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

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Abstract

Stakeholders in STEM education have called for integrating engineering content knowledge into STEM-content classrooms. To answer the call, stakeholders in science education announced a new framework, Next Generation Science Standards, which focuses on the integration of science and engineering in K-12 science education. 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. In this regard, researchers have suggested that new integrated STEM curricula should contain a list of key concepts for understanding the specific engineering content area. 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, we identified and verified key concepts in earthquake engineering necessary for high school learners to acquire a basic understanding of earthquake engineering. As a result, we created a key concepts list and strand map with 35 key earthquake-engineering concepts. High school science teachers as well as other teachers in STEM content areas can use these key concepts to understand and teach earthquake engineering content in their classrooms.

Introduction

Science, Technology, Engineering, and Mathematics (STEM) education in the last two decades has been a critical focus for stakeholders in public education (Erdogan & Stuessy, 2015a, 2015b; Lopez et al., 2011; Nathan, Atwood, Prevost, Phelps, & Tran, 2011; Navruz, Erdogan, Bicer, Capraro, & Capraro, 2014; 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., Next Generation Science Standards [NGSS], 2013; National Research Council [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.

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* (Common Core State Standards Initiative, 2011) announced the need for integrating mathematics with science and engineering. Similarly, the International Technology and Engineering Educators Association stressed the necessity of understanding connections across science, technology, engineering, and mathematics (International Technology Education Association, 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)

Table 1. The three dimensions of the NGSS framework

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

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 (Table 1). 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 (Cavlazoglu & Stuessy, 2016; 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.

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 Table 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 content has the potential to improve the literacy level of citizens about earthquake resilience (NRC, 2011b). 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 (Cavlazoglu & Stuessy, 2016). 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, we 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.

Method

Type of Research Design

In this study, we used a modified Delphi research design (Skulmoski, Hartman, & Krahn, 2007; see Figure 1). 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 et al., 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, we 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 our 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 1 displays the two phases of the modified Delphi study we 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. We used a one-round Delphi study via an online questionnaire to verify key concepts from the original list.

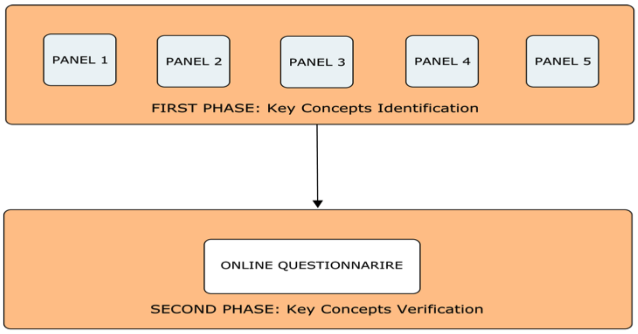

Figure 1. Modified Delphi research design used in this study

Participants

The participants in the two phases of the study were nine experts in earthquake engineering education research. We 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-12science 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, we 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, we again used descriptive statistics to report the results of respondents' ratings, including means, medians, and modes for each concept. For this phase, we established a criterion level of 80% consensus as suggested by related Delphi study literature (e.g., 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 were asked, "What are the important documents we 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 2).

Table 2. 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 their 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 2), 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 were asked, “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 2) 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), decided to continue to identify any remaining key concepts, and scheduled the fourth panel meeting one month later.

Table 3. 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 4).

Table 4. Final version of identified key concepts list in panel 5

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, six earthquake-engineering experts were asked to verify the identified 37 concepts by indicating their level of agreement on each concept. An online questionnaire was sent to the experts via email, which was completed in three weeks.

Table 5. 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
	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
Earth Systems	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 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: Physical Systems (six concepts); Designed Systems (eleven concepts); Social Systems (eight concepts); Earth Systems (five concepts), and STEM Proficiencies (seven concepts). Each of the six experts indicated their level of agreement for each concept to complete the verification process. Participant responses to the online questionnaire were analyzed and results for each concept are shown in Table 5.

In Table 5, 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.

The concept verification process resulted in 35 concepts verified by six experts. These 35 concepts reached 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 of 4.00 (i.e., $M_{oversight}$ =3.67 and $M_{theorizing}$=3.33). These concepts were dropped from the final key concepts list to yield a final list of 35 identified and verified concepts. Table 6 lists the 35 concepts considered essential for high school learners to understand earthquake engineering.

Table 6. 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, we created a strand map (see Figure 2) 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. Our 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.

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; Cavlazoglu & Stuessy, 2016). The purpose of 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 as a human activity integrating content and procedural knowledge, expressed as "content domains." In a two-stage process, (1) three researchers in earthquake engineering education identified

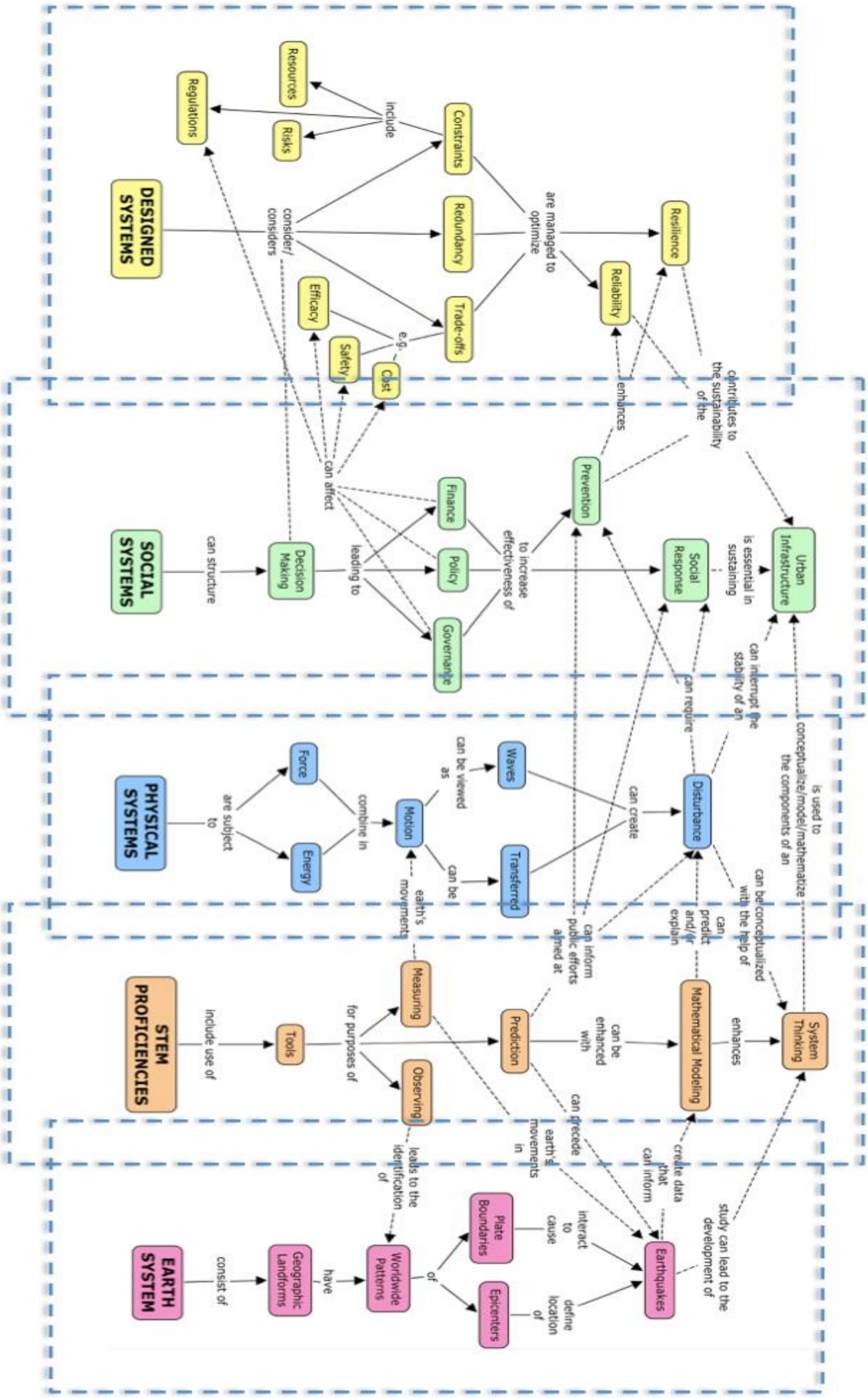

Figure 2. Strand-map linking concepts identified within the five domain areas (i.e., “strands”) of earthquake engineering

37 key concepts in five domains with 100% consensus, and (2) six experts in science education and civil engineering with research interests and expertise in earthquake engineering verified 35 of these concepts with at least 80% consensus. A key concepts list and strand map with 35 earthquake engineering key concepts were created to support high school 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, it is crucial to identify key concepts in critical 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 (Cavlazoglu, 2015; Cavlazoglu & Stuessy, 2016; 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 content can increase students' literacy level about earthquake resilience. Stakeholders in earthquake engineering research (e.g., NRC, 2011a, 2011b) identified the need to focus on social systems and designed systems domains in teaching and learning earthquake engineering to improve citizens' literacy level about earthquake resilience. Identified social and designed systems key concepts in this modified Delphi study, therefore, can be useful to develop a better understanding of these two earthquake engineering domains and result in achieving an earthquake-resilient society.

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