- National Research Council. (2011a). *Grand challenges in earthquake engineering research: A community workshop report*. Washington, DC: National Academy Press.
- National Research Council. (2011b). *Successful K-12 STEM education: Identifying effective approaches in science, technology, engineering, and mathematics*. Washington, DC: The National Academies Press.

- National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. Washington, DC: National Academy Press.
- National Research Council. (2014a). *Developing assessments for the next generation science standards*. Washington, DC: National Academy Press.
- National Research Council. (2014b). *STEM integration in K-12 education: Status, prospects, and an agenda for research*. Washington, DC: National Academy Press.
- Osborne, J., Ratcliffe, M., Collins, S., Millar, R., & Duschl, R. (2003). What ideas about science should be taught in school science? A delphi study of the "expert" community. *Journal of Research in Science Teaching*, 40(7), 692-720.
- Osborne, J., Erduran, S., & Simon, S. (2004). Enhancing the quality of argumentation in school science. *Journal of Research in Science Teaching*, 41(10), 994-1020.
- Osborne, J. (2010). Arguing to learn in science: The role of collaborative, critical discourse. *Science*, 328(5977), 463-466. doi:10.1126/science.1183944 [doi]
- Ozdemir, A. S. (2005). Analyzing concept maps as an assessment (evaluation) tool in teaching mathematics. *Journal of Social Sciences*, 1(3), 141-149.
- Piaget, J. 1952. *The origins of intelligence in children*. New York: Norton.
- Preszler, R. W. (2004). Cooperative concept mapping improves performance in biology. *Journal of College Science Teaching*, 33, 30-35.

- Purzer, S., Moore, T., Baker, D. & Berland, L. (2014). Supporting the implementation of the next generation science standards (NGSS) through research: Engineering. Retrieved from <https://narst.org/ngsspapers/engineering.cfm>
- Randolph, J. J. (2008). *Online Kappa Calculator* [Computer software]. Retrieved January 10, 2016, from <http://justus.randolph.name/kappa>
- Rossouw, A., Hacker, M., & de Vries, M. J. (2011). Concepts and contexts in engineering and technology education: An international and interdisciplinary delphi study. *International Journal of Technology and Design Education*, 21(4), 409-424
- Ruiz-Primo, M. A., Schultz, S. E., Li, M., & Shavelson, R. J. (2001). Comparison of the reliability and validity of scores from two concept-mapping techniques. *Journal of Research in Science Teaching*, 38(2), 260-278.
- Sadler, T. D., & Fowler, S. R. (2006). A threshold model of content knowledge transfer for socioscientific argumentation. *Science Education*, 90(6), 986-1004.
- Siler, S., Klahr, D., & Matlen, B. (2013). Conceptual change when learning experimental design. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (2nd ed., pp. 138-158). Florence, KY, USA: Routledge.
- Simon, S., Erduran, S., & Osborne, J. (2006). Learning to teach argumentation: Research and development in the science classroom. *International Journal of Science Education*, 28(2-3), 235-260. doi:10.1080/09500690500336957
- Skulmoski, G. J., Hartman, F. T., & Krahn, J. (2007). The delphi method for graduate research. *Journal of Information Technology Education*, 6, 1-21.

- Toulmin, S. E. (1958). *The uses of argument*. Cambridge, UK: Cambridge University Press.
- Toulmin, S. E. (2003). *The uses of argument (updated ed.)*. Cambridge, UK: Cambridge University Press.
- Venville, G. J., & Dawson, V. M. (2010). The impact of a classroom intervention on grade 10 students' argumentation skills, informal reasoning, and conceptual understanding of science. *Journal of Research in Science Teaching*, 47(8), 952-977.
- Von Aufschnaiter, C., Erduran, S., Osborne, J., & Simon, S. (2008). Arguing to learn and learning to argue: Case studies of how students' argumentation relates to their scientific knowledge. *Journal of Research in Science Teaching*, 45(1), 101-131.
- Vosniadou, S. (2013a). Conceptual change in learning and instruction: The framework theory approach. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (2nd ed., pp. 11-30). Florence, KY: USA: Routledge.
- Vosniadou, S. (2013b). *International handbook of research on conceptual change*. Hoboken, NJ: Taylor & Francis.
- Vygotsky, L. S. (1978). In Cole M., John-Steiner V., Scribner S. and Souberman E. (Eds.), *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

- Walshe, N. (2007). Understanding teachers' conceptualisations of geography. *International Research in Geographical and Environmental Education, 16*(2), 97-119. doi:10.2167/irgee212.0
- Wicklein, R. G., Smith, P. C., & Kim, S. J. (2009). Essential concepts of an engineering design curriculum in secondary technology education. *Journal of Technology Education, 20*(2), 65-80.
- Wilson, S. M. (2011). *Effective STEM teacher preparation, induction, and professional development*. Paper presented at the National Research Council Workshop on Successful STEM Education in K-12 Schools, Washington, DC.
- Wooten, K., Rayfield, J., & Moore, L. L. (2013). Identifying STEM concepts associated with junior livestock projects. *Journal of Agricultural Education, 54*(4), 31-44.
- Zohar, A. (2007). Science teacher education and professional development in argumentation. In S. Erduran, & M. P. Jimenez-Aleixandre (Eds.), *Argumentation in science education* (pp. 245-268). New York, NY: Springer.
- Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching, 39*(1), 35-62.

APPENDIX

EEEP WORKSHOP ACTIVITY

1. Constructing Concept Maps (Individual)

In this part, you will construct an individual concept map about your understanding of earthquake engineering. You have a list of earthquake engineering concepts and hands-on materials such as large papers, post-it notes in different colors and sizes, markers to construct your concept map. In this first part, you have three steps to complete in 30 minutes.

Step 1: Getting ready. Please write your name on the top right corner of your large paper in to identify your concept map. You may use large papers and post-it notes for your concept map. Please use yellow stickers for the concepts that you use from earthquake engineering concepts list and any other different color for your own concepts that you think essential for your concept map.

Step 2: Selecting your concepts. Think about some essential concepts that are critical to know for understanding earthquake engineering and use as much as possible number of concepts for your concept map. These concepts may be from the earthquake engineering concepts list or your own, or both. The concept list we gave you has some essential concepts we feel important. However, you are free to choose any concepts that you think essential to show your understanding of earthquake engineering in your concept map.

Step 3: Construct your concept map. Please write down your selected concepts on post-it notes. Then, organize the post-it notes anyway you want on your large paper.

Draw lines between the stickers you think that you have a connection one with another and write a word/words along with the line. In other words, with a marker, draw connections between the concepts you think connect and write a word or phrase on the line.

2. Individual Argumentation Discourse (In groups)

In the second part of the activity, you will be divided into groups for your monologic argumentation discourse about following question: How would you argue/defend your understanding of earthquake engineering? Please explain why we need to know the concepts you indicated in your concept map in learning earthquake engineering at high school level.

Each group member needs to argue/defend her/his understanding of earthquake engineering to your group and other member/s should listen to your argumentation discourse with no interaction during the monologic discourse. You have around 40 minutes to finish this second part.

3. Group Discourse and Group Concept Mapping (In groups)

In this part, as a group you will have an interactive group discourse about your concept maps and construct a group concept map. Please follow two steps below and finish this part in 40 minutes.

Step 1: Discuss your concept map. Have a conversation about your earthquake engineering concept maps and discuss similarities, differences, and other ideas you thought were important about earthquake engineering with your group members. (10 minutes)

Step 2: Constructing group map. Construct a concept map with your group members. As you did for your individual concept map, use maximum number of concepts as much as you can to construct your group concept map. Please make your decisions for any concepts and connections with your group members. You may use any part of your first concept map for your group concept map, including selected concepts from the concepts list, your own concepts, and connection words you used in your individual concept map. Try to agree on what to use and how to connect them in your groups (30 minutes)

4. Earthquake Engineering Discussion (In groups)

Discuss the following questions by giving each group member an opportunity to speak (30 minutes)

- 1) What do you think earthquake engineers do?
- 2) What are your ideas about the best way for your students to learn about earthquake engineering in your classroom?
- 3) What are some of good reasons to use earthquake engineering to incorporate the engineering part into a STEM (Science, Technology, Engineering, and Mathematics) lesson for your students?
- 4) What connections do you see between earthquake engineering education and each STEM (Science, Technology, Engineering, and Mathematics) domain?

*If you have any questions, please do not hesitate to ask the EEEP research team.