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Recent reports at the state, national, and international level have called for increased earthquake and tsunami education to increase knowledge of the causes of these hazards, risks from these hazards, and preparedness measures to reduce risk and increase resilience to these hazards. One recommended approach to meet this need is to integrate earthquake and tsunami education into instruction in the K-12 school system. However, there is also a need for a strong theoretical basis for what constitutes effective earthquake and tsunami education. The current study contributes to this theoretical basis by examining middle school students' knowledge and beliefs of earthquake and tsunami through the lens of conceptual change theory. Using the lens of conceptual change theory, students' science knowledge, preparedness knowledge, epistemic beliefs, and ontological beliefs of earthquake and tsunami were examined using multiple data collection instruments that required multiple response modes including textual, graphical, and verbal responses. Several prominent patterns and themes were identified in the students' responses that can inform the content and pedagogy of earthquake and tsunami education. Study results indicate that conceptual change theory is a valuable lens for examining students' knowledge and beliefs of earthquake and tsunami awareness and preparedness and has potential for examining students' knowledge and beliefs of other important socioscientific issues.

Examining Middle School Students' Knowledge and Beliefs of Earthquake and Tsunami

by
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I understand that my dissertation will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my dissertation to any reader upon request.

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Douglas S. Lownsbery, Author

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Chapter 1: Introduction

Problem Statement

The problem addressed in this study can be concisely stated as the need for increased earthquake and tsunami education in the United States in order to reduce risk and increase resilience to these potentially destructive natural disasters. To meet that larger need, there is an underlying need for a strong theoretical basis for what constitutes effective earthquake and tsunami education. This study contributes to that underlying need by examining middle-school students' knowledge and beliefs about earthquake and tsunami through the lens of conceptual change theory.

The methods and results of this study have implications for further developing a strong theoretical basis for effective earthquake and tsunami education in support of the many educators and researchers across disciplines who are dedicated to this important work not only in the United States, but around the world. While this study was situated in the Pacific Northwest, earthquake and tsunami educators and researchers in the United States are keenly aware that awareness and preparedness for these natural hazards are important concerns in many countries of the world, particularly those along the Pacific Rim of Fire, and that we have much to share with, and learn from, each other. The theory, methods, and results of this study can also inform improving the preparedness and resiliency for natural disasters in general including, but not limited to, floods, hurricanes, tornadoes, and landslides.

The need for increased, effective earthquake and tsunami education is of particular importance to residents and visitors in the Pacific Northwest of the United States in the region known as the Cascadia Subduction Zone because the region is subject to three types of tectonic earthquakes including (1) magnitude 8.0 to 9.0+ megathrust subduction earthquakes that may also generate destructive tsunamis, (2) magnitude 6.5 to 7.0 deep earthquakes, and (3) shallow crustal-fault earthquakes with magnitudes up to 7.5 (Butler, in press). Since earthquakes and tsunamis are unpredictable and occur suddenly, advance awareness and preparedness is the only way to reduce damage and loss of life, and education is a key factor in increasing awareness and preparedness (Dengler, 2005; Shaw, Shiwaku, Kobayashi & Kobayashi, 2004).

Natural hazards education in the United States has typically been framed in terms of public information campaigns (e.g., media outreach, community information dissemination, government-sponsored emergency preparedness training) (National Oceanic and Atmospheric Administration, 2013; National Research Council, 2011). What is often missing in these public information campaigns is a strong theoretical basis for the content and pedagogy of earthquake and tsunami education (Johnson, Ronan, Johnson & Peace, 2014).

In the absence of a strong theoretical basis, what is often operationalized is increased dissemination of information about earthquake and tsunami hazard and information about preparedness actions (National Oceanic and Atmospheric Administration, 2013; National Research Council, 2011). The implicit premise is that increased information will lead to increased knowledge, and increased knowledge will lead to increased preparedness actions. However, limited empirical studies of the effectiveness of public education efforts do not support this premise (Johnson, et al., 2014; Johnston et al., 2005). A strong theoretical basis has the potential to inform both the content and the pedagogy of earthquake and tsunami education. This study was designed to contribute to theory with implications for improved practice.

A component typically missing in natural hazards education efforts is an integration of disaster preparedness knowledge and practice with relevant science instruction in the K-12 school system (National Acadamies Press, 2011). Natural hazards education efforts focus primarily on preparedness knowledge, with the geoscience knowledge of the causes and effects of natural hazards as supporting information to substantiate the need for the preparedness measures that respond to the hazard. Earth science education in the K-12 school system focuses primarily on the geoscience knowledge of the causes of natural hazards. Preparedness measures tend to be minimally addressed, particularly the specific preparedness measures that are relative to local hazards.

Several studies, including those by Johnson, Ronan, Johnston, & Peace (2014); Katada and Kanai (2008); Ronan, Crellin, and Johnston (2010); and Shaw, Shiwaku, Kobayashi, & Kobayashi (2004) have examined earthquake and tsunami disaster awareness and preparedness education programs in the K-12 school system. While these studies show only moderate results as to the effectiveness of various programs, they do indicate the potential of integrating preparedness instruction into instruction in the K-12 school system as recommended in the *Hyogo Framework for Action 2005-2016: Building the Resilience of Nations and Communities to Disasters* report from the 2005 World Conference on Disaster Reduction (United Nations Office for Disaster Reduction, 2005).

My review of the literature for natural hazards education efforts, including those integrated into geoscience instruction in the K-12 school system, led me to consider what theoretical frameworks from science education may be applicable to earthquake and tsunami education to address the need for a strong theoretical foundation. That line of inquiry ultimately led me to conceptual change theory as the theoretical framework for this study.

Theoretical Framework

This study examines students' descriptions of earthquake and tsunami through the lens of conceptual change theory. Conceptual change theory is not a single unified theory, but rather can be viewed as a set of three related constructs—the learner's knowledge schema, the learner's epistemic beliefs, and the learner's ontological beliefs. Conceptual change theory seeks to explain the nature of learners' conceptions, how learners' conceptions change over time, how learners' represent their conceptions, and how instruction can promote change from more simplistic, naïve conceptions to more complex, scientifically-accepted conceptions (Brown, 2014; Chi, 2005; Chi, 2008; Chi, Slotta, & de Leeuw, 1994; Duit & Treagust, 2003; Hofer, 2001; Hofer & Pintrich, 1997; Sinatra, Kienhues, & Hofer, 2014; Vosniadou, 1994; Vosniadou & Skopeliti, 2014; Vosniadou & Brewer, 1992).

As applied in this study to students' descriptions of earthquake and tsunami, the three related constructs of conceptual change theory can contribute to the growing body of disaster education literature by examining students' conceptions of earthquakes and tsunamis as geoscience phenomena (*science knowledge*) and students' conceptions of preparedness to reduce risk of harm and damage (*preparedness knowledge*). As has been demonstrated extensively in the conceptual change literature, students often have conceptions that are not in harmony with accepted expert knowledge. Student conceptions are often highly resistant to change even after instruction and some conceptions are often prevalent among students (i.e., different students hold similar conceptions) (Duit, 2008). Examining students' science knowledge and preparedness knowledge has the potential to begin to explain why some conceptions and beliefs are prevalent and resistant to change and to inform the content and methods of instruction that promote increased earthquake and tsunami science and preparedness knowledge (Chi, Roscoe, Slotta, Roy, & Chase, 2012; Slotta & Chi, 2006; Vosniadou & Mason, 2012; Vosniadou, Ioannides, Dimitriakopoulou, & Papademetriou, 2001).

In this study, *science knowledge* of earthquake and tsunami refers to a student's knowledge of the geophysical causes and effects of earthquake and tsunami phenomena (e.g., types of tectonic plate boundaries, types of earthquakes, ground shaking, liquefaction, landslides, and inundation). As examined in this study, a student's science knowledge comprises multiple dimensions including scientifically-accepted conceptual understandings, synthetic conceptions that assimilate some scientifically-accepted knowledge into existing preconceptions, and naïve conceptions based on actual or vicarious phenomenological and sociocultural experiences.

Preparedness knowledge for earthquake and tsunami refers to a student's knowledge of the potential effects of earthquakes and tsunamis on human health and safety and the built environment and knowledge of the ways people can mitigate those effects by taking preparedness actions prior to, during, and after occurrences of earthquake and tsunami. As with science knowledge, a student's preparedness knowledge comprises multiple dimensions including preparedness understandings endorsed by natural hazard preparedness professionals, synthetic conceptions that assimilate some accepted preparedness knowledge into existing preconceptions, and naïve conceptions based on actual or vicarious phenomenological and sociocultural experiences.

Epistemic beliefs about earthquake and tsunami refer to the nature of a student's knowledge of earthquake and tsunami. In a seminal study, Hofer and Pintrich (1997) conducted a comprehensive review and synthesis of theoretical and empirical research on personal epistemologies and identified four distinct, but interrelated, dimensions of epistemic beliefs:

certainty of knowledge, simplicity of knowledge, sources of knowledge, and evidence for knowledge. These four dimensions of epistemic belief are operationalized in this study for the purpose of gathering data.

Ontological beliefs about earthquake and tsunami refer to student's beliefs about the essential nature of earthquake and tsunami natural phenomena and the nature of preparedness. Based on seminal work done by Chi and colleagues (Chi, Slotta, & de Leeuw, 1994; Slotta, Chi, & Joram, 1995), the primary dimensions of ontological beliefs are classifications of phenomena as either entities/things or processes. In further refinement of the construct, Chi (2005) and Slotta and Chi (2006), make a distinction between two fundamentally different types of processes: phenomena as direct processes or as emergent processes. For example, a conception of tsunami as a giant wave that just happens unexpectedly with no causal agent would be a *thing*. The conception that widespread destruction of a coastal community would be the inevitable result of a tsunami that was caused by an earthquake in the ocean would be an example of a *direct process*. A conception of tsunami that the effect on a community would be based on the magnitude of the earthquake that caused the tsunami, the time it took for the tsunami to reach the community, the inundation depth in different locations in the community, the types of structures in the community that resisted destruction, and the evacuation efforts that residents made before inundation would be an example of an *emergent process*. These distinct dimensions of ontological beliefs (things, direct processes, and emergent processes) are operationalized in this study for the purpose of gathering data.

Table 1 shows the three theoretical constructs and associated dimensions that were initially examined in this study. The Literature Review section of this paper describes the historical development of these constructs and their application to earthquake and tsunami awareness and preparedness education. The Methods section of this paper describes how these constructs and dimensions were operationalized *a priori* for data collection and analysis. The Results section describes how certain dimensions were modified based on inductive analysis of the responses from the students.

Table 1

Theoretical Constructs and Dimensions

Construct	Dimension			
Science knowledge	Naïve ideas	Synthetic conceptions	Scientifically accepted understandings	
Preparedness knowledge	Naïve ideas	Synthetic conceptions	Accepted preparedness understandings	
Epistemic beliefs	Certainty	Simplicity	Source	Evidence
Ontological beliefs	Thing	Direct process	Emergent process	

Study Purpose and Research Questions

The purpose of this study is to examine in detail a small group of middle-school students' textual, graphical, and oral descriptions of their knowledge and beliefs about earthquake and tsunami, and, from those descriptions, to infer the students' science and preparedness knowledge and epistemic and ontological beliefs. Based on conceptual change theory, the students' prior science and preparedness knowledge and their epistemic and ontological beliefs profoundly influence how they will assimilate and accommodate new information about earthquakes and tsunamis (Mason, 2007). To accomplish the intended purpose, this study addresses the following research questions:

1. How do middle school students who live in a region affected by earthquake and tsunami describe their knowledge and beliefs about earthquake and tsunami?
2. What science knowledge of earthquake and tsunami can be inferred from the students' descriptions?
3. What preparedness knowledge for earthquake and tsunami can be inferred from the students' descriptions?
4. What epistemic beliefs about earthquake and tsunami can be inferred from the students' descriptions?
5. What ontological beliefs about earthquake and tsunami can be inferred from the students' descriptions?

Researcher Perspective

As the primary researcher for this study (instrument for observation, data collection, and analysis), a brief description of the factors that led me to this particular study is warranted. As a former middle-school science teacher and then as a science curriculum and assessment developer in a variety of media including print-based, online, and interactive simulations, I became increasingly interested in relevant applications of science concepts and practices to students' lives to promote both interest and scientific literacy for all students. One strand of science education reform seeks to contextualize science learning in relevant socioscientific issues that require students to engage in decision-making and problem-solving (Sadler, Barab & Scott, 2007; Zeidler & Nichols, 2009). Earthquakes and tsunamis are profoundly important socioscientific issues that involve not only science concepts, but also a spectrum of sociocultural factors. I came to realize that earthquake and tsunami education is not only highly relevant, but also personally useful for students outside the classroom, especially those who live in the Cascadia Subduction Zone.

I am also a resident in the Cascadia Subduction Zone having moved in 2004 from the central coast of California to Oregon's capital city, Salem, in the Willamette Valley. Our residence in California was approximately 13 miles from the San Andreas Fault and approximately 30 miles from the epicenter of the 1989 Loma Prieta earthquake (magnitude 6.9) that shook the Monterey Bay and San Francisco region and caused 63 fatalities, more than 3,757 injuries, and estimated damage and losses of $5.9 billion (USGS, 1994). At the time we moved to Oregon, I was under the naïve impression that we were leaving earthquake country behind.

One of the reasons I find conceptual change theory so compelling in relationship to earthquake and tsunami education is the conceptual change that I have experienced, and continue to experience, in both my science knowledge and preparedness knowledge. One of the criticisms of conceptual change theory is that research tends to focus on cognitive processes and mental schema without sufficient recognition of the situated, sociocultural nature of learning (Greeno, Collins, & Resnick, 1996). However, effective earthquake and tsunami preparedness is inherently enacted as situated behavior in both the sociocultural and the physical environments. For me and my family, and for many others I have observed, both conceptual change and behavioral change needed to occur as we learned more about the nature of the hazard, the potential risks, and the actions we could take to minimize those risks.

This study uses constructs of conceptual change theory to examine students' knowledge and beliefs of earthquake and tsunami at a specific point in time. Conceptual change literature has documented the prevalence of robust preconceptions of science concepts and that many of these preconceptions are highly resistant to change (Duit, 2008). This study sought to make visible and examine in depth students' preconceptions about earthquake and tsunami prior to a classroom unit of instruction. As such, the study sought to examine the prevalence of robust preconceptions but did not examine the change, or resistance to change, of those preconceptions over time during or after instruction. An entirely different study design would have been necessary to examine the degree of change over time due to instruction.

Although this study examines students' preparedness knowledge for earthquake and tsunami, it does not examine students' actual preparedness actions. An entirely different theoretical framework and study design would have been necessary to examine the students' preparedness actions that may have included factors such as their family situation, family roles and responsibilities, access to resources, and community support systems.

The study was conducted over a period of four weeks with twelve participating middle-school students in a single classroom in a small rural public charter school in the central coast region of Oregon. As a qualitative research study examining in detail the earthquake and tsunami knowledge and beliefs of a small number of students in a specific location at a specific period of time, I do not make any claims as to the generalization of the results of the study. However, this limitation, and the others described here, does not diminish the overall potential significance of the study to build theory and to inform methods of study and suggest educational practice.

Study Significance

There are several potential significant aspects to this study. The first is that this study is unique in examining students' knowledge and students' epistemic and ontological beliefs in equal measure in the same study. Conceptual change researchers have typically focused on just one of these three constructs as the central topic of study even though the other two constructs may be acknowledged or referenced (Chi, Roscoe, Slotta, Roy, & Chase, 2012; Slotta & Chi, 2006; Vosniadou, 1994).

Secondly, this study examines two distinct, though potentially highly related, knowledge constructs in equal measure in the same study—*science knowledge* of earthquakes and tsunamis and *preparedness knowledge* for earthquakes and tsunamis. While the science knowledge focuses primarily on concepts and cause/effect relationships in geoscience phenomena, the preparedness knowledge focuses primarily on human behaviors (i.e., what to do and how to do it) and why to do it. By examining both domains of knowledge within subjects coupled with their epistemic and ontological beliefs, I am better able to describe the larger picture of how the **relevance** of earthquake and tsunami education relates to the **usefulness** of preparedness in students' lives.

A third significance of this study is the application of the conceptual change theory constructs of knowledge, epistemic beliefs, and ontological beliefs to the highly complex socioscientific issue of earthquake and tsunami awareness and preparedness. Empirical studies in the conceptual change literature over the last several decades have tended to focus on relatively specific knowledge domains (e.g., shape of the Earth, planetary motion, day/night cycle, plate tectonic movement, seasons, diffusion, heat transfer, electrical current, circulatory system) (see Duit, 2008, for a review of relevant literature). In contrast, this study demonstrates viable methods for gathering and analyzing data to infer students' knowledge and epistemic and ontological beliefs relative to a complex socioscientific domain. To accomplish this, I created protocols using multiple modes of response (textual, graphical, and oral) used in this study to externalize student thinking. I operationalized key concepts used in the protocols to analyze the students' responses to infer their internal knowledge and beliefs. These methodical elements can inform future research in this area as well as student learning of other complex socioscientific issues such as climate change, immunization practices, use of genetically modified organisms, antibiotic resistance of bacteria, and biological evolution to name a few.

A final potential significance of this study relates to the situative nature of the study. This study, consistent with most research in science education on conceptual change, is situated in a sociocultural constructivist perspective of teaching and learning (Mason, 2007). As a social science researcher, I believe that sociocultural factors profoundly influence students' earthquake and tsunami science and preparedness knowledge and epistemic and ontological beliefs. The sociocultural influences identified in this study can inform future studies that examine those influences in detail to further address the initial problem statement of the need for increased earthquake and tsunami education to reduce risk and increase resilience to these potentially destructive natural disasters.

Definitions

In the context of this study, *hazard* refers to the geophysical characteristics of earthquake or tsunami (e.g., magnitude, intensity, inundation depth, and run-up height). *Risk* refers to the potential of incurring injury or damage caused by earthquake or tsunami hazard. *Resilience* refers to the capacity of individuals and communities to resist injury or damage and to recover to an acceptable level of functioning following earthquake or tsunami. *Preparedness* refers to actions prior to, during, and after an earthquake or tsunami that minimize risk and increase resilience. *Mitigation* refers to preparedness actions that reduce the injury or damage caused by earthquake and tsunami.

Chapter 2: Literature Review

Need for Increased Earthquake and Tsunami Education

Recent reports at the national level (National Research Council, 2011; National Oceanic and Atmospheric Administration, 2013) and at the state level (Oregon Seismic Safety Seismic Policy Advisory Commission, 2013) call for increased earthquake and tsunami education. The 2013 *National Tsunami Hazard Mitigation Program 2013 - 2017 Strategic Plan* (NOAA, 2013) emphasizes the role of public education to increase knowledge of tsunami hazard, risk, and preparedness actions with the goal of developing tsunami-resilient communities with adaptive capacity to maintain important community functions and recover quickly from tsunami hazard. The National Tsunami Hazard Mitigation Program (NTHMP) was established by the U.S. Congress in 1996. According to the NTHMP, a tsunami-resilient community has the following characteristics: (a) understands the nature of the tsunami hazard; (b) has the necessary tools to mitigate the tsunami risk; (c) disseminates information about the tsunami hazard; (d) exchanges information with other at-risk areas; and (e) institutionalizes planning for a tsunami disaster (Dengler, 2005). As seen in this list, understanding the nature of tsunami hazard and the dissemination of tsunami hazard information are important characteristics of community resilience.

The National Earthquake Hazards Reduction Program (NEHRP) was established in 1977 by the U.S. Congress to reduce the risk to life and property from earthquakes through effective hazards reduction programs. As with the NTHMP for tsunami, one of the key objectives in the NEHRP 2009-2013 Strategic Plan (FEMA, 2008) is to increase public awareness of earthquake hazard and risk through a variety of educational outreach programs.

Reports issued by the National Academies Press of the National Research Council—*National Earthquake Resilience: Research, Implementation, and Outreach* (2011), and *Tsunami Warning and Preparedness: An Assessment of the U.S. Tsunami Program and the Nation's Preparedness* (2011) emphasize the need for both increased and improved education efforts to reduce risk and increase preparedness for individuals and communities. At the state level, *The Oregon Resilience Plan: Reducing Risk and Improving Recovery for the Next Cascadia Earthquake and Tsunami* (Oregon Seismic Safety Policy Advisory Commission, 2013) and the Washington State report *Resilient Washington State: A Framework for Minimizing Loss and Improving State Recovery after an Earthquake* (Seismic Safety Committee of the Washington State Emergency Management Council, 2012) emphasize the need for ongoing education to bring about a cultural shift in preparing citizens and visitors for a Cascadia Subduction Zone earthquake and tsunami. Educational materials, activities, and programs about earthquake and tsunami hazards, risks, and preparedness actions are essential for creating communities that are both earthquake-resilient and tsunami-resilient in coastal regions affected by these natural hazards.

The issue of earthquake and tsunami awareness and preparedness is of immense importance to residents and visitors in the Pacific Northwest. Scientific understandings of the imminent threat of a massive earthquake and resulting tsunami along the Cascadia Subduction Zone (CSZ) off the coast of Oregon are abundant and clear. However, these understandings are also relatively recent, with both theory and evidence having being largely developed within the last 30 years (Atwater, 1987; Atwater & Yamagouchi, 1991; Goldfinger, Ikeda, Yeats, & Ren, 2012). Since 1990, scientists have uncovered geologic evidence for as many as 40 megathrust earthquakes (magnitude 8.0 and greater) that have occurred over the last 10,000 years in the CSZ (Goldfinger, et al., 2012).

The CSZ extends approximately 600 miles from Northern California to southern British Columbia. The CSZ originates offshore at the convergent boundary where the eastward moving Juan de Fuca tectonic plate subducts under the westward moving North American plate. From this convergent boundary, the CSZ extends east to the arc of volcanoes in the Cascade Mountains extending from Mt. Lassen in Northern California to Mt. Garibaldi in British Columbia. Figure 1 shows the geographic profile of the CSZ and the different types of tectonic plate boundary movement in the region.

The rate of subduction of the Juan de Fuca plate under the North American plate is not constant. For extended periods of time, often hundreds of years, the two plates are firmly stuck together, causing the leading edge of the North American plate to bulge up from pressure. Eventually, the stuck area can no longer resist the pressure and ruptures along the subduction boundary. Earthquakes ranging in size from magnitude 8.0 to over 9.0 have occurred, on average, every 250 years along portions of the CSZ. The largest of these earthquakes, the magnitude 9.0 + earthquakes, which rupture along the entire subduction zone, have occurred approximately every 500 to 550 years (Geist, 2005; Goldfinger, Ikeda, Yeats, & Ren, 2012).

The last CSZ megathrust earthquake and resulting tsunami occurred in the year 1700, so coastal Oregon communities are clearly in the window of time where the potential of a near-field, or local, tsunami originating offshore is eminent. The first tsunami wave may reach the coast in Northern California, Oregon, and Washington in as little as 10-30 minutes with heights of 10-35 m above sea level. A local tsunami event requires immediate action by those in inundation zones to move to higher ground to prevent loss of life. Because roads, bridges, and other transportation infrastructure will most likely be severely damaged by shaking from the megathrust earthquake, movement to higher ground will be mostly on foot.

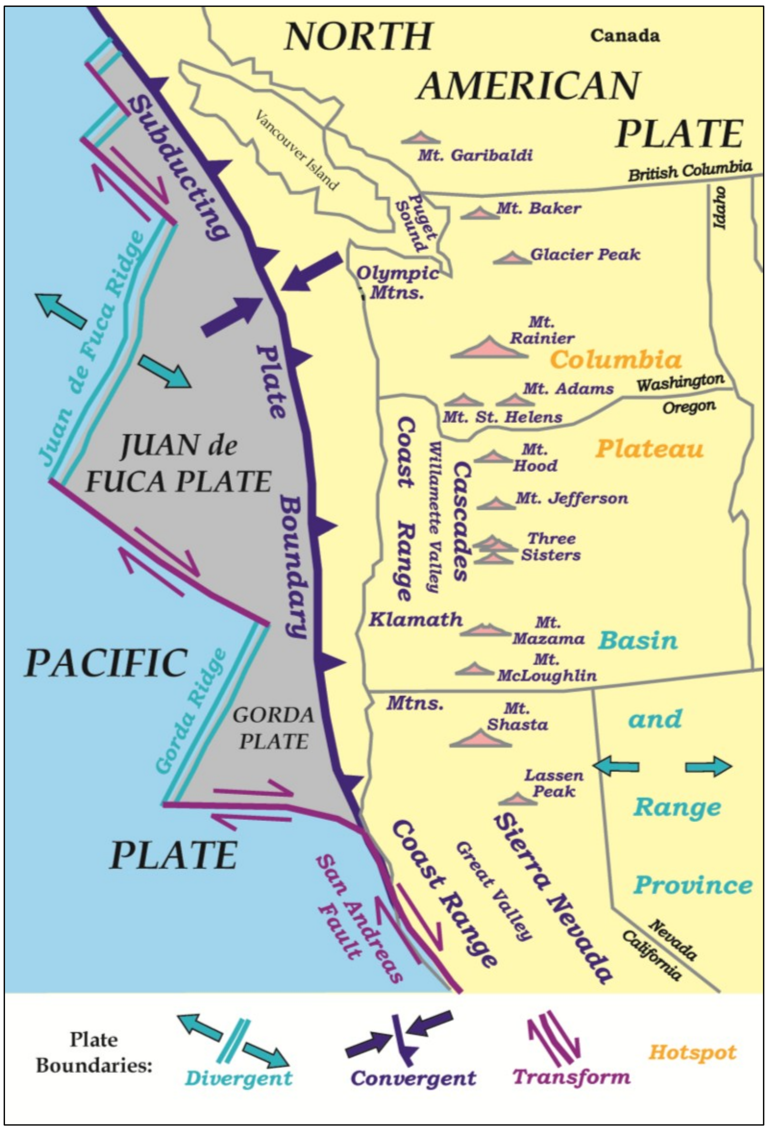

Figure 1. Geographic profile of the Cascadia Subduction Zone. Used by permission, Beauty from the Beast: Plate Tectonics and the Landscapes of the Pacific Northwest, by Robert J. Lillie, Wells Creek Publishers, 2015.

In addition to infrastructure damage, geological evidence shows that low-lying coastal areas in the CSZ can experience dramatic subsidence of 1-2 meters during a megathrust earthquake (Atwater & Yamaguchi, 1991). As a result of this subsidence, increased coastal areas will be subject to inundation from tsunami waves. Successive tsunami waves may continue to arrive at irregular intervals for a period of eight hours or longer. Often, the largest tsunami wave arrives hours after the first wave.

Evidence from recent megathrust subduction earthquakes and resulting tsunamis in developed countries (magnitude 8.8 in Chile in 2010, and magnitude 9.0 in Japan in 2011) demonstrates that the greatest loss of life and property damage in the inundation zones occurred, not as a result of the earthquake shaking, but from the tsunami waves (Inokuma & Nagayama, 2013). In a sobering evaluation, the *Oregon Resilience Plan* projects that, based on the current status of resilience to a CSZ megathrust earthquake and tsunami, it will take more than a year to restore function of essential systems (e.g., transportation, energy, telecommunications, health care, water/wastewater systems) in the hardest-hit coastal areas, and many years in those coastal communities that are directly inundated by the tsunami (OSSPAC, 2013).

It is important to note that coastal communities in the Pacific Northwest are also subject to tsunami inundation from tsunamis that originate at convergent subduction boundaries other than the CSZ, called distant-field tsunamis. For example, both the 1964 Alaska earthquake, and 2011 Japan earthquake caused both fatalities and property destruction in the Pacific Northwest. The distinction between a near-field CSZ tsunami and a distant-field tsunami is significant for earthquake and tsunami education in terms of the warning received, the evacuation time, the severity of inundation, and the evacuation process. The distinction between a near-field and a distant-field tsunami is an example of a potential relationship between science knowledge of earthquake and tsunami threat and preparedness knowledge to reduce risk and mitigate injury and damage.

Additionally, although public awareness of tsunami hazard in the CSZ has increased since the occurrence of three destructive megathrust earthquakes and tsunamis in the last 15 years in different regions of the world (magnitude 9.1 Sumatra-Andaman Earthquake, 2004; magnitude 8.8 Maule Earthquake, Chile, 2008; and magnitude 9.1 Great East Japan Earthquake, 2011), residents and visitors in the Pacific Northwest also face threat from the two other types of tectonic earthquakes—magnitude 6.5 to 7.0 deep earthquakes, and shallow crustal-fault earthquakes with magnitudes up to 7.5 (Butler, in press). The distinctions between the geophysical characteristics of these three types of earthquakes is another example of a potential relationship between science knowledge of the hazard and preparedness knowledge in order to reduce risk and mitigate injury and damage.

Need for a Theoretical Basis for Earthquake and Tsunami Education

The National Research Council report *Tsunami Warning and Preparedness: An Assessment of the U.S. Tsunami Program and the Nation's Preparedness* (2011) concludes:

> The committee concludes that current tsunami education efforts of each NTHMP member are conducted in an ad-hoc, isolated, and often redundant nature and without regard to evidence-based approaches in the social and behavioral sciences on what constitutes effective public risk education and preparedness training (p. 85).

In the absence of a strong theoretical basis, what is often operationalized is increased dissemination of information about earthquake and tsunami hazard and preparedness actions (National Oceanic and Atmospheric Administration, 2013; National Research Council, 2011). A strong theoretical basis is needed to inform both the content and the pedagogy of earthquake and tsunami education.

A study by Johnston et al. (2005) analyzed the results of over 300 surveys sent to adult residents of coastal communities in the state of Washington to assess their knowledge of tsunami hazard and their preparedness actions. Prior to the study, information had been disseminated in the surveyed communities in several forms of media including pamphlets, books, posters, school kits, mugs, magnets, warning signs, and tsunami inundation zone maps. The researchers reported that the dissemination initiatives were moderately to highly effective in raising public awareness of the hazard based on the respondents having seen, heard, or physically received the media communicating the information. However, the survey results also indicated that the disseminated knowledge of how to prepare for tsunamis did not translate in corresponding levels of actual preparedness actions.

A critique of several aspects of the Johnston et al. (2005) study relate to the research in this paper examining middle-school students' knowledge and beliefs of earthquake and tsunami through the lens of conceptual change theory. According to conceptual change theory, the residents who received the hazard and preparedness information that was disseminated held preexisting knowledge and epistemic and ontological beliefs about earthquakes and tsunamis. As shown in Table 1 in the Introduction, there are multiple constructs and dimensions of knowledge and belief that make up learners' conceptions of phenomena. However, the surveys administered in the study only addressed residents' hazard and preparedness knowledge; their epistemic and ontological beliefs of earthquake and tsunami were not assessed. According to conceptual change theory, preexisting knowledge and beliefs, or preconceptions, influenced how the residents assimilated and accommodated the new information that was disseminated. Specifically, aspects of the residents' preconceptions, both knowledge and beliefs, may have been highly resistant to change. Consequently, those preconceptions may have influenced the degree of enactment of recommended preparedness behaviors. Additionally, without having first established a baseline of the residents' preconceptions of tsunami hazard and preparedness prior to the dissemination campaign, all that can be reported is the residents' current level of knowledge, not the degree of change that occurred because of the information campaign.

A study by Paton et al. (2009) tested a hypothesized model of hazard preparedness that correlated the construct of Outcome Expectancy (positive or negative) with actual levels of tsunami preparedness of adults in coastal communities in Oregon and Alaska. Overall, the study found that Positive Outcome Expectancy, the perception that personal actions can make a difference in survival and quality of life, is positively correlated with actual preparedness. Negative Outcome Expectancy, the perception that the severity of tsunami consequences makes personal preparedness futile, is negatively correlated with actual preparedness. Additionally, in the model, Positive Outcome Expectancy is mediated by a set of sociocultural constructs including Community Participation, Collective Efficacy, Empowerment, and Trust.

The Paton et al. (2009) study relates to the study in this paper in several important ways. Paton et al. treated Outcome Expectancy as a fixed characteristic of the individual. According to the tested model, if the individual has the necessary information and resources, Positive Outcome Expectancy will predict preparedness behavior. According to conceptual change theory, Outcome Expectancy is a domain comprising knowledge schema and epistemic and ontological beliefs. A study examining Outcome Expectancy through the lens of conceptual change theory would ask what conceptions (knowledge and beliefs) do learners have about natural hazards and preparedness for those hazards and how do those conceptions form. The study in this paper examines the science and preparedness knowledge and epistemic and ontological beliefs of middle school adolescents. A greater understanding of the science and preparedness knowledge and epistemic and ontological beliefs of adolescents can potentially inform effective earthquake and tsunami education that develops the important construct of Positive Outcome Expectancy examined in the Paton et al. study. In this way, the theoretical constructs of conceptual change examined in this paper can be considered complementary to the model examined in the Paton et al. study. This complementary nature points to the fact that no single theoretical model can sufficiently encompass the entire domain of earthquake and tsunami knowledge, beliefs, and preparedness actions.

More specific to the disaster preparedness of youth, a literature review by Johnson, Ronan, Johnston, and Peace (2014) examined how researchers and practitioners measure and evaluate the effectiveness of disaster education programs for children 18 years and younger. The review examined 38 studies of 40 programs conducted in many countries that taught both the risks of natural hazards and the preparedness actions that reduce risk and mitigate injury and damage. Thirty of the programs (75%) addressed one or more specific types of disasters including earthquake, tsunami, volcano, storm, flood, fire, and tornado, and ten programs (25%) addressed non-specific disaster awareness and preparedness. Of the 38 studies, 22 (58%) were published in peer-reviewed journals, 2 (5%) were published in books, and the remainder were unpublished or un-catalogued reports. Of the 38 studies, 35 (92%) involved human subjects, with the remainder involving content analysis of websites. Of the 35 studies with human subjects, 25 (66%) occurred in a school setting.

In their review of the 35 studies with human subjects, Johnson, Ronan, Johnston, and Peace (2014) report that there was a predominance of knowledge-based outcome indicators used by researchers to evaluate the effectiveness of hazard education programs. In particular, children's ability to correctly answer knowledge-based questions of hazard risks was measured in 22 studies (63%) and preparedness actions during a disaster was measured in 18 studies (51%). Geophysical science knowledge of the hazard was measured in only 3 studies (9%). Of the 35 studies examined, 23 studies (66%) concluded that the education program caused, or was related to, positive outcomes in children's increased knowledge of disaster risks, improved attitudes toward disaster preparedness, or increased household preparedness actions. However, only 12 studies (34%) concluded that the educational program was effective based on statistically significant increases in children's knowledge.

The literature review by Johnson, Ronan, Johnston, and Peace (2014) examining how the effectiveness of disaster education programs for children is measured and evaluated is particularly relevant to the study in this paper. The program evaluations that Johnson et al. examined were not with adults but with children, and 14 of the studies (40%) were with children 7-13 years of age, which includes the ages of the middle-school students involved in this study. Additionally, 25 (66%) occurred in a school setting. The majority of the program evaluations were based on children's ability to correctly answer knowledge-based questions. However, what was not examined were children's epistemic and ontological beliefs that, based on conceptual change theory, profoundly influence how learners will assimilate and accommodate any new information taught in an education program into their existing knowledge and beliefs.

With the goal of examining both knowledge and beliefs, the current study focuses not on whether students have correct or incorrect knowledge, but what are the preconceptions and ontological and epistemic beliefs that make up their knowledge. Specifically, students' epistemic beliefs address their conceptions of the nature of their knowledge and include certainty of knowledge, simplicity of knowledge, sources of knowledge, and evidence for knowledge. The students' ontological beliefs address their conceptions of the nature of the geophysical and preparedness phenomena as entities/things, direct processes, or emergent processes.

Finally, a significant finding of the Johnson, Ronan, Johnston, and Peace (2014) literature review is that "most authors did not articulate an explicit theory or model of how the program would enable specific learning outcomes" (p. 119). The current study is designed to apply the constructs and dimensions of conceptual change theory to examine students' knowledge and beliefs to potentially inform both the content and the pedagogy of earthquake and tsunami education.

Two of the disaster education programs included in the literature review by Johnson, Ronan, Johnston, and Peace (2014) are studies by Ronan, Crellin, and Johnston (2010) and Shaw, Shiwaku, Kobayashi, and Kobayashi (2004). Ronan et al. surveyed a spectrum of factors including knowledge of threat, risk perception, emotional factors, and preparedness actions for hazards of 407 New Zealand school students from 7-18 years of age. The survey assessed knowledge of eight hazards including floods, storms with high winds, fires, earthquakes, tsunamis, volcanic eruptions, tornadoes, and chemical spills. The researchers describe two reasons for their focus on education programs for children. The first is that children have been found to be a highly vulnerable demographic to the effects of hazards (Norris et al., 2002). The second is that knowledgeable children are likely to positively influence family preparedness actions in the home (Ronan, Crellin, & Johnston, 2010). The researchers compared the responses of students who had participated in a hazards education program with those who had not participated. Those who had participated in a hazards education program had moderately greater knowledge of preparedness behaviors than students who had not participated. Although the study provided evidence for a moderate benefit of hazards education in a school setting compared to no education, what is not known is the content and methods of the various education programs that students participated in, and further, what was the theoretical basis for the content and methods of those programs. Additionally, what is not known is what did, or did not, change in the students' knowledge, risk perception, emotional factors, and preparedness actions as a result of their participation in the various programs.

A study by Shaw, Shiwaku, Kobayashi, and Kobayashi (2004) examined the relationship between four sources of earthquake education and the knowledge levels and preparedness behaviors of Japanese students in the first year of high school, aged 15-16 years old. A survey was administered to 1,065 students in 12 schools in five prefectures. The survey questions addressed four sources of earthquake education defined as *school* (disaster related instruction in lectures, courses, drills), *family* (interactions and activities in the home with parents and other family members), *self* (self-initiated activities such as internet searches, reading articles and books, visiting disaster management facilities, etc.), and *community* (participation in volunteer community activities such as drills, training, seminars, etc.). The study found that school education and self-education were highly correlated with students' science knowledge of earthquake hazard and preparedness knowledge, but family education and community education were more highly correlated with actual preparedness actions.

The focus of the study by Shaw, Shiwaku, Kobayashi, and Kobayashi (2004) on sources of knowledge is particularly relevant to the study in this paper where source of knowledge is one of the four dimensions of the epistemic belief construct in conceptual change theory. The Shaw et al. study also asked a set of survey questions about the Japanese high school students' personal experience with earthquakes at any time during their life, including whether family members, neighbors, or friends had been affected by an earthquake. This set of questions would have been particularly relevant for Japanese students because of the devastating Great Hanshin Awaji earthquake in Kobe in 1995 and the occurrence of several other major earthquakes in the western and northern parts of Japan in 2000, 2001, and 2003. Today, questions about personal experience of both earthquake and tsunami would be highly relevant to current Japanese K-12 students in light of the devastating 2011 Great East Japan Earthquake and tsunami. In contrast to the study in this paper, current K-12 students in Oregon are unlikely to have experienced an earthquake or tsunami unless that experience was outside of Oregon. However, various forms of media, particularly online media, may provide a vicarious experience and source of knowledge that form part of an Oregon student's epistemic beliefs about earthquake and tsunami.

A study by Katada and Kanai (2008) examined the effectiveness of a tsunami education program at two elementary schools in the potential tsunami inundation zone in Kamaishi City, Japan. The educational program consisted of three days of learning activities over approximately a two-month period involving students in grades 4-6 and their parents. The results of the study indicated that student knowledge of tsunami hazard, risk, and preparedness measures all increased as a result of participation in the program. For example, after the program, 69% of the students indicated they would evacuate immediately if they were home alone compared to 40% before the program. After the program, 82% of the students indicated they would evacuate to the nearest high ground if they were traveling from school to home compared to 47% before the program.

Several months after the education program was completed, an unplanned test of the students' actual preparedness came when a magnitude 8.3 earthquake occurred near the Kuril Islands, and the Japanese government issued a tsunami evacuation order for the residents of Kamaishi City. As it turned out, there was no tsunami resulting from that earthquake. The evacuation order came while school was not in session. A subsequent survey of students who had participated in the program at the two schools and students from a third school also in the potential inundation zone who had not participated showed little difference in actual response behavior. Only 4.2 % of the students who had participated in the program actually evacuated compared to almost none of the children who had not participated. As a result, additional and extended earthquake and tsunami education programs were implemented in all of the Kamaishi City schools.

When the Great East Japan earthquake and tsunami occurred on March 11, 2011, tsunami surges of more than 10 meters in height flowed into Kamaishi City resulting in approximately 1,150 fatalities or missing persons in a population of approximately 40,000, and complete or partial destruction of approximately one-third of the homes. Despite these catastrophic results, nearly all of the approximately 3,000 elementary and junior high school students escaped to safety, and their safety has been directly attributed to the earthquake and tsunami education conducted at the Kamaishi City elementary and middle schools. In direct relationship to the study in this paper, there may have been ontological and epistemic beliefs about earthquake and tsunami that made the students' behavior resistant to change as evidenced by the initial response to the Kuril Islands earthquake tsunami evacuation order, even though a high percentage had responded correctly to knowledge-based questions.

Conceptual Change Theory Applied to Earthquake and Tsunami Education

Conceptual change theory is not a unified theory, but rather can be viewed as a related set of theoretical constructs that seek to explain the nature of concepts, how concepts change, how concepts are represented, and how instruction can promote conceptual change.

As applied to earthquake and tsunami education, the three prominent constructs of conceptual change theory examined in this study—knowledge, epistemic beliefs, and ontological beliefs—can contribute to the growing body of disaster education literature by focusing on students' preconceptions, at whatever the level of a student's knowledge and preparedness. This focus has the potential to identify conceptions and beliefs that are prevalent and possibly resistant to change, to begin to explain why those conceptions and beliefs are prevalent and resistant to change, and to inform the content and methods of instruction that promote increased earthquake and tsunami science and preparedness knowledge that result in increased preparedness actions.

Framework Theory of Knowledge

Since the 1970s, research on conceptual change in science has shown that students' pre-instructional conceptions about natural phenomena are not in harmony with expert or canonical science understandings, and those conceptions are often firmly held and resistant to change (diSessa, 1993; Driver & Easley, 1978; Posner, Strike, Hewson, & Gertzog, 1982; Vosniadou, 1994). Several terms are used in the literature to describe these conceptions including misconceptions, alternative conceptions, and synthetic conceptions. The term synthetic conception is used in this paper. Theoretical and empirical conceptual change research in science education has largely focused on the following two issues: the nature of students' naïve and synthetic conceptions and the process of change from naïve and synthetic conceptions to more scientific conceptions. The large majority of studies on students' conceptions address physical science phenomena, particularly related to forces, motion, and energy. Though not as prevalent, other studies have addressed students' conceptions in the Earth sciences (Baytiyeh & Naja, 2014; Becker, Paton, Johnston, & Ronan, 2013; Cheek, 2010; DeLaughter, Stein, Stein, & Bain, 1998; diSessa, Gillespie, & Esterly, 2004; King, 2000; Libarkin, 2005; Philips, 1991; Ross & Dargush, 1992; Sibley, 2005).

Research on conceptual change in science can be traced back to Piaget's empirical studies with children. Piaget proposed that children bring their own naïve ideas of physical phenomena to science learning in the form of cognitive structures or mental organizations called schema that are based on the child's sensorimotor perceptions of physical phenomena and their developmental stage of logical reasoning (Piaget, 1964; Piaget & Cook, 1954). From the initial Piagetian perspective, conceptual change can be defined as the child constructing his or her own knowledge through assimilation of new information into existing schema or by modification of schema (accommodation). The child actively engages in knowledge construction through assimilation and accommodation in resolving cognitive disequilibrium and reaching some degree of equilibrium. Piaget's ideas about sensorimotor perceptions, schema, assimilation and accommodation, and equilibrium and disequilibrium are present in various degrees in the development of cognitive change theory over the last 40 years.

Current conceptual change research and theory is strongly influenced by Vosniadou's framework theory of conceptual change (Vosniadou, 1994) that is more inclusive of multiple interacting elements than the initial Piagetian perspective. A student's framework theory comprises multiple interacting elements, including naïve preconceptions, ontological categorizations, epistemological beliefs, representations, and situational contexts, that function as a complex system. A child's naïve physics is derived from early experiences and observations that form a relatively coherent conceptual framework with some limited power for explaining physical phenomena—hence the term framework theory. Early seminal studies that demonstrated students' framework theories of natural phenomena include students' concept of force (Ioannides & Vosniadou, 1992), models of the Earth (Vosniadou & Brewer, 1992), concept of heat transfer (Vosniadou & Kempner, 1993), and explanations of Earth's day/night cycle (Vosniadou, 1994).

The study of students' models of the Earth (Vosniadou & Brewer, 1992) provides an example of the framework theory. The researchers asked 60 children (20 first-graders, 20 third-graders, and 20 fifth-graders) to respond to 15 interview questions about the shape of the Earth. The response formats included verbal responses, drawings, and construction of physical models. In analyzing each student's responses to all the questions, the researchers tested for internal consistency or a pattern that could be explained by the student's use of an underlying mental model, or framework theory. The researchers found that 49 of the 60 students (82%) were consistent in the use of an underlying mental model across his or her responses. Additionally, they found that the students' underlying models could be categorized into one of six different models of the shape of the Earth.

Vosniadou and Brewer (1992) view students' naïve physics as meaningful preconceptions that form the basis for subsequent conceptual change. Conceptual change in a student's framework theory is a slow and gradual process of constructing synthetic conceptions that are incomplete and incorrect from an expert scientific view, but represent change from naïve conceptions to more scientifically correct conceptions (Vosniadou & Skopeliti, 2014). Synthetic conceptions typically consist of new scientific information assimilated into preexisting naïve conceptions within the student's overall framework theory of the phenomena. Vosniadou and Skopeliti posit that one possible mechanism for conceptual change involves the gradual reinterpretation of the preconceptions and beliefs of the learner's framework theory in response to new information. According to Vosniadou and Skopeliti:

> Synthetic conceptions are produced when learners, in the search for coherence and internal consistency, incorporate the scientific information to their incompatible prior knowledge distorting it and creating an alternative conception or model which however has some internal consistency and explanatory value (p.1430).

The application of a framework theory to students' science knowledge and preparedness knowledge of earthquake and tsunami poses some important challenges. First of all, the premise that children's naïve ideas about phenomena are based on sensorimotor experiences in everyday life does not necessarily apply to earthquake and tsunami phenomena in the same way as most prior science phenomena studied. In my own extensive educational outreach activities with students and families in Oregon, very few individuals have had any direct experience with earthquakes and tsunamis. Instead, their experience can be considered as vicarious (Kaya, 2010) in that they have been exposed to these phenomena through media or instructional materials. My observation of internet media and informational sites about earthquake and tsunamis is that they typically highlight the most severe and destructive examples of these phenomena and that both correct and incorrect information, and sometimes completely false images and information, are easily accessible to students through internet searches. Additionally, students' framework theories of phenomena are considered highly domain specific, and, as described earlier, the majority of domains studied in the conceptual change literature address natural science phenomena.

In this study, not only is earthquake and tsunami treated as a science phenomenon, but preparedness for earthquake and tsunami is also treated as a phenomenon. This study addresses students' knowledge of preparedness behaviors and the rationale for those behaviors. Applying a framework theory of students' conceptions to the domain of preparedness knowledge suggests that students have naïve conceptions based on their sociocultural experiences, and students have synthetic conceptions that incorporate aspects of naïve conceptions with accepted preparedness understandings. The Methods section of this paper describes how the earthquake and tsunami science knowledge and preparedness knowledge constructs were operationalized based on the framework theory of students' conceptualization of these phenomena.

Ontological Beliefs

Another view of student conceptions as relatively coherent and theory-like is based on students' ontological classification of science concepts (Chi, Slotta, & de Leeuw, 1994; Slotta, Chi, & Joram, 1995). An ontological category refers to the nature, or origin, of a concept in the student's perception of reality. As with Vosniadou and many other conceptual change researchers, Chi, Slotta, and de Leeuw proposed that students' naïve conceptions are based on early phenomenological perceptions and are highly resistant to change. However, Chi, Slotta, and de Leeuw proposed that students' naïve conceptions are especially resistant to change when they are mistakenly assigned to an inappropriate ontological category.

Chi, Slotta, and de Leeuw (1994) initially proposed three distinct and parallel ontological categories for organizing science concepts about the natural world: *matter/entities*, *processes*, and *mental states*. In subsequent studies, Chi and associates refined those ontological categories to *entities/things*, and two types of processes, *direct processes* and *emergent processes* (Chi, 2005; Chi, 2009; Chi, Roscoe, Slotta, Roy, & Chase, 2011; Slotta & Chi, 2006). Concepts in one ontological category have distinct attributes from concepts in another ontological category. Entities/things are objects or substances that have identifiable attributes and/or behave in identifiable ways. In reviewing students' descriptions of the physics concepts of force, heat transfer, electrical current, and light energy, Chi and other researchers found that students attributed object-like or substance-like properties to these concepts (Reiner, Slotta, Chi, & Resnick, 2000). For example, force was often described as a substance that an object possessed that could be transferred or used up (McCloskey, 1983), and heat was an intrinsic characteristic of the object itself (as in molecules of heat) or a substance that objects such as marbles possessed that could be contained or transferred (Wiser & Amin, 2001).

Processes are ontologically distinct from entities/things in that they involve change over time and cause/effect relationships. For example, instead of heat being the transfer of a substance-like entity between two objects, conduction involves the transfer of thermal energy between the objects in contact with each other through the *process* of random molecular motion.

To continue using thermal energy transfer for illustration, a *direct process* conception would be that faster-moving molecules move from the hotter object to the colder object or that the increased speed of individual molecules moved unidirectionally from the hotter object to the colder object. In contrast, an *emergent process* understanding of thermal energy transfer would be that random molecular motion in all directions results in the net transfer of thermal energy from the hotter object to the colder object until both objects came to equilibrium for average molecular motion, and after equilibrium is reached, random molecular motion still continues in all directions. In the direct process conception, thermal energy transfer is a constrained (unidirectional), sequential, and terminal process of molecular motion from the hotter object to the colder object. In the emergent process conception, thermal energy transfer results from the random, simultaneous, independent, and continuous motion of all of the molecules of the objects.

A fundamental argument of Chi and colleagues is that these three ontological categories, entity/thing, direct process, and emergent process, are incompatible and that conceptual change occurs not because new knowledge results in a gradual change from one category to another, for example, from heat as an entity/thing to thermal energy transfer as a direct process, to thermal energy transfer as an emergent process. Additionally, conceptual change does not occur as one ontological category is extinguished or replaced by another ontological category. Instead, conceptual change occurs when the learner develops a completely new ontological conceptualization of the concept and, as a result, the prior ontological conceptualization remains intact. In what is referred to as “Chi’s incompatibility hypothesis,” the learner can hold multiple parallel ontologies for the same concept that may be manifest in different contexts (Chi, 2005; Slotta, 2011).

In addition to Chi's incompatibility hypothesis, another fundamental argument of Chi and colleagues (Chi, Roscoe, Slotta, Roy & Chase, 2012) is that students' conceptions of many emergent science processes as direct processes results from their everyday experiences in which they have developed a generic, cause/effect, or sequential, narrative, referred to as a Direct-causal schema, to explain those everyday events. A Direct-causal schema is similar to a story line which typically has a beginning, a central character, a sequence or series of logical cause/effect interactions toward a goal, and a conclusion. Chi et al., hypothesize that students apply a Direct-causal schema, which is useful in interpreting and explaining their everyday experiences, to their initial understanding of science phenomena. While a generic Direct-causal schema may work well for students to understand sequential or cyclical processes in science such as the flow of blood in the circulatory system or photosynthesis, it poses a problem for students to understand emergent processes such as thermal energy transfer described earlier. Particularly problematic is when the product or outcome of the process has the appearance of a direct process (as in the net transfer of thermal energy in conduction) but the underlying process is an emergent process.

The application of the ontological categories of entities/things, direct processes and emergent processes to students' science knowledge and preparedness knowledge of earthquake and tsunami poses some important challenges for this study. Earthquakes and tsunamis result from geophysical processes that operate over large physical and temporal scales. The large temporal and physical scales of these geophysical processes differ from the ways that more discrete physics processes such as diffusion, electrical current, light energy, and thermal energy transfer are typically experienced by students. Additionally, applying the ontological categories of entities/things, direct processes and emergent processes to earthquake and tsunami preparedness as a phenomenon requires some adjustment to the categorical definitions that were derived from analysis of discrete physical science processes. The Methods section of this paper describes how the ontological categories of entities/things, direct processes and emergent processes were operationalized for earthquake and tsunami science and preparedness concepts.

Epistemic Beliefs

In a seminal study, Hofer & Pintrich (1997) conducted a comprehensive review and synthesis of theoretical and empirical research on personal epistemologies and identified two overarching themes in extant literature: studies that examine the nature of knowledge and studies that examine the nature of knowing. Based on a review of the studies examining these two overarching themes, they identified four distinct, but interrelated, dimensions of epistemic beliefs. Under the nature of knowledge, they identified two dimensions: the *certainty of knowledge* and the *simplicity of knowledge*. Under the nature of knowing, they also identified two dimensions: *sources of knowledge* and *evidence for knowledge*. As applied in this study, epistemic beliefs refer to the student's beliefs about the nature of his or her own knowledge of earthquake and tsunami. This is distinct from an epistemology of science which refers to the student's beliefs about the nature of science knowledge and how knowledge is constructed in science (Khishfe & Lederman, 2007).

Certainty of knowledge refers to the degree to which the individual believes his or her knowledge about earthquakes and tsunamis is fixed and certain versus changeable and tentative. In examining student comprehension of multiple textual resources, Bråten, Britt, Strømsø, and Rouet (2011) found that students who believed in absolute knowledge were confused when they encountered contradictory information in the texts. Kienhues and Bromme (2011) found that epistemic beliefs about the certainty of knowledge influenced how people processed inconsistent or conflicting information that they encountered on the internet.

Simplicity of knowledge refers to the degree to which the individual believes his or her knowledge is an accumulation of isolated objective facts versus complex concepts that are contextualized and that relate together many facts and perspectives. Though minimally supported by empirical evidence, the assumption is that individuals who hold simplistic beliefs about a concept will be more likely to process one-sided information consistent with their preexisting beliefs and less likely to assimilate information from differing viewpoints (Sinatra, Kienhues, & Hofer, 2014).

Sources of knowledge refers to where the individual believes his or her knowledge of earthquake and tsunami originates and resides, which includes the individual as a receiver of knowledge from external sources or as a constructor of knowledge as an internal source. Students' beliefs about the sources of their knowledge may reflect their perceptions about the credibility of certain sources and may demonstrate that some sources are privileged over other sources. For example, an overreliance on personal experience or firsthand knowledge might result in ascribing a high degree of truthfulness to an informant's account of his or her personal (or vicarious) experience (Sinatra, Kienhues, & Hofer, 2014) with earthquake and tsunami, even though that account may be at odds with accepted science or preparedness knowledge.

The student's personal epistemic beliefs about earthquake and tsunami knowledge may also indicate their epistemic beliefs about the nature of science knowledge if they ascribe authority and credibility to scientists, scientific sources of information, and evidence to support claims. As described earlier in the study by Shaw, Shiwaku, Kobayashi, and Kobayashi (2004), school education and self education was highly correlated with Japanese high school students' knowledge of earthquake hazard and risk, but family education and community education were more highly correlated with actual preparedness actions. Evidence for knowledge refers to what evidence the student uses to justify his or her own knowledge claims and how the student evaluates the knowledge claims of others based on the evidence provided to support those claims.

Hofer (2001) posits that individuals can have different epistemic beliefs along the dimensions of certainty, simplicity, sources, and evidence, for different subjects (domain-specific), rather than having an overall general set of epistemic beliefs that govern knowledge and knowing for all domains (domain-general). Empirical studies also suggest that individuals can hold both domain-general and domain-specific epistemic beliefs depending on the context of the knowledge claims they are evaluating (Hofer, 2006; Muis, Bendixen, & Haerle, 2006). In relationship to the highly domain-specific issue of earthquake and tsunami in this study, it is possible for the same student to be highly accepting of sources of science knowledge about the causes of earthquake and tsunami as geophysical phenomena, but at the same time to be skeptical about claims of earthquake and tsunami risk and the appropriateness or benefit of recommended preparedness actions.

Summary

A review of the extant literature on earthquake and tsunami education indicates that while there are strong national and state calls for increased education, there is also a need for a strong theoretical basis for the content and pedagogy of effective earthquake and tsunami education.

The need for increased, effective earthquake and tsunami education is particularly acute for residents and visitors in the CSZ of the Pacific Northwest who face risks from inland earthquake hazards as well as from a magnitude 9.0+ megathrust earthquake that will affect the entire region and possibly create a destructive tsunami that will impact coastal communities in Northern California, Oregon, Washington, and southern British Columbia.

Empirical studies of public information campaigns and earthquake and tsunami education efforts in the K-12 public school system in the United States and other countries have shown moderate effectiveness of these programs in increasing knowledge of earthquake and tsunami hazard, risk, and preparedness knowledge. However, the same studies often show limited effectiveness in increasing actual preparedness behaviors. Given the risks that students who live in the CSZ face from earthquake and tsunami hazards, science knowledge of the geophysical causes and effects of these phenomena is highly relevant to their lives, and preparedness knowledge is highly useful in responding adequately to those hazards and risks.

Conceptual change theory can be viewed as a set of three related theoretical constructs—knowledge, epistemic beliefs, and ontological beliefs. Conceptual change theory, which has decades of application in examining how students learn science concepts, has promise for examining students' preconceptions of earthquake and tsunami awareness and preparedness. According to conceptual change theory, students' preconceptions, including their epistemic and ontological beliefs about earthquake and tsunami, influence how they will assimilate and accommodate new science and preparedness information. By extension, students' knowledge and beliefs about earthquake and tsunami may influence the degree to which they enact preparedness measures that reduce their risk to these natural hazards.

Conceptual change literature addressing the framework theory of students' knowledge championed by Vosniadou and associates and the incompatibility hypothesis of ontological beliefs championed by Chi and associates focuses highly on conceptual change from students' naïve conceptions of science phenomena based on phenomenological experiences in their everyday lives to more scientifically-accepted understandings. However, students living in the CSZ are highly unlikely to have any direct phenomenological experience with earthquake and tsunami. As a result, a student's naïve conceptions of earthquake and tsunami are likely to result from indirect or vicarious experience through media exposure, school instruction, and family and community interactions.

A review of the extant conceptual change literature indicates that this study is unique in several important respects. First, this study examines all three constructs of conceptual change—knowledge, epistemic beliefs, and ontological beliefs—in equal measure in the same study. Second, this study examines two distinct, but related knowledge constructs in equal measure—students' science knowledge of earthquake and tsunami phenomena and students' preparedness knowledge for earthquakes and tsunamis. Additionally, students' preparedness knowledge, which focuses on knowledge of appropriate human behavior to reduce risk from a geophysical hazard, is very different from the physical science domains typically examined in conceptual change studies.

Chapter 3: Methods

Setting and Participants

The study was conducted during the 2016-2017 school year with a self-contained, combined 7th/8th-grade class in a school in the central coast region of the Pacific Northwest. Of the 22 students in the class, 12 students (55%) voluntarily agreed to participate in the study, and parent/guardian consent and student assent forms were collected for each participant. Of the 12 participating students, eight were 7th-graders, and four were 8th-graders. Eight students were male and four students were female. All 12 participating students were fluent in English. Additional demographic information about the participating students is not available.

In the 2016-2017 school year, the school enrolled 211 students across all grades. Across all grades, 77% of students identified their race/ethnicity as White, 9% as Hispanic/Latino, 8% as American Indian/Alaskan Native, and 7% as Multi-Racial. The percentage of students classified as Ever English Learners, or students who had at any time been eligible to participate in, or enrolled in, a program to acquire academic English, was not reported because less than six students in the entire school met this classification. Since the school offered lunch at no charge to all students, there is no data for the percentage of students classified as economically disadvantaged. In the 2016-2017 statewide science assessment, 73% of the school's 8th-grade students met or exceeded minimum performance levels compared to the statewide average of 63% and the 53% average for schools in the state with similar demographics.

I intentionally sought the participation of this school and the combined 7th/8th grade class of students for several reasons. The first is that I had established rapport with the classroom teacher, Mr. B, who was recognized as an outstanding science teacher. In the 2013-2014 school year, Mr. B and his 6th-grade class were chosen as the winner of the Samsung Solve for Tomorrow award for their work on the topic of past and future CSZ earthquakes and tsunamis. His class did field work by extracting sediment cores from a local river channel that indicated inundation from the last large CSZ earthquake and tsunami in the year 1700. Two of the students in Mr. B's 2013-2014 6th-grade class participated in this study in 2017 as 8th-graders.

In addition to the tsunami coring fieldwork, Mr. B's 6th-grade class created a detailed plan for an emergency evacuation center on the school property that that could serve hundreds of community members in the next CSZ event. The plan included maps, lists of supplies, and an overall budget for the evacuation center. I was able to observe the last stage of the class project when they presented the emergency evacuation center plan to a group of local emergency management personnel that included local representatives from the Red Cross, law enforcement, and fire departments. In the following school year, 2014-2015, I participated as a volunteer with Mr. B's 6th-grade class in conducting a similar tsunami coring project in a coastal estuary in a state park. The project included creating a descriptive poster of the coring results for display in the park Interpretive Center.

The school is located along a two-lane highway approximately 20 driving miles east of a mid-sized coastal city on the Pacific Ocean. The school is located along a branch of a river which flows west into the Pacific Ocean. Emergency planners anticipate that the area where the school is located will be severely affected by a large-scale CSZ event. Because of the school's location in a narrow river valley surrounded by steep coastal mountains, the region is expected to experience severe landslides and bridge failures during a CSZ earthquake that will isolate the community from outside support for an extended period of time. Although the school will not directly experience tsunami inundation due to its inland location, many of the students who attend the school live in coastal communities or have family members that work in coastal communities that will potentially experience direct or indirect impact from tsunami inundation. For the students at this school, earthquake and tsunami science knowledge and preparedness knowledge is not only highly relevant, but highly useful for minimizing their risk of harm and damage from these hazards.

In addition to Mr. B's work with his students on earthquake and tsunami awareness and preparedness, the school is part of a school district that is designated as a TsunamiReady® Supporter agency within the county which is designated as TsunamiReady® through a program established by the National Oceanic and Atmospheric Administration (NOAA). The TsunamiReady® program verifies that counties, communities, and supporters meet criteria for tsunami awareness and preparedness including implementing ongoing community education programs. As a result, students at the school are situated in a larger community of entities that value and practice disaster preparedness.

Data Collection

Instruments.

Three data collection instruments were used in this study—the Earthquake Booklet for Students, the Tsunami Booklet for Students, and the Interview Protocol for individual semi-structured interviews. Prior, less comprehensive versions of the three data collection instruments were pilot tested with Mr. B's 6th-grade science class in the 2014-2015 school year. The final versions of the instruments were reviewed for content validity by two internal science education researchers in the College of Education at Oregon State University and by one external geoscience researcher active in earthquake and tsunami education in the Pacific Northwest. These three instruments are included in Appendix A.

Each student participating in the study completed all three instruments. These instruments were designed to elicit students' textual, graphical, and verbal responses relative to the four constructs of science knowledge, preparedness knowledge, epistemic beliefs, and ontological beliefs. For example, students' epistemic beliefs of earthquake and tsunami are potentially tapped in different questions across the three instruments. Additionally, more than one construct, and more than one dimension of a construct may potentially be tapped by a single question. For example, a question designed to tap a student's preparedness knowledge of earthquakes and tsunamis may also tap the student's ontological beliefs about the nature of preparedness. This design reflects the theoretical framework of the study that conceptual change comprises multiple constructs and multiple dimensions within each construct.

Both the Earthquake Booklet for Students and the Tsunami Booklet for Students contained nine prompts (see Tables 2 & 3). The progression of questions in the Earthquake Booklet for Students and the Tsunami Booklet for Students followed the same pattern. Questions 1 through 4 addressed the causes and effects of the geophysical phenomenon, questions 5 through 8 addressed preparedness, and question 9 was designed as a "generative question" for which the student may not have received direct instruction or that the student may not have previously thought about in the same manner. This follows the work of Vosniadou and Brewer (1992) and is designed to provide greater information about students underlying knowledge schema by requiring students to generate a novel response rather than a response that simply repeats prior instruction. The Interview Protocol included 15 planned questions that were asked of all students (see Table 4). The planned questions were designed to probe the students' responses in the booklets which were referenced during the interview. As a semi-structured interview, the interviewer also asked spontaneous questions to further probe both the students' booklet responses and interview responses.

Table 2 shows the nine questions in the Earthquake Booklet for Students. Table 3 shows the nine questions in the Tsunami Booklet for Students, and Table 4 show the fifteen fixed questions in the Interview Protocol.

Table 2

Questions in the Earthquake Booklet for Students

1. Describe what you think causes earthquakes to occur. If you are not sure of your response, that is OK. Just describe what you think *might* cause earthquakes to occur.
2. Based on your response to **Number 1**, draw and label a diagram that shows what you think causes earthquakes to occur.
3. Describe what you think are some of the effects of earthquakes. If you are not sure of your response, that is OK. Just describe what you think *might* be some of the effects of earthquakes.
4. Based on your response to **Number 3**, draw and label a diagram to show what you think are some of the effects of earthquakes.
5. Do you think an earthquake will ever occur in this area? Why do you think this?
6. Describe some of the ways people can prepare for an earthquake. If you are not sure of your response, that is OK. Just describe some of the ways you think people *might* prepare for an earthquake.
7. Suppose you experience an earthquake in the future. What do you think you would do during the earthquake? Why would you do this?
8. Suppose you experience an earthquake in the future. How do you think you would feel during the earthquake? Why would you feel this way?
9. Suppose a friend asked you the following question: "Do you think people can know when and where an earthquake will occur? What would you tell your friend?

Table 3

Questions in the Tsunami Booklet for Students

1. Describe what you think causes tsunamis to occur. If you are not sure of your response, that is OK. Just describe what you think *might* cause tsunamis to occur.
2. Based on your response to **Number 1**, draw and label a diagram that shows what you think causes tsunamis to occur.
3. Describe what you think are some of the effects of tsunamis. If you are not sure of your response, that is OK. Just describe what you think *might* be some of the effects of tsunamis.
4. Based on your response to **Number 3**, draw and label a diagram to show what you think are some of the effects of tsunamis.
5. Do you think a tsunami will occur along the coast of Oregon? Why do you think this?
6. Describe some of the ways people can prepare for a tsunami. If you are not sure of your response, that is OK. Just describe some of the ways you think people *might* prepare for a tsunami.
7. Suppose in the future you were somewhere at the coast. How would you know whether or not a tsunami was coming?
8. Suppose in the future you were at the coast and you thought a tsunami was coming. What do you think you would do? Why would you do this?
9. Suppose a friend asked you the following question: “Do you think people can prevent tsunamis from occurring? What would you tell your friend?

Table 4

Planned Questions in the Interview Protocol

1. Let’s first look at your *Earthquake Booklet for Students*. Can you describe for me what your diagram in **Number 2** is showing about what causes earthquakes to occur?
2. Can you describe for me what your diagram in **Number 4** is showing about the effects of earthquakes?
3. How sure are you about your descriptions of the causes and effects of earthquakes? For example, are you very sure, somewhat sure, just a little bit sure, or not sure at all?
4. Can you tell me how each of the ways you described in **Number 6** will help people prepare for an earthquake?
5. For **Number 7**, you answered that you would ________________ if an earthquake occurred in the future. Suppose an earthquake occurred right now, what would be the best thing for

you to do?

6. **Number 9** was about what you would tell your friend if they asked whether people can know when and where an earthquake will occur. You said you would tell your friend ________________________. What reasons would you give for your answer to your friend?
7. Let's now look at your *Tsunami Booklet for Students*. Can you describe for me what your diagram in **Number 2** is showing about what causes tsunamis to occur?
8. Can you describe for me what your diagram in **Number 4** is showing about the effects of tsunamis?
9. How sure are you about your descriptions of the causes and effects of tsunamis? For example, are you very sure, somewhat sure, just a little bit sure, or not sure at all?
10. Can you tell me how each of the ways you described in **Number 6** will help people prepare for a tsunami?
11. **Number 9** was about what you would tell your friend if they asked whether people can prevent tsunamis from occurring. You said you would tell your friend ________________________. What reasons would you give for your answer to your friend?
12. We have been talking a lot about earthquakes and tsunamis. Where have you learned about earthquakes and tsunamis and where do your ideas come from?
13. Do you think your knowledge about earthquakes and tsunamis will change in the future, and why do you think this way?
14. Who do you think is most responsible for helping people be prepared for earthquakes and tsunamis?
15. Suppose a friend asked you the following question: "If earthquakes and tsunamis can be so destructive to people and buildings, why do you think they happen at all?" What would you tell your friend?

In addition to the three data collection instruments already described, three other artifacts were introduced to many of the students in the semi-structured interviews: (1) an outline map of the state, (2) a pair of tsunami evacuation signs, and (3) a blank rectangle. Not all additional artifacts were introduced to all students based on how each interview was progressing and the responses a student had already provided. In one case, a student exhibited some discomfort discussing the effects of earthquakes and tsunamis. When asked, the student wanted to continue with the interview, and I thought it would be best to not introduce the artifacts and additional questions beyond the Interview Protocol. For the outline map, students were asked to mark where they were currently located, where the epicenter of a large earthquake might occur, how far the earthquake shaking might be felt, and how far the tsunami inundation might reach. For the tsunami evacuation signs, students were asked to describe where they had seen signs and what the signs meant to them. For one student, the tsunami evacuation signs were not introduced since the student had already indicated his knowledge of evacuation locations in prior interview responses. For the blank rectangle, students were asked to divide the rectangle into parts and label each part to represent the *sources* of their current science and preparedness knowledge of earthquake and tsunamis.

As a research method for data collection, the use of different data collection instruments and different response formats has the potential to elicit greater depth and breadth of students' knowledge and beliefs than can be done with a single instrument and response format (Maxwell, 2013). The use of related instruments and multiple response formats has been used in previous conceptual change studies to make visible not only students' knowledge about a domain, but also the basis for that knowledge (Slotta, Chi, & Joram, 1995; Libarkin, 2005; Vosniadou, 1994). For example, a student may be able to accurately replicate a diagram of a convergent subduction tectonic plate boundary based on what was learned in science instruction, but not be able to accurately explain how that subduction interaction causes an earthquake and tsunami in an interview. Conversely, a student may provide a very comprehensive description of how he or she would prepare for an earthquake during an interview interaction, but may have provided a very limited written description in a workbook.

Noble, DiMattia, Nemirovsky, and Barros (2006) refer to *highlighting*, or what the student has made prominent about the phenomenon, in a student's representation of his or her knowledge. Equally important in examining and interpreting the student's representation is *backgrounding* (Noble et al., 2006), or what the student has made less prominent or omitted. Spontaneous interview questions allow the interviewer to probe further what the student has highlighted or backgrounded in his or her workbook and interview responses and can provide a starting point for additional conceptualization by the student. Brown (2014) argues that students' conceptions are dynamically emergent structures that emerge from the students' conceptual resources in response to new perceptions and information, even as those new perceptions and information become part of the student's resources. In the interview process, the interviewer has the opportunity to ask questions that may give rise to dynamically emergent student conceptions that result from new perceptions and information during the interview interaction (Sherin, Krakowski, & Lee, 2012).

Figure 2 shows examples from the Tsunami Booklet for Students and the Interview Protocol of multiple questions and response formats that elicit greater depth and breadth of students' knowledge and beliefs than isolated questions and that may give rise to dynamically emergent student conceptions.

The design of Question 9 in both the Earthquake Booklet for Students and the Tsunami Booklet for Students, and Question 15 in the Interview Protocol was intended to reflect an aspect of narrative theory most often used in psychological therapy that "externalizes the issue" (White & Epston, 1990). According to White and Epston, when an individual is deeply involved in an issue, the dominant narrative in their thinking about the issue is "problem-saturated," and therefore constrains their ability to form new ways of thinking about the issue and to conceptualize new solutions and outcomes.

Tsunami Booklet for Students Question 3 - Describe what you think are some of the effects of tsunamis. If you are not sure of your response, that is OK. Just describe what you think *might* be some of the effects of tsunamis. (written response)

Tsunami Booklet for Students Question 4 - Based on your response to Number 3, draw and label a diagram to show what you think are some of the effects of tsunamis. (graphical response)

Interview Protocol Question 7 - Can you describe for me what your diagram in Number 4 is showing about the effects of tsunamis? (verbal response)

Interview Protocol Question 8 - How sure are you about your descriptions of the causes and effects of tsunamis? For example, are you very sure, somewhat sure, just a little bit sure, or not sure at all? (verbal response)

Spontaneous Follow-up Interview Question - Where would the land be in your tsunami diagram, can you draw it in? (verbal and graphical response)

Spontaneous Follow-up Interview Question - Based on the earthquake and tsunami you described and drew in your diagram, would the tsunami reach where we are today? (verbal response)

Figure 2. Multiple questions and response formats addressing the same concept.

According to narrative theory, externalizing the issue allows the individual to identify other feelings, thoughts, intentions, and experiences that are present, but fall outside of the dominant narrative. Externalizing the issue can be facilitated by having an external audience that the individual creates the narrative for and presents the narrative to (White & Epston, 1990). An attempt to structure select questions in this study as externalizing the issue was used because of the potential anxiety students can experience when thinking about and discussing earthquakes and tsunamis. In a small but intentional way, the potential benefit of externalizing the issue to an external audience was reflected in the structure of these three questions. For example, Interview Protocol Question 15 was presented in the following manner: “Suppose a friend asked you the following question: 'If earthquakes and tsunamis can be so destructive to people and buildings, why do you think they happen at all?' What would you tell your friend?"

Activities prior to data collection.

Prior to the administration of the data collection instruments, I spent five 45-minute science class periods with Mr. B and the students. The first two class periods provided an opportunity for Mr. B to introduce me to the students and for me to observe the construction of the structures they were making for a Tsunami Structure Challenge activity. During this engineering design activity, the students worked in teams using specified materials to construct a model vertical evacuation structure to meet specified criteria. During the third class period, I observed the testing of their structures at the Hinsdale Wave Lab at the Oregon State University campus in Corvallis, Oregon.

In preparation for the Tsunami Structure Challenge activity, Mr. B had shown two videos to the class. The first was a FEMA video *Tsunami Forces and Design for Vertical Evacuation* (https://www.fema.gov/media-library/assets/videos/79474) that discussed the characteristics of tsunamis and the forces that vertical evacuation structures must be designed to withstand. The second was a dramatic video of live footage taken during the tsunami inundation in Kesennuma City, Miyagi Prefecture, Japan, during the March 11, 2011 tsunami.

Originally, the research study was to have been conducted before students completed the Tsunami Challenge Activity as part of a complete unit of instruction on earthquakes and tsunamis. However, scheduling the class trip to the Hinsdale Wave Lab necessitated a different sequence. The remainder of Mr. B's unit of instruction on earthquakes and tsunamis was done after the research study was concluded several weeks later.

During the last two class periods I spent with the students prior to the study, Mr. B allowed me to conduct four different activities titled "What Do You Think" to prepare the students for the study. These activities were considered an important part of the study design in several ways. First, the activities required the students to create written, graphical, and verbal explanations for phenomena as they would be doing during the study. Second, they allowed the students an opportunity to represent their ideas about cause/effect relationships in phenomena even if they didn't know the answer or had never even thought about cause/effect relationships in the phenomena before. Third, students were encouraged to use their knowledge and experience to make thoughtful conjectures about phenomena without fear of their answers being evaluated as correct, partially correct, or incorrect as on a test. However, because they knew I would randomly call on a few students to present their explanations to the class and answer questions from me, Mr. B, and other students, it was hoped that they would make thoughtful responses. Lastly, the activities allowed me to build rapport with the students that would be beneficial during the individual semi-structured interviews.

Intentionally, the four phenomena examined did not have anything to do with earthquakes or tsunamis. The four phenomena were: (1) Where did the mass in a maple tree come from since it started as such a small seed; (2) How did a piece of wood turn into petrified wood; (3) Why are there whirlpools around the bridge supports in a river, and which way do they spin; and (4) How does a spider make a web that hangs between two trees that are far apart? At the beginning of each activity, I displayed artifacts to stimulate the students' thinking including winged maple seeds, a heavy section of maple tree branch, pieces of petrified wood, and video and pictures of whirlpools and spider webs. Based on the written and graphical responses the students provided and the lively discussions we had about each phenomenon, I felt the activities were successful as an informal preparation for administering the data collection instruments during the study.

Data collection process.

The data collection instruments were administered during the first two weeks of May, 2017. The Earthquake Booklet for Students and the Tsunami Booklet for Students were administered on separate days in the first week, and the interviews were conducted during the second week. All students completed the workbooks as part of the regular classroom activities. Only the workbooks from those students with signed consent and assent forms were included in the study, and only those students were interviewed.

The workbooks were administered by the teacher after reading an Introductory Script (Appendix B) provided by the researcher and after reading through the workbook prompts to see if the students had any questions. The Introductory Script stated that the workbooks were not a test and encouraged students to do their best work and to describe what they think might be an answer even if they were not sure. Students completed the workbooks independently without any time limit, but all students completed the workbooks within 30 minutes. The semi-structured individual interviews were conducted in the school building and were video recorded. The interviews varied in length from the shortest at 28:45 minutes to the longest at 49:31 minutes. The average length was 36:54 minutes.

Data Analysis

Categorical definitions.

The students' written and graphical responses to the prompts in the Earthquake Booklet for Students and the Tsunami Booklet for Students, and the students' transcribed oral responses to the interview questions were analyzed through a process that reflects both deductive and inductive approaches to content analysis (Berg & Lune, 2012). As the first stage in the deductive approach, I developed an initial matrix of categorical definitions for each of the four theoretical constructs of the study—science knowledge, preparedness knowledge, epistemic beliefs, and ontological beliefs—and for the predetermined dimensions within each construct based on a review of the literature. These categorical definitions operationally define the constructs and dimensions of conceptual change theory in relationship to earthquake and tsunami science and preparedness knowledge.

The initial categorical definitions for the constructs and dimensions of science knowledge and preparedness knowledge of earthquake and tsunami derive directly from definitions by Vosniadou and associates (Vosniadou & Skopeliti, 2014) for *naïve*, *synthetic*, and *accepted* conceptions. For example, the construct *Preparedness Knowledge* is operationally defined as "the learner's knowledge of the risks to life, safety, and property from earthquake and tsunami and the knowledge of preparedness actions to reduce those risks." The dimension *Naïve Ideas* of the Preparedness Knowledge construct is operationally defined as "incorrect preparedness ideas that derive from perceptions of direct or vicarious phenomenological and sociocultural experiences; these ideas reflect perceptions that would be prior to, or without direct connection to, earthquake/tsunami preparedness instruction and learning."

Table 5 shows the initial set of categorical definitions for the Science Knowledge construct, and Table 6 shows the initial set of categorical definitions for the Preparedness Knowledge construct.

Table 5

Categorical Definitions for Science Knowledge

	Dimension		
Science knowledge	Naïve ideas	Synthetic conceptions	Accepted scientific understandings
the learner's knowledge of the geophysical causes and effects of earthquake and tsunami	scientifically incorrect ideas that appear to derive from perceptions of direct or vicarious phenomenological and sociocultural experiences; these ideas reflect perceptions that would be prior to, or without direct connection to, science instruction and learning	descriptions or explanations that combine aspects of incorrect conceptions with scientifically correct knowledge in a somewhat functional manner	descriptions or explanations that are consistent with current scientifically accepted understandings

Table 6

Categorical Definitions for Preparedness Knowledge

	Dimension		
Preparedness knowledge	Naïve ideas	Synthetic conceptions	Accepted preparedness understandings
the learner's knowledge of the risks to life, safety, and property from	incorrect preparedness ideas that derive from perceptions of direct	descriptions or explanations that combine incorrect conceptions with	descriptions or explanations that are consistent with current accepted

earthquake and tsunami and the knowledge of preparedness actions to reduce those risks	or vicarious phenomenological and sociocultural experiences; these ideas reflect perceptions that would be prior to, or without direct connection to, earthquake/tsunami preparedness instruction and learning	correct preparedness knowledge in a somewhat functional manner	understandings of preparedness actions prior to, during, and after an earthquake or tsunami

The categorical definitions for the *Epistemic Belief* construct derive directly from the definitions in the seminal study by Hofer and Pintrich (1997) based on their comprehensive review of the literature on personal epistemologies. However, the dimension *Evidence* as identified by Hofer and Pintrich was revised to reflect the student's use of a *rationale* in their response as opposed to the more formal use of evidence to support a claim. The initial set of categorical definitions for the Epistemic Belief construct is shown in Table 7.

The greatest challenge in developing the categorical definitions was for the *Ontological Belief* construct and the associated dimensions of *Thing*, *Direct Process*, and *Emergent Process* in relationship to the phenomenon of preparedness for earthquake and tsunami. Treating a conceptual and behavioral domain like preparedness for earthquake and tsunami as a phenomenon and examining students' ontological beliefs of that phenomenon is atypical in the conceptual change literature. The authors had many discussions in developing the initial set of categorical definitions and in refining those definitions during the calibration rounds of coding the student responses.

Table 7

Categorical Definitions for Epistemic Beliefs

Epistemic beliefs	Dimension			
	Certainty	Simplicity	Source	Rationale
the learner's beliefs about the nature of his or her science and/or preparedness knowledge of earthquake and tsunami	the degree to which the student represents his or her science or preparedness knowledge as complete, certain, fixed, tentative, or subject to change	the degree to which the science or preparedness knowledge that the student represents is simplistic or complex conceptual understandings that relate facts together	the sources that the student represents for his or her knowledge of earthquake and tsunami	the student's use of a rationale to support his or her claims of science or preparedness knowledge

The starting point for our discussions was Chi's definitions of Entity/Thing, Direct Process, and Emergent Process (Chi, 2008) derived from analysis of students' understandings of physical science phenomena. The challenge for us was to apply those definitions to preparedness as a phenomenon. The first dimension, Thing, was relatively unproblematic. Chi (2008) describes things as "*objects* or *substances* that have various attributes and behave in various ways" (p. 73).

An important characteristic of Thing as an ontological category is that things are static; they are not processes that occur over time. For example, an emergency evacuation bag, or "go-bag" is a thing, but putting together a go-bag is a process. If a student characterized his or her preparedness as having an emergency go-bag, as in, "I'm prepared, I have a go-bag ready whenever I need it," that would be an example of an ontological belief of preparedness as a Thing. Being prepared is having a go-bag. Such a belief differs from a process of thinking through what is needed in a go-bag, finding where to procure what is needed, assembling the go-bag over time, and restocking supplies as needed.

In application to preparedness, we expanded the definition of Thing to include an isolated event or occurrence. For example, having attended a community workshop on emergency preparedness is also categorized as Thing in that it is not a process, but a completed event. This differs from thinking about a workshop as only part of an ongoing process of developing knowledge of hazard and risks and taking preparedness measures to reduce those risks.

Operationally defining a Direct Process and an Emergent Process for earthquake and tsunami preparedness was much more challenging. In Chi's definitions of processes (2005, 2008), the term "agent" refers to individual participants that have some role in the process. In Chi's (2005) description of the process of diffusion, those agents were molecules of the water and ink interacting together. As applied to earthquake and tsunami preparedness, we had to include a much broader spectrum of agents including agents of the natural environment (e.g., the earthquake, the tsunami, the topography of the land), agents of the built environment (e.g., buildings, roads, bridges), and of course people as agents (e.g., students, family members, friends, teachers). We also had to consider a much broader spectrum of interactions between and among agents.

We distilled three primary distinctions between a Direct Process and an Emergent Process as applied to preparedness following Chi's work (2008). First, in a Direct Process, the process results from *linear or sequential cause/effect or dependent relationships* between agents.

In an Emergent Process, the relationships between agents are *non-linear or non-sequential*, and agents can act *independently and simultaneously*. Second, in a Direct Process, there is a *single controlling agent* that directly or indirectly causes the process pattern or outcome. In an Emergent Process, the process pattern and outcome result from the *collective action of many agents*. Third, a Direct Process has a *limited duration and is not related to an ongoing process*. In an Emergent Process, the process can *continue beyond the observed pattern or outcome*. Table 8 shows the initial set of categorical definitions for Ontological Belief used in the study.

Table 8

Categorical Definitions for Ontological Belief

	Dimension		
Ontological belief	Thing	Direct process	Emergent process
the learner's beliefs about the nature of earthquake and tsunami phenomena and/or the nature of individual and group preparedness phenomena	- unconnected to process - isolated entity, occurrence, or event - random, unpredictable or predictable entity, occurrence, or event - controllable or uncontrollable entity, occurrence, or event	- the observed occurrence/event or outcome/pattern is the result of a linear, sequential, or cause/effect interaction - a single controlling agent directly or indirectly causes the occurrence/event or outcome/pattern - a limited duration occurrence/event or outcome/pattern is not related to an ongoing process (i.e., what happened prior to, what will happen after)	- the interactions of multiple agents cause the occurrence/event or outcome/pattern - the agents can act simultaneously and independently - the outcome/pattern emerges from the collective interactions of the agents - the process can continue beyond the observed occurrence/event

Coding guidelines and scheme.

The second stage in the deductive approach to analyzing the data was to define a coding scheme and set of guidelines for coding the student responses. The coding scheme translates the categorical definitions of the dimensions previously described into indices that indicate the presence of, identify subcategories of, or measure the magnitude of, those dimensions (Berg & Lune, 2012). The coding guidelines developed by the researchers define how to apply the coding scheme to the student responses. The Coding Guidelines and Scheme are shown in Appendix C.

For example, the coding scheme for the epistemic dimension *Simplicity* has three codes for three levels of magnitude: SS for a Simplistic Conception defined as a response with one or two simple facts or components; SM for a Moderately Complex Conception defined as a response with several components or a relationship between components; and SC for a Complex Conception defined as a response with multiple relationships between components. Additionally, the coding guidelines state that Simplicity should only be coded for Science Knowledge or Preparedness Knowledge responses and are based on the researcher's interpretation of the student's response. In contrast, the coding scheme for the epistemic dimension *Source* lists subcategories of different sources of student knowledge (e.g., OI for internet/online/web, OP for parents/family/siblings, and OS for school). The coding guidelines state that Source should only be coded for sources explicitly stated by the student and multiple sources may be coded for each response.

Unit of analysis.

The third stage in the deductive approach to analyzing the data was to define the unit of analysis for applying the coding scheme and guidelines. In reviewing the options, we adopted the individual response to each question as the unit of analysis. The interview transcripts were chunked into question/response pairs and each response was coded per the coding scheme and guidelines. Because all student responses in the Earthquake Booklet for Students, the Tsunami Booklet for Students, and the other artifacts (outline map of Oregon and rectangle divided into sources) were referenced as part of the interview questions, only the student responses in the interview transcripts were coded.

The individual question response was chosen as the unit of analysis for several reasons. First, chunking the interview into question/response pairs was relatively easy, and a minimal amount of interpretation was required to define question/response pairs as opposed to the interpretation that would have been required to chunk each student's response data into larger aggregates, particularly because the spontaneous questions made parts of each interview unique. The individual question/response pair provided a consistent unit of analysis across all student interviews.

Second, coding at the individual question/response pair had the potential to see if Vosniadou's (1994) framework theory of a relatively coherent theory-like conception of phenomenon could be inferred even though individual indicators of that conception could have different levels of sophistication (i.e., naïve, synthetic, accepted understandings). Additionally, Chi's (2005) incompatibility hypothesis of parallel ontologies for the same phenomenon could be manifest even though one ontology may be dominant compared to the others. Finally, coding the individual question/response pairs allowed for identification of dynamically-emergent conceptions (Brown, 2014) that occurred during the actual interview process.

Coding process.

The first author selected two complete sets of interview responses from two students for the initial round of calibration coding (approximately 17% of the total responses). The authors independently applied the categorical definitions and coding scheme and guidelines to the first set of interview responses and then met to compare coding, discuss agreements and discrepancies, and agree on consensus codes and any modifications or clarifications to the categorical definitions and coding scheme and guidelines. The first set of responses we independently coded had 60 question/response pairs and involved 420 potential individual codes for applicable constructs and dimensions. While there were disagreements in codes for each construct and dimension, most discrepancies were readily resolved through discussion and consensus was reached. The discrepancies that were the most difficult to reach consensus on were for the Ontological Belief construct.

We focused not on tallying inter-rater agreement rates to meet a set percentage of agreement, but rather on refining and clarifying the categorical definitions, coding scheme, and coding guidelines. We went through three rounds of independent coding, discussion and consensus for the first set of responses before we had sufficient clarity of criteria and consistency of application to move to the second set of student responses. The first author selected the second set of student responses to be qualitatively different from the first set. In the first set, the student’s responses tended to be short and succinct. In the second set, the student’s responses were longer and more elaborate. After two rounds of independent coding and discussion, we felt that the coding scheme and guidelines were sufficiently clear and application of the codes was sufficiently consistent for the first author to independently complete the coding of the remaining 10 student interviews.

Inductive analysis process.

Although the constructs and dimensions of conceptual change theory were operationalized for earthquake and tsunami science and preparedness knowledge, the functionality and adequacy of those definitions were manifested when applied to coding the actual student responses. During the calibration coding rounds, a few of the challenges we encountered resulted from student responses that did not fit well with the *a priori* categorical definitions. We noted those instances, but since the calibration rounds involved only two sets of student responses, it was not clear whether they were isolated instances or represented gaps in the *a priori* categorical definitions. However, while coding the remaining 10 students, patterns emerged in the student responses that necessitated defining new dimensions within the existing constructs. Specifically, the dimension *Imprecise Conception* was added to the Science Knowledge and Preparedness Knowledge constructs, and the dimension *Superintendent* was added to the Ontological Belief construct. The student responses that necessitated these new categories and the definitions for these categories are described in the Results section of this paper.

Answering the Research Questions

The analysis of the coded student responses focused on directly answering the following research questions for this study:

1. How do middle school students who live in a region affected by earthquake and tsunami describe their knowledge and beliefs about earthquake and tsunami?

2. What science knowledge of earthquake and tsunami can be inferred from the students' descriptions?
3. What preparedness knowledge for earthquake and tsunami can be inferred from the students' descriptions?
4. What epistemic beliefs about earthquake and tsunami can be inferred from the students' descriptions?
5. What ontological beliefs about earthquake and tsunami can be inferred from the students' descriptions?

To answer these research questions, the coded student responses were analyzed at two levels: (1) the knowledge and beliefs of the individual student, and (2) the knowledge and beliefs of the students as a group. Completing the first level of analysis, the knowledge and beliefs of the individual student, was a prerequisite to completing the second level of analysis, the knowledge and beliefs of the students as a group. To complete the first level of analysis for each individual student, the first author looked at the entire set of responses with a given code (e.g., construct code as Science Knowledge and dimension code as Naïve Ideas, Synthetic Conceptions, Imprecise Conceptions, or Accepted Understandings) and identified patterns or prominent themes across responses as well as discrepant or isolated responses. The first level of analysis generated a reasonable characterization of each student's science knowledge, preparedness knowledge, epistemic beliefs, and ontological beliefs. The first level of analysis was not an end point but a starting point for the second level of analysis.

The second level inter-student analysis was facilitated by the structure of the workbooks and the Interview Protocol because specific questions were designed to elicit responses relative to targeted constructs and dimensions. Here it was possible to discern patterns or themes that were prevalent in the set of responses for all students. For example, Interview Protocol Question 7 asked, “Suppose an earthquake occurred right now, what would be the best thing for you to do?” Interview Protocol Question 10 asked, “Can you tell me how each of the ways you described in Number 6 (Tsunami Workbook for Students) will help people prepare for a tsunami?” These questions targeting Preparedness Knowledge facilitated looking across all the student responses and the assigned codes for patterns or prominent themes as well as discrepant or isolated responses.

To fully answer the research questions for this study, we looked at not only the patterns or prominent themes for a given code by itself (e.g., Preparedness Knowledge) but the inferred relationship between codes (e.g., Preparedness Knowledge and Ontological Belief). Since each student response may be coded for multiple constructs and dimensions, examining the inferred relationships between constructs was an intentional design of the study to fully answer the research questions. The multiple data collection instruments used in the study, the multiple response formats used in those instruments, the categorical definitions and coding process used to code the student responses, and the deductive and inductive analysis of those responses has allowed us to provide answers to each of the research questions addressed in this study.

Chapter 4: Results

Overview

The results of the current study are reported in the order of the five research questions addressed in the study. The first question asked, "How do middle school students who live in a region affected by earthquake and tsunami describe their knowledge and beliefs about earthquake and tsunami?" To answer this question, the students' descriptions of their knowledge and beliefs were examined relative to the three methods of response in the data collection instruments (textual, graphical, and verbal) and students' gestural responses that were manifest during the semi-structured interviews. Additionally, students' descriptions were examined based on their inclusion of emotional and geographic information. The other four study questions examining students' science knowledge, preparedness knowledge, epistemic beliefs, and ontological beliefs are addressed in depth separately in this Results section.

How Do Students Describe Their Knowledge and Beliefs

Textual responses.

The two workbooks, the Earthquake Booklet for Students and the Tsunami Booklet for Students, required students to respond both textually and graphically. With the exception of one student, the textual responses for describing the causes of earthquakes and tsunamis were heavily dependent on geoscience-specific vocabulary for objects or substances (e.g., tectonic plates, Juan de Fuca Plate, oceanic plate, continental plate, subduction, and liquefaction). These geoscience vocabulary words were mixed with general vocabulary such as pressure, heat, sliding, colliding, rubbing, vibrating, rippling, shaking, and grinding. The use of geoscience vocabulary words indicates sources of science information such as prior instruction or information from the internet or other media.

Graphical responses.

In the workbooks, all but one of the students incorporated some graphical representation of tectonic plates to describe the causes of earthquakes and tsunamis. Ten students represented two plates interacting, and one student showed only one plate in motion. Of the ten students that showed two plates interacting, six showed some representation of one plate going under the other plate as in a convergent subduction plate boundary. Four students showed the two plates colliding, but not subducting. The highly specific subduction plate boundary representations could only have come from students' exposure to geoscience information. There are no observable phenomena or everyday experiences in students' lives that would result in this type of graphical representation.

In contrast to the students' graphical representation of the *causes* of earthquakes and tsunamis reflecting exposure to geoscience information, most students' representations of the *effects* of earthquakes and tsunamis included some form of a highly stylized giant wave representing a tsunami. The stylized tsunami wave typically looked like a giant surf wave cresting and about to crash over. In the Earthquake Booklet for Students, four students showed a giant tsunami wave as the result of an earthquake. In the Tsunami Booklet for Students, four additional students showed a giant tsunami wave. As will be discussed further in this Results section, the giant, even supergiant, tsunami wave was a prominent theme across all data collections instruments and across all student responses. Unlike representations of a subduction plate boundary, representations of a giant tsunami wave are present in students' life experiences and prominent in media. Interestingly, the giant tsunami wave motif is prominent in tsunami warning and evacuation signage in coastal communities and ubiquitous in tsunami preparedness print and internet media.

Figure 3 shows one student's representation of a giant tsunami wave. During the interview, the interviewer stated, "The drawing you put there (referring to the student's drawing shown in Figure 3) you said you did that quickly, but it looks a whole lot like this" (interviewer shows a picture of a roadside tsunami warning sign common in the coastal region). The student responded, "That's where I got my (idea), that's how I usually draw tsunamis." However, when another student was asked whether the tsunami warning signs he had seen at the coast had any influence on his drawing of a giant tsunami wave, he responded, "No, but it does look like that, but no."

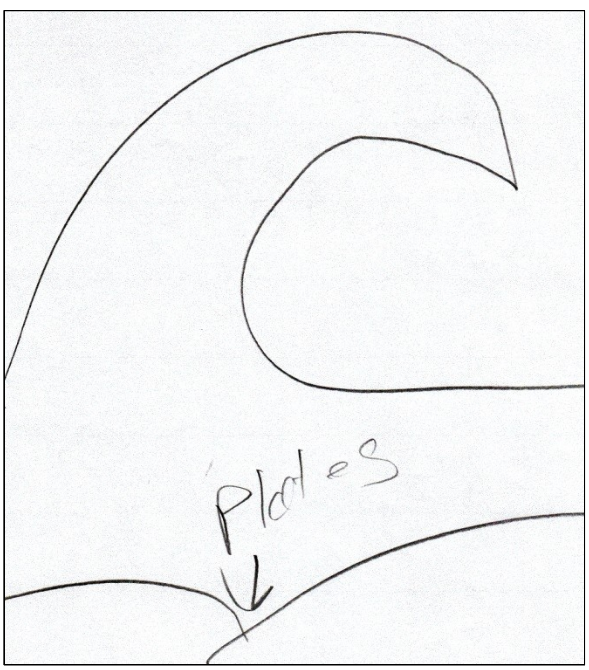

Figure 3. Student's graphical representation of a giant tsunami wave.

Verbal responses.

The semi-structured individual interviews provided an opportunity for students to represent their knowledge and beliefs verbally. The Interview Protocol included 15 fixed questions but also allowed for spontaneous questions. Of the 15 fixed questions, nine referred directly to students' prior responses in either the Earthquake Booklet for Students or the Tsunami Booklet for Students. This format allowed the interviewer to ask probing questions for further explanation about both what was in the original response and what was not in the original response. This format also allowed the students an opportunity to elaborate on, modify, or even replace their original workbook responses. With the exception of one student, the other students often provided a reason or rationale for a workbook response that would have made for a much longer written response. As a result, the researchers learned much more about the students' knowledge and beliefs than from the workbook responses alone. Figure 4 shows the format of the notations used in this report to represent the workbook and interview questions and student responses.

Format: Student Identifier.Data Collection Instrument.Question or Answer Number

Student Identifier: S1-S12

Data Collection Instrument:
I = Interview, EBS = Earthquake Booklet for Students, TBS = Tsunami Booklet for Students

Question or Answer Number: Q = Question, A = Answer, Number = 1 to n

Examples:
S1.I.A5 = Student1.Interview.Answer 5
S9.EBS.Q2 = Student 9.Earthquake Booklet for Students.Question 2
S12.TBS.A7 = Student 12.Tsunami Booklet for Students.Answer 7

Figure 4. Notations to represent questions and student responses.

The following sequence of questions/answers demonstrates how the interview allowed the student an opportunity to elaborate on the original workbook response, and consequently, allowed the researchers to learn more about the student's knowledge and beliefs.

S6.EBS.Q5	Do you think an earthquake will ever occur in this area? Why do you think this?
S6.EBS.A5	Yes, because we are due for one.
S6.I.Q25	So where does that knowledge come from? If a 5th-grader asked, what evidence would you give to support that, what would you tell them?
S6.I.A25	Because I think, I don't remember the exact year, I think was something like every 50 years, or I don't know if you know, but it was like every 50 years or 100 years we are due for an earthquake right, here at the coast. Yeah, and this is the time we are due for one, and it could happen anytime from now to awhile.
S6.I.Q26	So you've heard about this in science class (referring to a prior student response during the interview), but where did that original knowledge come from that we are due?
S6.I.A26	Well, I've been told that we've been due for one for like quite a while.
S6.I.Q27	Oh, okay, so you've heard it outside of science class too. So what would be the sources of that information?
S6.I.A27	My parents have told me that before.
S6.I.Q28	Your science teacher or your parents, where did they get that information? What is the source of our knowledge about earthquake and tsunami, where does it come from?
S6.I.A28	I don't really know. Ok, well I've heard it on the news before.

In this example, although the initial workbook response represented accurate and accepted science and preparedness knowledge, it also provided very limited insight into the student's knowledge and beliefs behind the response. During the interview interaction, the student elaborated on the initial workbook statement about why an earthquake will occur with a rationale (related to epistemic belief) that included a possible timeframe of "every 50 or 100 years" (related to science knowledge). The possible timeframe may have been a response to the researcher's question about what evidence to give to a 5th-grader.

For the researcher, in addition to learning more about the student's science knowledge of the timeframe, the elaborated response also demonstrated uncertainty (related to epistemic belief) about that timeframe. The elaborated response added emphasis to the student's claim that "we are due for one" by stating "it could happen anytime." In further probing the sources of the student's knowledge (related to epistemic belief), the student recalled hearing that "we are due" for an earthquake from parents and also from the news media. Taken together, these responses indicate that the student had received consistent messages from multiple sources that the area is due for an earthquake. It can be inferred that the student ascribed some degree of authority to those sources in making that claim, but that the student was uncertain about the ultimate source of evidence for that claim.

Gestural responses.

Students frequently used gestural responses during the interviews to describe their knowledge of the causes of earthquakes and tsunamis. Those gestures were recorded as parenthetical observations in the interview transcripts and were considered in the coding of the student responses. All but one student spontaneously used their hands to show the movement of tectonic plates during an earthquake and/or to show the movement of water during a tsunami. A student's gestural response matched very closely to his or her graphical response in showing the relative positions and movements of the components (e.g., one plate moving diagonally under another plate, two plates colliding with each other, and ocean water moving above the plates). What the gestures added to the textual and graphical responses was greater representation of the relative movements of the components.

The gestural representations became particularly important for the researchers to learn about the students' understanding of the mechanism for the cause of tsunamis since terms like grinding, flicking, snaps, and pops-up were typically used to describe the movement of the tectonic plates causing the tsunami, and words like vibrating, rippling, and shaking were typically used to describe the movement of water in the tsunami. In general, students' textual, graphical, and verbal descriptions of the mechanisms of tsunami formation tended to be vague. The gestural representations helped the researchers learn more about the students' conceptions of tsunami.

In the following example from the interview, the student's description of the tectonic plate movements causing the earthquake is quite thorough, but the description of the tsunami formation is vague. The student's lateral movement of his hands to show the formation of the tsunami while stating "it would make that rippling things and make the tsunami" added some additional information for the researchers.

S5.I.A2	I was showing (referring to S5.EBS.A2 diagram) the North American Plate and the Juan de Fuca Plate for this one. And I was putting that when they rub, it creates heat too, and the tension is building, the more it builds (student gestures with hands in

> contact to show two plates rubbing), the bigger the tsunami will be, or I mean earthquake will be. And I put that if it was under water it would make that rippling things and make the tsunami (student gestures with hands moving apart laterally from each other with fingers spread wide apart to show movement of the water), and debris would fall into the water and be coming in the water when the tsunami happens.

Other descriptions of earthquakes were not as well developed, but it was common for students to express a clearer understanding of a mechanism for earthquake than for tsunami. Gestures tended to elaborate more on the conception of "earthquake" than "tsunami."

Emotional responses.

An important aspect of answering the first research question, how do middle school students who live in a region affected by earthquake and tsunami describe their knowledge and beliefs about earthquake and tsunami, was to examine their emotional responses. Unlike most of the physical science topics addressed in conceptual change literature, asking students to think, write, diagram, and talk about earthquakes and tsunamis was asking them to address an emotionally charged topic, particularly given their location so near the Pacific Ocean in the Cascadia Subduction Zone. Every student in the study demonstrated knowledge that a very large earthquake and tsunami could occur in the region where they live at any time. They also typically represented their conceptions of the effects of earthquake and tsunami on the region as catastrophic.

Research has shown that when topic specific emotions are present in the learning environment, and they impact learning outcomes (Pekrun & Stephens, 2010; Goetz, Frenzel, Pekrun, Hall, & Ludtke (2007). Sinatra, Broughton, & Lombardi (2014) suggest that topic specific emotions, or emotions that are triggered by the characteristics of the information about a specific topic, are particularly important in relationship to controversial topics. In this study, the students' emotional responses about earthquakes and tsunamis could not be ignored, even though they did not fit well with the *a priori* conceptual change theoretical framework of knowledge schema, epistemic beliefs, and ontological beliefs (see Table 1) used in the study.

We categorized students' responses as representing emotion based on two criteria. The first criterion was did the student use an emotion-laden word in their response (e.g., scared, afraid, sad, terrified, devastated, anxious). All 12 students use emotion-laden words in describing the effects of earthquakes or tsunamis. The most commonly used emotional word was scared. During the interview, one student exhibited anxiety discussing the effects of earthquakes and tsunamis and stated, "I don't like thinking about this kind of stuff really …I get really bad anxiety thinking about this stuff, kind of, so that's why I haven't thought about it much." Interestingly, when asked if it was fine to continue the interview, she agreed, and she seemed more relaxed during the remainder of the interview.

Although emotional words or phrases were distributed throughout the students' responses, Question 8 in the Earthquake Booklet for Students was specifically designed to elicit an emotive response. Question 8 asked, "Suppose you experience an earthquake in the future. How do you think you would feel during the earthquake? Why would you feel this way?" The following examples show some of the student responses to this question.

S5.EBS.A8	Scared because I might die.
S7.EBS.A8	Devastated because my world would crumble before my eyes.
S9.EBS.A8	I would feel scared because I don't want my family dying.

S11.EBS.A8 Sick and scared because I can't move and am shaking uncontrollably.

S12.EBS.A8 Nervous and anxious because stuff would be falling and trying to kill you and me.

The second criterion we used for an emotional response was did the student use words or images that represented physical harm or death. Eight of the students used words or images that represented death. Four of those students represented dead people in their diagrams showing the effects of tsunamis. All of the student representations of death showed cartoon-like stick-figure people with x's over their eyes and typically laying in a prone position. It may be that the graphical format allowed students to represent their perception of this extreme effect of tsunamis in a less personal way that "externalized the issue" as discussed in narrative theory used in psychological therapy (White & Epston, 1990).

Geographic responses.

The last category in presenting the general results of how students describe their knowledge and beliefs of earthquake and tsunami examined students' use of geographical responses. In their responses to the workbook and interview questions and in response to questions using the outline map of the state, students demonstrated a high degree of familiarity with their geographic setting. All but one student named a specific location for high ground to evacuate to before tsunami inundation including several designated tsunami evacuation centers. Nine students accurately identified on the outline map the relative location of the small town where the school was located in the coastal mountains. All of the students were familiar with the nearest coastal town on the Pacific Ocean approximately 20 driving miles west of the school and the large city in the inland valley approximately 30 driving miles east of the school. This geographic knowledge was demonstrated extensively in students' descriptions of the causes and effects of earthquakes and tsunamis.

Students' Science and Preparedness Knowledge

Overview.

The second research question addressed in this study asked what science knowledge of earthquake and tsunami can be inferred from the students' descriptions? The third research question asked what preparedness knowledge of earthquake and tsunami can be inferred from the students' descriptions? For this study, science knowledge was defined as "the learner's knowledge of the geophysical causes and effects of earthquake and tsunami." Preparedness knowledge was defined as "the learner's knowledge of the risks to life, safety, and property from earthquake and tsunami and the knowledge of preparedness actions to reduce those risks."

To answer these research questions, we initially analyzed students' responses according to the three dimensions of knowledge derived from conceptual change literature (Naïve Idea, Synthetic Conception, and Accepted Understanding). According to the Coding Guidelines and Scheme (see Appendix C), each student interview response that demonstrated science or preparedness knowledge of earthquakes and tsunamis was initially coded as *Naïve Idea*, *Synthetic Conception*, or *Accepted Understanding* (science or preparedness) as evaluated by the researchers (see Tables 5 and 6).

During the two coding calibration rounds, we refined the original *a priori* operational definitions and identified example student responses for each code that served as references for applying the codes to subsequent student responses. However, during subsequent coding, we identified some student responses that could not be coded as *Accepted Understanding* because the response contained some lack of clarity or incompleteness. These responses also did not fit the operational definition for *Synthetic Conception* which required some aspects of incorrect conceptions combined with accepted understandings. As a result, we operationally defined a fourth knowledge dimension for science and preparedness knowledge called *Imprecise Conception*. The final set of four knowledge dimensions is operationally defined for science knowledge in Table 9 and for preparedness knowledge in Table 10.

Table 9

Final Dimensions of Science Knowledge

Naïve idea	Synthetic conception	Imprecise conception	Accepted scientific understanding
scientifically incorrect ideas that appear to derive from perceptions of direct or vicarious phenomenological and sociocultural experiences; these ideas reflect perceptions that would be prior to, or without direct connection to, science instruction and learning	descriptions or explanations that combine aspects of incorrect conceptions with scientifically correct knowledge in a somewhat functional manner	descriptions or explanations that lack precision and clarity in representing scientifically accepted understandings	descriptions or explanations that are consistent with current scientifically accepted understandings

Table 10

Final Dimensions of Preparedness Knowledge

Naïve idea	Synthetic conception	Imprecise conception	Accepted preparedness understanding

incorrect preparedness ideas that derive from perceptions of direct or vicarious phenomenological and sociocultural experiences; these ideas reflect perceptions that would be prior to, or without direct connection to, earthquake/tsunami preparedness instruction and learning	descriptions or explanations that combine incorrect conceptions with correct preparedness knowledge in a somewhat functional manner	descriptions or explanations that lack precision and clarity in representing accepted preparedness understandings	descriptions or explanations that are consistent with current accepted understandings of preparedness actions prior to, during, and after an earthquake or tsunami

Examples of dimensions of students' science and preparedness knowledge.

Each student's set of interview responses demonstrated a range of the dimensions of science and preparedness knowledge. The following examples illustrate the coding of each of the dimensions. These example question/response pairs are all from the same student (Student 1).

S1.I.Q1 Can you describe for me what your diagram here (referring to student diagram in EBS Q2) is showing about what causes earthquakes to occur?

S1.I.A1 Plates push against each other and so one is like that (student gestures with hands to show the interaction of the two plates) like because it pops back up and so it pushes back on the plate and shakes. *(This response was coded as Imprecise Conception for Science Knowledge because it contained many elements of an accepted scientific understanding but also was vague about what happens when the earthquake occurs.)*

S1.I.Q10 Where might those plates be and where might the earthquake occur (referring to the outline map of the state)?

S1.I.A10	I've heard like one is over here (student moves finger in a downward line off the coast of the outline map of the state). It's like small (referring to the oceanic plate) starting to go under. *(This response was coded as Accepted Scientific Understanding because the student accurately represented the relative location of the Cascadia Subduction Zone and referred to the smaller oceanic plate going under the other plate.)*
S1.I.Q12	Anything that you can think about or recall about earthquakes outside of the one you described here (referring to the outline map of the state where student had drawn the location of the offshore subduction zone)?
S1.I.A12	Probably in the United States, like how they (referring to tectonic plates) are pretty much big islands, like they are pretty much moving [What are moving?] the lands (referring to the lands that make up the states). *(This response was coded as Synthetic Conception for Science Knowledge because the response referred to moving plates causing earthquakes but mistakenly associated tectonic plates with states as land masses.)*
S1.I.Q40	Would this table be a good table (to go under) or where would we go (referring to if the ground started shaking right then and the student's previous statement to go under a table)?
S1.I.A40	No, I'd go to the classroom. *(This response was coded as Synthetic Conception for Preparedness Knowledge because the student had prior knowledge of a safer location but did not provide the accepted response to immediately take cover.)*
S1.I.Q66	Describe some of the ways you can prepare for a tsunami.
S1.I.A66	If you pack stuff like I was mentioning with the earthquakes, like have medical stuff, food, water, cards, it you have that with you and the tsunami came, just run as fast as you can upstairs, or no, up to higher ground. *(This response was coded as Accepted Preparedness Understanding because the*

	student described a variety of useful supplies and described moving quickly to high ground.)
S1.I.Q67	Ok, and how would you know where high ground is?
S1.I.A67	You'd go to the highest place you could see. *(This response was coded as Imprecise Conception for Preparedness Knowledge because the student refers to the "highest place" which is an accepted preparedness response, but the response does not take into account any other potentially relevant factors such as how to reach the highest place and how long it would take.)*
S1.I.Q76	Suppose in the future you were at the coast and you thought a tsunami was coming. What would you do?
S1.I.A76	I would try to take pictures, you know, before and after pictures. *(This response was coded as Naïve Idea for both Science Knowledge and Preparedness Knowledge because the response does not demonstrate science knowledge of the potential suddenness and power of repeated incoming and outgoing tsunami surges and does not demonstrate knowledge to first move quickly to high ground.)*

Distribution of students' science and preparedness knowledge codes.

Each student demonstrated some degree of distribution in the dimensions of science and preparedness knowledge coded for his or her responses. Table 11 shows the percentage of each student's responses that was coded to the four dimensions of Science Knowledge. Table 12 shows the percentage of responses coded to the four dimensions of Preparedness Knowledge. Two observations stand out in an initial review of these tables. First, the distribution of responses for the four dimensions differs greatly between individual students. For example, the percentage of responses coded as Naïve Idea for Science Knowledge ranged from a low of 0% for six students to a high of 23% for one student. The percentage of responses coded as Accepted

Science Understanding ranged from a low of 0% for one student to a high of 76% for one student. In comparing the responses coded for Preparedness Knowledge, the percentage coded for Naïve Idea ranged from a low of 0% for two students to a high of 27% for one student. Accepted Preparedness Understanding ranged from a low of 36% for one student to a high of 79% for one student. These differences suggest that even within the same classroom of learners, there can be significant differences between students' science and preparedness knowledge of earthquakes and tsunamis. Decades of research in science education examining the effect of prior knowledge and experience validate the result that learning experiences in the same classroom will vary widely.

Table 11

Percentage of Responses Coded to Each Science Knowledge Dimension

	Dimension			
Student	Naïve idea	Synthetic conception	Imprecise conception	Accepted scientific understanding
S12	0	56	44	0
S9	0	74	13	13
S10	0	80	0	20
S2	0	47	16	37
S7	0	33	25	42
S5	0	0	24	76
S11	7	69	13	19
S8	7	31	38	25

S6	11	26	11	53
S1	14	50	7	29
S3	16	71	0	15
S4	23	45	9	23
Average	7	49	17	29

Table 12

Percentage of Responses Coded to Each Preparedness Knowledge Dimension

	Dimension			
Student	Naïve idea	Synthetic conception	Imprecise conception	Accepted preparedness understanding
S7	0	28	6	67
S2	0	18	9	73
S3	4	25	4	68
S5	4	0	17	79
S8	5	15	5	75
S10	6	28	6	61
S9	7	20	7	67
S6	11	32	11	47
S12	13	0	40	47
S11	13	7	7	73
S1	17	43	3	38
S4	27	27	9	36

Average	9	20	10	61

The second observation that stands out in examining these tables is that average percentages across all students differed greatly between Science Knowledge and Preparedness Knowledge. Specifically, the average percentage for Accepted Preparedness Understanding (61%) was more than double the average percentage for Accepted Scientific Understanding (29%). Additionally, the average percentage for Preparedness Knowledge Synthetic Conception (20%) was less than half the average percentage for Science Knowledge Synthetic Conception (49%).

The differences in the average percentages across all students between Science Knowledge and Preparedness Knowledge may be interpreted to mean that for the same group of learners, science knowledge and preparedness knowledge for earthquake and tsunami are largely unrelated. However, a closer look at the student responses that generated the codes suggests a more nuanced interpretation. The design of this study to code at the level of individual question/response pairs allowed for more fine-grained analysis of students' knowledge and beliefs and facilitated a broader synthesis across similar codes for possible patterns and themes. Additionally, students' responses were coded not only for science and preparedness knowledge but also for epistemic and ontological beliefs.

Patterns and Themes in Students' Responses

In conducting a more fine-grained content analysis, we first focused on three students (S1, S4, and S6) who exhibited a similar pattern in the distribution of percentages across the four dimensions of science and preparedness knowledge, but the pattern differed significantly from the other nine students. These three students had relatively high percentages for Science

Knowledge Naïve Idea (14%, 23%, and 11% respectively) and relatively high percentages for Preparedness Knowledge Naïve Idea (17%, 27%, and 11% respectively). These three students also had relatively low percentages of Accepted Preparedness Understanding (38%, 36%, 47% respectively). According to conceptual change theory, students' naïve ideas of phenomena that derive from perceptions of phenomenological and sociocultural experiences are often highly resistant to change and are often assimilated into students' synthetic conceptions after having received domain specific instruction (Chi, Slotta, & de Leeuw, 1994; Vosniadou & Brewer, 1992). Since these three students had relatively high percentages for Naïve Ideas codes, we examined their responses to identify themes in their naïve ideas. We also examined their Accepted Preparedness Understanding responses to identify themes that were present even though the students also had relatively high percentages of naïve ideas.

In examining the Accepted Preparedness Understanding codes for these three students, two major themes emerged. The first theme was that earthquake and tsunami could occur at any time in the area where they lived. The second theme was strong intent to protect self and family from harm. In subsequent analysis, these two themes were prominent in the Accepted Preparedness Understanding codes for all students.

In examining the Naïve Idea codes for these three students, two additional major themes emerged. The first was giant, even supergiant, tsunami waves with near absolute and unavoidable catastrophic effects. The second was the diminished effects of earthquakes as compared to tsunamis. In subsequent analysis, these two themes were almost exclusively the basis for all of the naïve ideas expressed by all students. Out of 41 total student responses coded Naïve Idea, only three responses did not directly relate to these two themes. Additionally, these themes were also evident in many of the responses that were coded Synthetic Conception indicating that some aspects of students' naïve ideas of earthquake and tsunami were combined with correct scientific or preparedness conceptions.

The theme of earthquake and tsunami occurring at any time was prominent in the Accepted Preparedness Understandings for all students. All students recognized that they lived in a region where a large, destructive earthquake and tsunami could occur as described in the following examples.

S8.EBS.A5	Yes (earthquake will occur in the area) because we have had one before and we are due for one soon.
S11.I.A10	It (earthquake) could happen in the time of this interview. But if not, you never know how long you you're going to live, so it could happen when I'm alive. I'm going to mostly say that it will happen in this area because that's where everything is supposed to happen.
S2.TBS.A5	Yes (tsunami will occur along the coast) and very soon because one hasn't happened in a long time. We are overdue.

The theme of the students' strong intent to protect self and family from harm was also prominent in the Accepted Preparedness Understandings for all students as described in the following examples.

S3.I.A21	You want to try to stay safe because I mean you want to live to the fullest. You don't want to die because like an earthquake or something like that you want to stay safe. You want to stay alive for as long as possible.
S9.EBS.Q7	Suppose you experience an earthquake in the future. What do you think you would do during the earthquake? Why would you do this?
S9.EBS.A7	Try to protect my little sister and brother as much as I could because I love my whole family very much

and also try to stay in contact with my family and (student names friend).

S11.I.A16 And you definitely want to get enough food and water to sustain yourself and your family because you're not going to be able to just walk to the store when there's an earthquake going on. You probably won't walk at all, but yeah, you just want to make sure that you have water and food. My family always has like canned food and water because we honestly think that it will happen soon.

The theme of a giant, even supergiant, tsunami wave with near absolute and unavoidable catastrophic effects was manifest in several concepts. Although all students related tsunamis in some way to plate motion or earthquakes, the mechanism for tsunami formation was often unclear, vague, or not understood at all. In some cases, the plate motion or earthquake causing the tsunami was described as a vibrating motion. The vibrating motion was related to waves that built up into a giant tsunami wave. In some cases, the relatively weak earthquake motion needed to be augmented with other mechanisms to form the giant tsunami wave. The following examples describe these conceptions.

S9.I.A8 I don't remember if it was like first a tsunami comes then the earthquake or if the earthquake then a tsunami, so I just did like a tsunami coming toward land (referring to student diagram).

S10.I.A31-32 I think usually they (tsunamis) occur after an earthquake. I don't know, when the ground is shaking a lot, then a tsunami occurs.

S11.I.A23 Well, like in the earthquake one (student diagram) the plates are shifting and the ground is moving and everything is kind of shaking. What that does, it causes massive waves, or more like waves and then one giant wave to occur.

S3.I.A29-30 So the earthquake shakes up the land, and the waves of course are going to get going faster and faster and the waves are going like this (student waves hand back and forth in the air) and in and out really fast and eventually the waves will build up to one big wave and that will just come crashing in… the water can get caught up in the tornado and still be like spinning and once it is done, the water will splash… it will be like a really big wave.

S1.I.A52 So there's an earthquake and the wind helps the wave get pushed over.

S2.I.A53 I feel like it's probably sort of like a nice day probably just a little cloudy, and that's when the earthquake is going to happen. But then I feel like as the tsunami is coming in, it's going to start to get windy, and probably a little rainy, and nasty.

Eight of the twelve students graphically represented a tsunami as a giant cresting wave in their diagrams in the Earthquake Booklet for Students or Tsunami Booklet for Students. Four of the students indicated on the outline map of the state that a tsunami would inundate the large inland city which is approximately 50 miles from the coast and separated by the coastal mountain range. Given the students' high degree of familiarity with the geographic setting demonstrated during the interviews, the extensive penetration of the tsunami to the inland valley suggests their conception of an extremely powerful wave. Four students represented dead people in their diagrams showing the effects of tsunamis, but no students represented death in their diagrams of earthquakes. In many of the student diagrams, the giant tsunami wave was approximately three times taller than the buildings. In general, the students described the effects of tsunami in catastrophic terms and expressed much greater concern about harm and damage from tsunami than from earthquake. The following examples describe these conceptions.

S6.I.A47-48 (Describing diagram in TBS) It's just like a view of what the tsunami will be like, how big it is up close. It's like a big tsunami wave coming through and dipping down…The wave is like hitting the person and he's like, he can't do much.

S11.I.A5 The real reason that people are getting scared of this earthquake at least around here is because the tsunami that will probably take out almost all of (student names the nearest coastal town).

S11.I.A27 Tsunamis are normally 100 to 200 foot waves and we actually looked on this website that showed how much range it should have and so the best places to be are … out of this general area. (The student draws an arc on the outline map of the state to show how far the tsunami will reach and the arc is almost to the location of the school. The school is located in the coastal range approximately 20 driving miles from the coast).

S12.I.A38-39 The trees would be affected, a lot of the buildings in the (student names two large inland cities) would be gone. The beaches and stuff would be ruined. All the houses along the beach in (student names nearest coastal town) and on those hills would be gone … (from) the tsunami and maybe the earthquake.

S6.I.A31-32 I would run away probably (if experiencing an earthquake). I would try to get away as fast as I can with anything … as far away from the ocean as I can so the tsunami doesn't hit me, and the earthquake doesn't have as much power.

The giant tsunami wave theme was also represented in an important aspect of students' preparedness knowledge. Rather than understanding that the shaking from an earthquake would be the warning to evacuate to high ground to avoid tsunami inundation, four students indicated that they would know that a tsunami was coming by seeing a giant wave, or waves build up as described in the following examples. Students may have been confused about the distinction between distant and near-field tsunamis, but that that did not seem to be the case because only two students mentioned tsunamis coming from someplace else to their coastal area.

S4.I.A47	I am sure if a giant wave was coming at me, I would get the idea. I don't really know how to tell if a tsunami is coming.
S8.I.A43	Once you start seeing the waves build up like further and further out, once you start seeing them getting bigger, then you might want to go to high ground.
S12.TBS.A7	You would see huge waves.

In addition to some of the examples already cited, students' conceptions of the diminished effects of earthquakes compared to tsunamis were represented in some unexpected ways. Two students who described the cause of earthquakes as the motion of tectonic plates also described the size of those plates as extremely small in comparison to accepted scientific understandings. Two other students referred to one of the plates in the Cascadia Subduction Zone as the "small" plate. Perhaps these students' conceptions of the relatively small size of tectonic plates resulted in conceptions of relatively small effects from earthquakes caused by the plate movements. The following are interview excerpts where students talk about the size and extent of earthquake. Note the language about "plate" size suggesting that the colloquial understanding of a dinner plate may interfere with the concept of tectonic plate.

S3.I.Q5	So where are these plates?
S3.I.A5	They can be anywhere, like under the ground pretty much.
S3.I.Q6	When you think of them, are they huge or are they small?
S3.I.A6	They are pretty big I think, about the size of this table, maybe even bigger, just kind of sliding around bumping into each other.
S12.I.Q6	Where are these plates at? Are they all over the world? Are there many of them or few of them?

S12.I.A6	I mean there are many of them in the oceans and stuff.
S12.I.Q7	And about how big are these plates of the Earth?
S12.I.A7-8	I don't know. I would say pretty big…maybe like a four-wheeler or something.
S4.I.Q32	Would this area where we are right now (the school approximately 20 driving miles from the coast) be affected (by earthquake)?
S4.I.A32	I'm sure, yes. We are pretty close to the coast (where the student previously stated the earthquake would occur), so I would assume it would affect us a little.
S4.I.Q34	And what might be some of the effects?
S4.I.A34	I don't know, maybe feeling some shaking in the ground or even a tree or two falling.

Although all of the students had participated in earthquake drills in school and described some form of the accepted preparedness response of Drop, Cover, and Hold On, several students also described one way of preparing for earthquakes was to have a safe place to go to. It was not always clear whether the student was referring to going to the safe place before the earthquake, (as if there was some advance warning), as soon as the earthquake occurred (as if there was time before severe shaking), or after the earthquake stopped to avoid tsunami inundation. Several students stated that their first response to an earthquake would be to run or to get out of the building. Some of the students' responses seemed to imply that the less powerful effect of earthquake afforded time to go to the safe place or get out of the building. The following are examples of variations of these ideas.

S1.I.Q36	So let's say there was an earthquake right now. What do you recommend we do?
S1.I.A36	Run out of the building.

S2.I.Q30	So let's say an earthquake happened right now and we felt the shaking, what would we do?
S2.I.A30	Well, obviously you're going to want to get to open ground, so I would go up to the track. Probably that's the most open place to go to. Or, if you don't have time, go under something steady. That would be fine. Just go under a table or something and wait.
S2.I.A32	Is this like an outside exit (student quickly and unexpectedly opens the nearby exterior door)? Yes, it is. Amazing, so I can just run out.
S5.I.Q23	Now let's say the earthquake did occur. What do you think you would do and why would you do it?
S5.I.A23	I would just naturally run. I would just run because I always think that running away you can get to safety …I would always think trees would fall down during the earthquake. I would always want to be in an open area where there are no trees, a high area too where the tsunami couldn't reach.
S5.I.Q24	So here we are right now and we feel the ground shake. Right now what do we do?
S5.I.A24	I would just run out, run to the track because it's open and there are no big trees that would fall on me.
S3.I.Q19	Can you explain for me how each of the ways you have here (referring to the Earthquake Booklet for Students) helps people be prepared for earthquake?
S3.I.A19	First, you want to find a safe place you can go if an earthquake is going to happen like somewhere with no windows or anything that can break and hurt you. A basement with nothing in it would be a really good idea with no windows or anything like that.

To summarize the results of analyzing the codes for students' science and preparedness knowledge, four major themes emerged in the students' responses. The two themes which reflected more Accepted Understandings were earthquake and tsunami could occur at any time in the area, and strong intent to protect self and family from harm. Two other major themes which reflected more Naïve Ideas were the giant, even supergiant tsunami wave with near absolute and unavoidable catastrophic effects, and the diminished effect of earthquakes as compared to tsunamis.

Students' Epistemic Beliefs

The fourth research question addressed in this study asked what epistemic beliefs about earthquake and tsunami can be inferred from the students' descriptions? Epistemic belief refers to the student's beliefs about the nature of his or her knowledge about earthquake and tsunami. Based on conceptual change literature, four dimensions of *Epistemic Belief* were incorporated in this study—*Certainty*, *Simplicity*, *Source*, and *Rationale*. The results for each of these dimensions are described separately.

Certainty.

As operationally defined for this study, Certainty refers to the degree to which the student represents his or her science or preparedness knowledge as complete, certain, fixed, tentative, or subject to change. Each student interview response was coded for Certainty if the student explicitly stated a word or phrase that indicated his or her level of certainty about the response using the following coding scheme: *low certainty* (e.g., "I guess," "don't know," "not sure," "maybe," "possibly," "could be"); *moderate certainty* (e.g., "I think," "pretty sure," "most likely"); and *high certainty* (e.g., "know for sure," "I am positive, "definitely"). During the calibration coding rounds it became evident that although we could apply the codes consistently to the student responses, the inconsistent presence of words or phrases indicating certainty in a response and the students' idiosyncratic use of the words or phrases invalidated any comparisons based on the codes.

Although it was not possible to compare Certainty across a wide spectrum of responses, two targeted questions in the Interview Protocol provided for analysis at the student level. Question 3 asked, “How sure are you about your descriptions of the causes and effects of earthquakes?” Question 9 asked, “How sure are you about your descriptions of the causes and effects of tsunamis?” Only one student expressed that he was highly certain about his knowledge of both earthquake and tsunami. This student also had the highest percentage of Accepted Science Understandings and Accepted Preparedness Understandings. Interestingly, this student stated that 100 percent of his knowledge of earthquakes and tsunamis came from school. This student was one of two students in the study who had also been in Mr. B’s science class as a 6th-grader in the 2013-2014 school year and had participated in the tsunami coring project.

Two students expressed that they had very little confidence in their knowledge of both earthquake and tsunami. One of these students had the highest percentage of naïve ideas in both science knowledge and preparedness knowledge. Interestingly, this student stated that 100 percent of her knowledge of earthquakes and tsunamis came from “Google.” Two students stated that they were highly certain about their knowledge of earthquakes, but had very little confidence in their knowledge of tsunamis.

A spontaneous interview question answered by seven students asked if they would consider themselves to be a leader who knew what to do, or a follower of someone else, if there was an earthquake and tsunami. Three of these students stated that they would be leaders. One student qualified her answer based on her situation in the following manner:

> S2.I.A62-63 Well, if I was at home, I’d probably consider myself a follower of my parents. If I was here (at school) I would probably consider the teacher … (but if with

> a bunch of students) and we're like all panicking
> around the room, and what do we do, I would
> probably be like, okay, I can do this.

Question 13 in the Interview Protocol asked, "Do you think your knowledge about earthquakes and tsunamis will change in the future, and why do you think this?" One student stated that his knowledge would probably not change because "the stuff that I've learned in class is the only stuff I've ever learned about earthquakes, and I think my knowledge would stay the same as it is say 10 years from now." However, the other 11 students stated that their knowledge would change because of several possible reasons including that they would learn more in school and learn more if the earthquake and tsunami actually happened.

Simplicity.

As operationally defined for this study, Simplicity refers to "the degree to which the science or preparedness knowledge that the student represents is simplistic or complex conceptual understandings that relate facts together." Each student interview response that was coded for science or preparedness knowledge was also coded for Simplicity using the following coding scheme: *simplistic conception* (one or two simple facts or components); *moderately complex conception* (multiple components or a relationship between components); and *complex conception* (multiple relationships between multiple components). The coding for Simplicity required the researcher to evaluate the student's response, so the assigned code represented not the student's belief about the simplicity or complexity of his or her own knowledge about earthquakes and tsunamis, but the researcher's evaluation of the student's knowledge.

Although the researchers could consistently apply the codes for Simplicity to the student responses, the unit of analysis, the individual student response, complicated any meaningful analysis of the Simplicity codes. For example, one student may have given a detailed response to a single interview question that was coded as a *complex conception*, but another student may have demonstrated the same level of complex conceptual understanding, but distributed over several questions from the interviewer. As a result, only a general observation can be made about the Simplicity codes. In general, *simplistic conceptions* were often coded for responses that were also coded as naïve science knowledge or preparedness knowledge. The responses that reflected more accepted understandings of earthquakes and tsunamis required talking about more than one concept and how they interacted.

Source.

As operationally defined for this study, Source refers to “the sources that the student represents for his or her knowledge of earthquake and tsunami.” A Source code was given to each interview response where the student explicitly stated a source, and multiple codes could be assigned to each response. Twelve specific source codes and two generic codes (*other* and *unsure*) were used to categorize the sources identified by the students. Some students mentioned the sources of their information in the course of answering a question without being prompted. In many cases, the students identified their source of knowledge when asked a follow-up question by the researcher (e.g., Where does that knowledge come from? and Where would you search for that information?). The most prevalent sources identified in the individual codes were school, teacher, internet/online, movies/TV/videos/radio, and parents/family.

Toward the end of each interview, the student was asked to draw a large rectangle and then divide it into parts and label each part to represent the sources of their current science and preparedness knowledge of earthquake and tsunamis. Two students asked for clarification of the task, and with that clarification, all students completed the task without any difficulty. To analyze the students' responses, we assigned approximate proportional values to each section and grouped common student labels into categories (e.g., "class" with "school").

Table 13 shows the percentages of students' science and preparedness knowledge of earthquakes and tsunamis. The most prominent self-reported source of earthquake and tsunami knowledge for these students was School/teacher. The next most prevalent category was Internet/media where media represented primarily TV and radio. The third category, Parents/family, was approximately half as prevalent as Internet/media. Five students indicated that parents and family was a significant source of their knowledge of earthquake and tsunami. During the interviews, four students described emergency preparedness activities they had participated in as a family.

When student S1 was asked what was meant by "mind" being a source of his knowledge, he replied that it meant his own thinking about earthquakes and tsunamis. Student S2 had attended a camp where they discussed earthquake and tsunami safety and her family had attended a community event on disaster preparedness. Student S3 was the only student who listed friends as a source of knowledge, but friends also came up from time to time in the interview response codes. Both student S3 and student S7 listed scientists as a source of knowledge which was inferred to mean the original source of the science knowledge that was learned through some other source. Student S4 was the only student to list Internet/media as the complete source of knowledge. She was the student who described her anxiety thinking about earthquakes and tsunamis during the interview. Student S6 had participated in a robotics activity at school which included earthquake and tsunami information. Student S11 stated that he had lived by the ocean all of his life and "seeing changes in the ocean" was a significant source of his knowledge.

Table 13

Percentage of Students' Sources of Knowledge of Earthquakes and Tsunamis

Student	School/ teacher	Internet/ media	Parents/ family	Other	Other
S1	25	25		50 (mind)	
S2	40		30	20 (camp)	10 (community)
S3	20		25	30 (friends)	25 (scientists)
S4		100			
S5	100				
S6	60		25	15 (robotics)	
S7	30	30	30	10 (scientists)	
S8	40	60			
S9	20	30	50		
S10	100				
S11	35	35		30 (ocean)	
S12	50	25		25 (books)	

Rationale.

As operationally defined for this study, Rationale refers to "the student's use of a rationale to support his or her claims of science or preparedness knowledge." Rationale was coded as either present or not present for each interview response that was also coded for Science Knowledge or Preparedness Knowledge. The original intent of the Rationale code was to determine if students voluntarily provided rationales for certain knowledge claims and did not provide rationales for other claims in their responses. In practice however, the student's own approach to answering questions, which may reflect individual habits and motivation at the time of the study was probably the prime determinant of whether or not a rationale was provided for a claim. As a result of these confounding factors, we did not analyze the Rationale codes.

Students' Ontological Beliefs

The fifth research question addressed in this study asked what ontological beliefs about earthquake and tsunami can be inferred from the students' descriptions? As operationally defined for this study, Ontological Belief refers to the student's beliefs about the nature of earthquake and tsunami phenomena and/or the nature of individual and group preparedness phenomena. Based on conceptual change literature, we identified three *a priori* dimensions of ontological belief for analysis in this study—*Thing*, *Direct Process*, and *Emergent Process*. Each interview response that was coded for Science Knowledge or Preparedness Knowledge was also coded for Ontological Belief.

In the early stage of the coding process we encountered a few student responses that didn't fit well with any of the three *a prior* categorical definitions. These responses incorporated some degree of an entity or process acting with intent as a governing agent toward a certain outcome. Based on these student responses, we created a fourth dimension called *Superintendent* that was operationally defined as responses that described a governing agent or teleological process.

We did not encounter any student responses that referenced a deity or divine power, but this may not be surprising since the study was conducted in a public school setting. Given the presence of faith-based belief systems in the general population, we may have encountered these types of responses if the study had been conducted in a private school or an informal learning setting. The final set of dimensions for Ontological Belief are operationally defined in Table 14.

Table 14

Final Categorical Definitions for Ontological Belief

	Dimension			
Ontological belief	Thing	Direct process	Emergent process	Superintendent
the learner's beliefs about the nature of earthquake and tsunami phenomena and/or the nature of individual and group preparedness phenomena	- unconnected to process - isolated entity, occurrence, or event - random, unpredictable or predictable entity, occurrence, or event - controllable or uncontrollable entity, occurrence, or event	- the observed occurrence/event or outcome/pattern is the result of a linear, sequential, or cause/effect interaction - a single controlling agent directly or indirectly causes the occurrence/event or outcome/pattern - a limited duration occurrence/event or outcome/pattern is not related to an ongoing process (i.e., what happened prior to, what will happen after)	- the interactions of multiple agents cause the occurrence/event or outcome/pattern - the agents can act simultaneously and independently - the outcome/pattern emerges from the collective interactions of the agents - the process can continue beyond the observed occurrence/event	- a governing agent or teleological process

Of the 435 responses that were coded with an Ontological Belief code, 104 (24%) were coded as Thing. Of the responses coded as Thing, 57 (55%) were for responses also coded as Science Knowledge and 47 (45%) were also coded as Preparedness Knowledge. The giant tsunami wave theme was prominent in responses coded as Thing where there was no causal agent described for the tsunami wave. The following examples illustrate students' responses coded as Thing. An explanation of the coding is provided with each example.

S4.I.A1	Well, I wasn't really sure exactly how earthquakes are made or formed …so I just showed the Earth shaking. *(The student's response was the only response that did not show some process of tectonic plate interaction as the cause of earthquakes. The student's diagram shows a circle labeled "Earth" with symbols and labels indicating that it is shaking. The diagram included the phrase "Something happened." No process is represented in the diagram or in the interview response.)*
S4.I.Q15	What might be a good way that people could prepare generally for an earthquake?
S4.I.A16	Like, kind of like shelter, or like I guess a bomb shelter is the only thing that's coming to mind right now. *(The student represents a thing, a bomb shelter, as a way to prepare for an earthquake. No process is represented.)*
S1.I.Q46	Can you describe for me what your diagram here (in workbook) is showing about what causes tsunamis to occur?
S1.I.A46	Pretty much an earthquake in water. *(The student's diagram just showed a large tsunami wave with no representation of any process causing the tsunami. In a subsequent response, the student did describe a process in the formation of tsunami, and that response was coded with a process code.)*

Of the 435 responses that were coded with an Ontological Belief code, 316 (73%) were coded with a process code. Of the responses coded with a process code, 264 (84%) were coded as Direct Process, and 52 (16%) were coded as Emergent Process. Direct Process responses often represented a fixed sequence or fixed outcomes that were determined by a single controlling agent. Two common responses that were coded as both Direct Process and Accepted Preparedness Understanding were some form of the recommended Drop, Cover, and Hold On response to earthquake and the recommended Go To High Ground response to risk of tsunami inundation. The following examples illustrate students' responses coded as Direct Process.

S10.I.Q1 So could you describe for me what is going on in your diagram (of the causes of earthquakes) and explain to me what you are thinking?

S10.I.A1 They are like shifting over each other. *(The student represents a simplistic direct causal process, shifting over each other, for producing an earthquake.)*

S8.I.Q30 If you had to lead an earthquake drill for an elementary school class, what would you be telling them?

S8.I.A30 Get under tables and make sure you head is under covers so that they don't keep getting hit. *(The student describes the Drop, Cover, Hold On response. The response is a highly recommended earthquake preparedness response but is also an example of a fixed sequential direct process.)*

S4.I.Q49 Suppose you were at the coast and you thought it (tsunami) was actually coming. So what would you do?

S4.I.A49 I am sure the brain probably wouldn't be working because of all the fear and adrenaline running through me. My first reaction would probably be to run. (*The student represents a direct cause/effect sequence with no other factors or decision-making* *affecting the response such as knowledge of where to go.)*

Emergent Process responses have one or more of the following characteristics: multiple agents acting simultaneously and independently, the outcome emerging from the collective actions of the agents, and the process continuing beyond the observed event. The following examples illustrate students' responses coded as Emergent Process.

S8.I.A56	I think they happened because of the plates and stuff moving, but then they're so destructive because of the vibrations coming up and shaking the ground so much that things aren't built to sustain that much strength, that much vibration. So like concrete and steel would withstand that, but most of the houses around here are made out of wood, which could snap and fall and do a whole bunch of other things. *(The student includes multiple agents affecting the outcome including the plate motions, the ground shaking, how things are built, and three different building materials.)*
S3.I.A52	Yeah, the evacuation route, like we (family) have walked the trail before to the evacuation route before. We kind of know where it is, like we've been there only a couple times, so I'm not quite sure yet. So we were trying to learn more everything like where this is so that in case it does happen, we know right where to go. *(The student describes an ongoing preparedness process where they are interacting with the trail to learn everything they can so they are agents that influence the outcome, not just the tsunami as the controlling agent.)*
S5.I.A67	The land is moving and the continental plates are pushing on each other, and forming new lands and stuff, but when they're rubbing against each other they build up pressure like I said in the earthquake. And the more pressure or stuff that they push against, rub against each other, more earthquakes will happen and more plates that are pushing into each other. *(The student describes ongoing*

geophysical processes involving multiple agents acting simultaneously with various outcomes.)

In examining the distribution of Ontological Belief codes across students, the responses from two students, S3 and S11, accounted for half of all of the Emergent Process codes. For these two students, most of their Emergent Process codes were for Preparedness Knowledge responses indicating that they had a different conception of the nature of preparedness than the other students. What characterized these students' conceptions of preparedness was an awareness of multiple factors or actions that influence a successful outcome and an if/then thought process rather than a fixed way of thinking.

We found that the Superintendent dimension was only present in students' Science Knowledge responses. Of the 435 responses that were coded with an Ontological Belief code, only 15 (3%) were coded as Superintendent. The following examples illustrate students' responses coded as Superintendent.

S9.I.A13	People could say there's not going to be one (an earthquake) but you don't know how the world works. If the world decided that "oh, I'm going to have an earthquake," then it could, because anything could happen.
S11.I.A35	It's just a natural thing that happens. You can't stop what Nature has planned. If the Earth wants to basically cause and earthquake, then that's what is happening.
S7.I.Q67	Suppose a friend asks you, if earthquakes and tsunamis are so destructive to people and to buildings, why do you think they happen at all?
S7.I.A67	Because it's always good to like, kind of, have a little small restart or like a setback. Sometimes places like need a wildfire because like some big trees could be there for like hundreds of years and kill all the small plants. They won't be able to be

> grow. But if a like a wildfire came through there and took that out, then more life would be able to grow back. So I believe sometimes things do need to happen, so it could be like a setback and you could learn more things about it.

The complexity of the natural science processes involved in earthquakes and tsunamis and the complexity of the preparedness knowledge, which includes knowledge of risk and behaviors to mitigate risk, make students' ontological beliefs an informative construct in this study. The additional ontological belief category identified in the results of this study, Superintendent, suggests an important dimension of learners' conceptions that challenges traditional instruction in science as well as in public safety and preparedness.

Chapter 5: Discussion

This study examined students' knowledge and beliefs of earthquake and tsunami through the lens of conceptual change theory. The goal of the study was to add to the body of research that addresses the theoretical basis for effective earthquake and tsunami education.

Conceptual change theory was used as the theoretical framework for this study based on the premise that students' conceptions of earthquake and tsunami comprise multiple constructs including their science knowledge, preparedness knowledge, epistemic beliefs, and ontological beliefs and that each of these constructs comprise multiple dimensions. Our results support this premise and indicate that the constructs and dimensions of conceptual change theory provide a valuable lens for examining students' conceptions of earthquake and tsunami and for understanding how those constructs and dimensions influence concept development. This understanding can contribute to the content and pedagogy of effective earthquake and tsunami education. We believe that the results of this study indicate that conceptual change theory can be a useful lens to examine learners' conceptions of other important socioscientific issues such as climate change.

Methodological Implications

Many studies of students' knowledge of earthquake and tsunami have focused on whether or not students have correct knowledge of accepted science understandings of the geophysical causes and effects of earthquakes and tsunamis and correct knowledge of accepted preparedness measures. This study differed in that all four constructs that make up a student's conception of earthquake and tsunami—science knowledge, preparedness knowledge, epistemic beliefs, and ontological beliefs—were examined. Additionally, using the lens of conceptual change theory, the focus was not on whether students had correct knowledge, but what naïve ideas, synthetic conceptions, and accepted understandings made up those conceptions and what epistemic and ontological beliefs underlie those conceptions.

The methods used in this study were designed to make visible the multiple dimensions of students' knowledge and underlying beliefs. This required the use of multiple data collection instruments including two workbooks, a semi-structured interview, an outline map of the state, and a template for recording students' sources of knowledge. The data collection instruments were designed to elicit multiple modes of student response including textual, graphical, and verbal responses. Additionally, students used gestural responses to represent their conceptions of geophysical phenomena. Each mode of student response contributed in unique and complementary ways to making visible the students' knowledge and beliefs. The students' responses demonstrated that earthquakes and tsunamis are emotionally-charged topics for these students who live in a region subject to the occurrence of a megathrust Cascadia Subduction Zone earthquake and resulting tsunami at any time.

The pre-study activities with the students, the phrasing of the workbook prompts, and the semi-structured interview format were designed to encourage students to think about earthquakes and tsunamis in ways they may not have done so before and to express their thinking without concern of being evaluated as correct or incorrect. The purpose of this method was to make visible students' underlying knowledge resources and beliefs even as their knowledge "dynamically emerged" (Brown, 2014) in response to probing questions. Our results indicate that the methods used in this study can be useful to examine learners' conceptions of other important socioscientific and emotionally-charged issues.

Study Limitations

Three limitations of the study are related to the study sample, the operational definitions of direct and emergent processes, and the unit of analysis for coding the interview responses. The study sample was limited to twelve students in the same class in a purposefully-selected school and participation was voluntary. As a result of the study sample and study design, the results are not generalizable to other student populations. It is interesting to note that, even within the small study sample, there was significant diversity in the dimensions of students' knowledge and beliefs. Although the study results are not generalizable, the data collection instruments and questions, with modification, could be used with any population irrespective of age or location. The workbook and interview questions are not location specific and were not based on any particular instructional materials or learning activities.

In developing the operational definitions for direct and emergent processes, we had to define key properties of each process that could be applied to earthquake and tsunami geophysical phenomena and preparedness phenomenon for coding student responses. Our primary reference was a set of detailed characteristics developed by Chi (2008). Many of the examples used by Chi to illustrate the characteristics of direct and emergent processes referred to very discreet physical processes such as diffusion. Our challenge was to distill a set of key properties that could be applied to earthquake and tsunami geophysical and preparedness phenomena to consistently code responses.

The operational definitions that we developed and the application of those definitions to code student responses was the first time that we are aware of that this has been done to examine student knowledge of earthquake and tsunami geophysical and preparedness phenomena. As a result, our definitions may not fully represent the dimensions of ontological beliefs as defined by Chi. However, we had to start somewhere. Additionally, it should be noted that Chi's definitions of direct and emergent processes were developed and clarified over years of research primarily with physical science subject matter. We believe that additional research will result in further clarification of the characteristics of direct and emergent processes as applied to complex geophysical and preparedness phenomena.

The unit of analysis for coding the student responses was the individual question/response set. For each individual question, the student's response was coded according to the Coding Guidelines and Scheme. Although each student responded to the same set of fixed questions in the workbooks and in the interview, the spontaneous interview questions introduced potential variance in the number of questions that a student might answer about a given concept and in the content of the student's answers about the concept. To illustrate, two students would both provide an initial answer to the same interview question, and that initial answer would be coded. In the spontaneous follow-up questions, one student might answer one follow-up question and the other might answer three questions. That difference would result in a different number of codes for each student for the same concept addressed in the questions.

More important than the number of codes was the content of the responses upon which the codes were based. As a general observation, the more a student talked about his or her knowledge in response to the interviewer asking probing questions, the more likely it would be that an imprecise, synthetic, or even naïve conception would be made visible. As a result, limited inferences of students' knowledge and beliefs could be made by looking at just the distribution of codes or at individual responses. We endeavored to mitigate this limitation by using the distribution of codes as a reference but then closely examining the content of related responses to infer students' knowledge and beliefs.

Theoretical Implications

The following four themes emerged in students' descriptions of the science and preparedness knowledge: (1) earthquake and tsunami could occur at any time in the area, (2) strong intent to protect self and family from harm, (3) the giant tsunami wave with near absolute and unavoidable catastrophic effects, and (4) the diminished effect of earthquakes as compared to tsunamis.

Our analysis of the students' descriptions lends support to Vosniadou's (1994) framework theory of students' knowledge. The theme of the giant, even super giant, tsunami wave with near absolute and unavoidable catastrophic effects was prominent in the students' naïve ideas and synthetic conceptions of science and preparedness knowledge. The giant tsunami wave provided coherence to the students' descriptions of the causes and effects of tsunami. For example, at the individual question/response level, students' descriptions of ways to augment tsunami generation from earthquakes (e.g., adding tornadoes, high winds, bad weather, stormy waves, vibrating tectonic plates) appeared as isolated and disassociated knowledge elements. However, when viewed in light of the entire set of a student's responses, these additional phenomena were necessary to maintain the student's conception of the giant, even supergiant, tsunami wave that would almost completely destroy the nearest coastal city and reach to the school or even to the inland valley.

Based on the results of the study, students identified school as the most prominent source of their knowledge of earthquakes and tsunamis. However, for many of the students in the study, any new information from the school source, whatever that information was, appears to have been assimilated into their framework theories that included a giant tsunami wave. The prominence of the giant tsunami wave conception suggests the influence of students' epistemic and ontological beliefs about the phenomenon. Students identified internet/media as the second most prominent source of their knowledge of earthquakes and tsunamis. Possible sources of students' naïve conceptions of a giant tsunami wave are internet sites and media sources that represent incorrect information. During the interviews, several students described how they had in the past, and they would in the future, search for information about earthquakes and tsunamis on the internet. The internet is a very "normal" and typical way for young people in our culture to search for information on a topic, and that practice is only likely to increase in the future. However, unfiltered information from the internet may reinforce the conception of the giant tsunami wave.

Figure 5 shows a screen shot of the first 18 images that came up from a recent Google® image search of the word "tsunami." To an individual with clear knowledge of the causes and effects of earthquakes and tsunamis, many of these images are easily recognizable as false representations of tsunamis. What is shown in these false images is the giant tsunami wave with near absolute and unavoidable catastrophic effects. For learners who do not have clear knowledge of the causes and effects of tsunamis, these images and other easily accessible internet sources may reinforce what Chi, Roscoe, Slotta, Roy, and Chase (2012) refer to as a direct-causal schema. In the giant tsunami wave direct-causal schema, there is a fixed sequential narrative from earthquake → giant tsunami wave → catastrophic destruction, where the giant tsunami wave is the central character controlling the outcome of the process. People, the natural environment, and the built environment are diminished actors in this direct-causal schema.

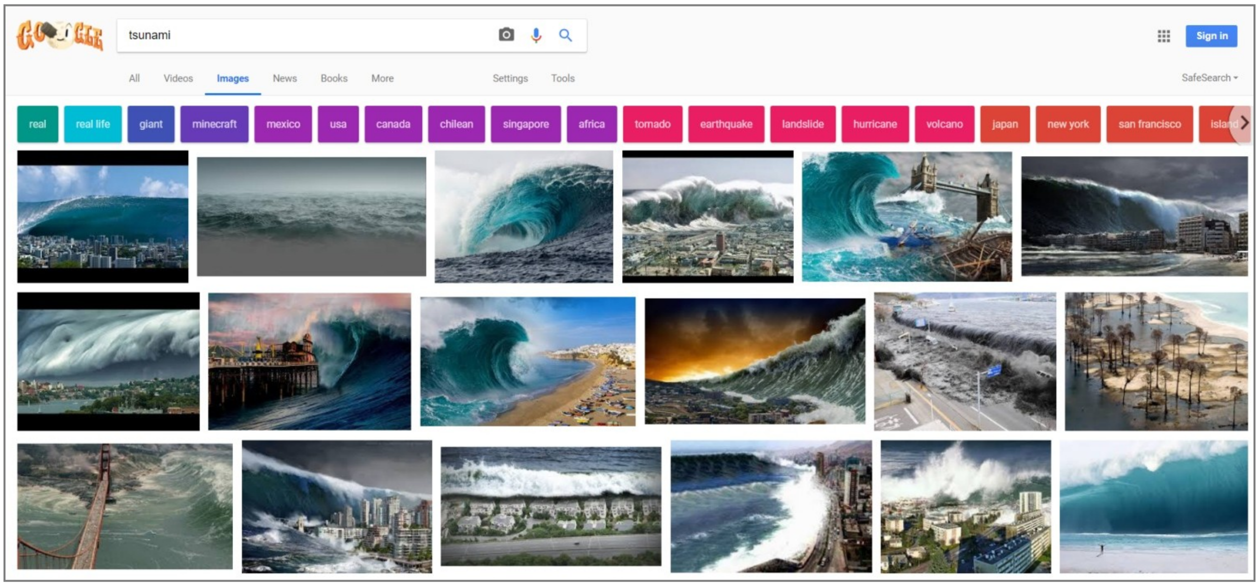

Figure 5. Screen shot of image search for tsunami.

It may also be that internet and media sources with correct earthquake and tsunami information, including hazard preparedness information, *unintentionally reinforce* a direct-causal schema by focusing on the most destructive examples of natural disasters, including tsunami, and by highlighting the outcomes of death, injury, and damage through text, graphic images, and verbal descriptions and by backgrounding the outcomes of survival and resilience. A tension may exist between communicating the potential severity of a hazard to *intentionally* develop the learner's awareness of risk and to incentivize preparedness action and the *unintentional* result of developing or reinforcing the learner's naïve and synthetic conceptions based on a direct-causal schema.

It is worth consideration by hazards preparedness professionals whether the giant wave motif typically found on tsunami warning signs and tsunami informational materials unintentionally reinforces the giant wave direct-causal schema. In this case, a tension may exist between the intent to have an easily recognizable image that represents an appropriate response to tsunami and the way that learners of all ages interpret the meaning of the image. Figure 6 shows a tsunami hazard zone sign common in the coastal region where the study was conducted.

Figure 6. Tsunami hazard zone sign with big wave.

During the interviews, one student, who stated he had seen the sign, was asked, "Is this guy going to make it?" The student replied, "I don't (shakes head back and forth) …he's not high enough yet. Depends on how fast the waves are going to crash."

As an alternative to the tsunami hazard zone sign with a big wave motif, Figure 7 shows the image from a magnet distributed by the Redwood Coast Tsunami Work Group associated with Humboldt State University in Arcata, California. The magnet shows a sequence including DROP! COVER! HOLD ON! during the earthquake, GO TO HIGH GROUND! to avoid tsunami inundation, and STAY THERE! as a precaution against repeated surges. In contrast to the big wave motif, the middle image shows the tsunami as a surge or roiling bore of water. Although the tsunami is threatening to the person evacuating up the cliff, the bottom image shows successful evacuation as the people are safe on high ground above the tsunami inundation.

Figure 7. Magnet image showing tsunami surge.
Image courtesy of the Redwood Coast Tsunami Work Group

Although students had a diminished conception of the effects of earthquakes, the common first response to "run out of the building" when an earthquake occurs may reflect the resistance of naïve ideas because each student had participated in regular school earthquake drills and was familiar with the recommended Drop, Cover, Hold On response to earthquake shaking. As with the catastrophic effects of tsunami highlighted in the media and on internet sites, the highlighting of collapsed and "pancaked" buildings in emotionally-charged visual images may reinforce a naïve impulse to run out of a building to avoid these catastrophic results. Figure 8 shows a screen shot of the first 18 images that came up from a recent Google® image search of the word "earthquake." Unlike the tsunami images in Figure 5, all of these earthquake images appear to be real. However, all the images with buildings show catastrophic damage and may communicate the message that this level of damage is the typical effect of earthquakes.

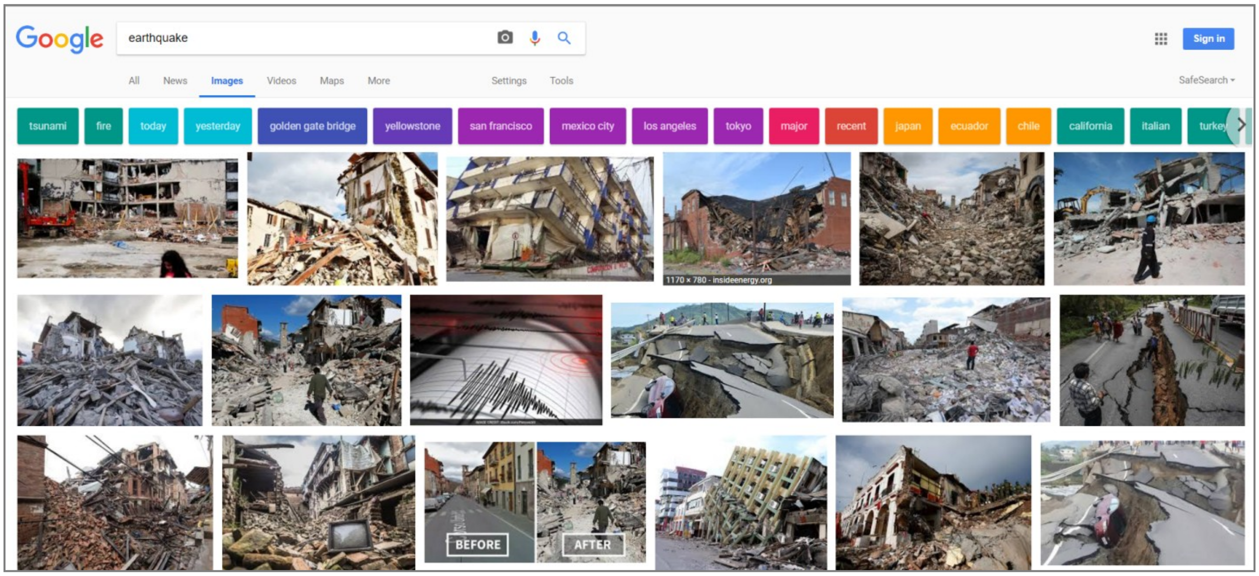

Figure 8. Screen shot of image search for earthquake.

Implications for Earthquake and Tsunami Education

The methods and results of this study have implications for the content and pedagogy of earthquake and tsunami education in the K-12 school setting. The methods used in this study can inform teachers' use of formative assessment strategies to make visible students' conceptions of earthquake and tsunami prior to and during instruction. Formative assessment in the classroom is defined as assessment that directly informs the learning process in contrast to summative assessment that is used to evaluate prior learning (Black, 1993). The process of formative assessment involves activities designed to make explicit various aspects of students' conceptions in some form of representation (Bell & Cowie, 2001; Ruiz-Primo & Furtak, 2007). As was used is this study, teachers can use different instruments and different formats for students' responses (textual, graphical, verbal, and gestural) to make visible aspects of students' science knowledge, preparedness knowledge, epistemic beliefs, and ontological beliefs. For example, Kaya (2010) had high school students use metaphor to complete the following statement, “Earthquake is like _____; because _____” (p. 713) to elicit students’ affective responses prior to instruction.

The formative nature of formative assessment includes two distinct aspects. One formative aspect is relative to instruction in that teachers use inferences from the students’ representations to plan subsequent instruction or provide feedback (Bell & Cowie, 2001; Black, 1993; Black & Wiliam, 1998). Multiple research studies support the claim that students’ preconceptions must be engaged and modified or new conceptions developed for meaningful conceptual change to occur (Brown, 2014; Donovan & Bransford, 2005; Duit & Treagust, 2003). Consistent with conceptual change theory, instruction or feedback should reference students’ current conceptions and create some degree of cognitive dissonance relative to new science information or preparedness practice. A second formative aspect of formative assessment is relative to metacognition in that students develop greater awareness of their own conceptions through the process of making them explicit (Black, 1998; Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001).

Formative assessment activities are not only formative for teacher instruction and student metacognition, they are also generative for new student conceptions. In the context of a formative assessment activity, whether responding to a writing prompt or to a teacher question during dialogue, elements of a student’s framework theory can be instantiated in constructing the response. For students to feel free to represent their conceptions that are naïve or dynamically emergent (Brown, 2014) requires a classroom culture that values asking questions, making conjectures, considering alternative points of view, and acknowledging the limitations of one’s own conceptions (van Zee, Iwasyk, Kurose, Simpson, & Wild, 2001; Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001) particularly for the emotionally-charged topic of earthquake and tsunami.

The results of this study indicate possible interactions between students' science knowledge of earthquake and tsunami and their preparedness knowledge. Students' understandings of the causes and effects of the hazard may influence their understandings of the appropriate preparedness response. For example, students' conceptions about the relationship between near-field and distant-field tsunamis and earthquakes may potentially influence their understandings of the warnings of impending tsunami inundation and the timeframe for safe evacuation. Students' understandings of the scale of tectonic plates and of the different types of tectonic earthquakes may potentially influence their conceptions of risk from earthquake hazard.

One implication of the possible interactions between students' science knowledge and preparedness knowledge is for teachers to provide instruction that not only relates the causes and effects of the hazard to the potential risk that students and their families may face, but also to specific preparedness measures that students and their families can take that are both relevant and useful in response to the hazard and risk. One strategy for making earthquake and tsunami instruction useful is to contextualize instruction in a socioscientific issue that is relevant to students' lives. Socioscientific issues are real-world problems that involve not only science and engineering concepts, but also sociocultural factors that influence decision-making and action, and those decisions and actions may also be controversial and involve ethical considerations (Sadler, Barab, & Scott, 2007; Zeidler & Nichols, 2009). Examples of socioscientific issues in the context of earthquake and tsunami could be how would individuals, families, or communities meet their needs for water or food or medicine in the aftermath of a CSZ megathrust earthquake and tsunami.

Situated learning theory (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991) provides a theoretical framework for teaching earthquake and tsunami education in the context of socioscientific issues. According to situated learning theory, concepts must be learned in an authentic context, and students must participate in using that knowledge in authentic ways in a culture or community of practice. According to Brown et al., “Activity, concept, and culture are interdependent. No one can be totally understood without the other two. Learning must involve all three” (p. 33). Based on the premise that earthquake and tsunami awareness and preparedness is a multifaceted socioscientific issue, providing instruction in an authentic socioscientific context is most likely to engage the full spectrum of students’ science knowledge, preparedness knowledge, epistemic beliefs, and ontological beliefs. Consistent with situated learning theory, the goal of earthquake and tsunami awareness and preparedness education is for students to become legitimate participants in a culture of preparedness.

One view of conceptual change is that a student’s framework theory changes through a slow and gradual process of constructing synthetic conceptions that are incomplete and incorrect from an expert view, but that represent change from naïve to more correct conceptions over time (Vosniadou & Skopeleti, 2014). In relationship to earthquake and tsunami education, this view of conceptual change argues for a planned sequence of instruction across the grades that develops conceptual understandings of the geophysical causes and effects of earthquake and tsunami and develops preparedness measures for these hazards. A planned sequence of earthquake and tsunami instruction over time that is integrated into instruction in the K-12 school system as recommended by the *Hyogo Framework for Action 2005-2016* (UNODRR, 2005) has the potential to develop students' sense of geologic scale and other important science and preparedness conceptions of earthquake and tsunami. One example from this study highlights an issue found in many studies of students' understanding of physical science concepts. The term 'tectonic plate' utilizes the word "plate" which has a colloquial meaning to students and interferes with the scientific meaning conveying geologic scale. For several students in the study, the colloquial meaning of the word plate, having a small scale, may have carried over into their conceptions of the diminished magnitude, intensity of ground shaking, and geographical range of earthquakes caused by tectonic plate movement.

In contrast to a gradual process of conceptual change over time, Chi (2005) posits that in some cases, conceptual change requires the development of a new ontological belief and that the old and new beliefs coexist in the student's conceptions as parallel ontologies. In relationship to earthquake and tsunami education, the results of our study support Chi's parallel ontologies hypothesis in that the students described geophysical phenomena and preparedness phenomena as things and also as both direct processes and emergent processes. For example, all the students in the study described the recommended Go to High Ground response to avoid tsunami inundation. This reflects a direct process response. Go to High Ground is a valuable preparedness message that is simple to understand, very memorable, and has proven beneficial to saving lives. However, several students in the study also described an emergent process response such as planning ahead to identify where the high ground is located and identifying alternate routes to safety in case one escape route was obstructed. Recent studies (Chi, Roscoe, Slotta, Roy, &

Chase 2012; Slotta & Chi, 2006) have examined the effect of ontology training on students' understanding of challenging topics.

Chi and colleagues have theorized that conceptions that fall into a different ontological category (e.g. Thing, Direct Process, or Emergent Process) from accepted scientific conceptions are more resistant to change. Students expressed thinking about earthquakes and tsunamis can be placed in a progression from thinking of these phenomena as a Thing, and then as a Process (Direct then Emergent). One implication for earthquake and tsunami education is that a planned sequence of instruction across the grade levels can help students construct new ontological categories that move them in the progression from Thing to Direct Process to Emergent Process. For science knowledge, that progression can lead to a more complete understanding of the different types of earthquakes, variations in earthquake scales (magnitude, intensity of ground shaking, and geographical range), and the interaction of earthquakes and tsunami generation. For preparedness knowledge, that progression can lead to more complete understanding of situated risk, ways to prepare for hazards as individuals, families, and communities, resources for preparing, strategies for responding to emergent situations, and relationships between the built environment and earthquake and tsunami hazards.

Implications for Future Research

There are several implications of the results of this study for future research. The first is that the study could be replicated for different student populations representing different grade levels and geographic locations. The sample in this study was chosen based on the relevance and usefulness of earthquake and tsunami education to these students living in the coastal region of the Cascadia Subduction Zone. An argument can be made that earthquake and tsunami education is useful and relevant to all of the residents in the region, including those who live in the larger cities in the inland valley. For residents in the inland valley cities, the earthquake hazard is more relevant to their day to day lives than tsunami hazard, but those residents will likely also be visitors to the coastal region at some time. Comparing the results from similar studies with different student populations has the potential to identify common themes across demographic groups as well as distinctions between groups.

A second implication for future research is to examine how learners' science and preparedness knowledge and epistemic and ontological beliefs influence actual preparedness actions. This line of research extends the topic of study from the learner's individual conceptual understandings to their behavioral practices and may require examining the dimensions of epistemic and ontological beliefs in a larger context of situated learning and the social construction of knowledge.

A third implication of this study for future research is that the complex nature of earthquake and tsunami knowledge, beliefs, and preparedness behaviors suggests that no one theoretical framework and no one discipline is comprehensive enough to address the need for increased, effective earthquake and tsunami education. Rather, complementary theoretical frameworks and researchers from various disciplines including education, psychology, sociology, geosciences, and engineering are needed to understand how sociocultural factors influence learners' knowledge, beliefs, and practices, and how to develop educational content, materials, and pedagogy that foster increased individual and social resilience to earthquake and tsunami hazards.

One model for this interdisciplinary approach to earthquake and tsunami preparedness education is the NSF-funded Cascadia EarthScope Earthquake and Tsunami Education Program (CEETEP) hosted by Oregon State University. The CEETEP program (http://ceetep.oregonstate.edu/) includes geoscience researchers and educators, classroom teachers, park and museum interpreters, and emergency management outreach educators in communities in the Pacific Northwest. The CEETEP program has developed and assembled an extensive set of resources including classroom lessons and activities, online animations, and field trips to support earthquake and tsunami education. The goal of the program is to foster community engagement in earthquake and tsunami science and preparedness and to encourage collaboration and exchange between formal and informal coastal educators.

Another model for an interdisciplinary approach to earthquake and tsunami preparedness education is the Research Center for Disaster Reduction Systems in the Disaster Prevention Research Institute at Kyoto University, Japan, directed by Dr. Katsuya Yamori. The first researcher in this study spent three months in Japan in 2017 conducting graduate research with Dr. Yamori's laboratory. The professors, visiting researchers, post-doctoral researchers, and graduate students in the laboratory represented a diversity of academic disciplines including psychology, sociology, communications, informatics, economics, engineering, and physical science. The diversity of expertise of the laboratory members has allowed them to develop a variety of educational materials and activities for a variety of audiences including instructional card games for very young children, map-making activities for students in the schools, GPS-based software applications for residents to track their progress on evacuation routes, and role-playing simulations for disaster management officials.

The goal of future research, as was the goal of the current study, is to contribute to meeting the need for increased earthquake and tsunami education in the United States in order to reduce risk and increase resilience to these natural hazards. This study contributes to that goal by demonstrating that conceptual change theory is a valuable lens for examining students' science and preparedness knowledge and epistemic and ontological beliefs of earthquake and tsunami. The results of this study identified four major themes prevalent in students' science and preparedness knowledge and indicated potential influences of students' epistemic and ontological beliefs on those themes. This knowledge can be used to design more effective earthquake and tsunami educational content and pedagogy. Additionally, the results of this study indicate that the theoretical framework and methodological design used in this study can be useful to examine learners' conceptions of other important socioscientific issues such as climate change and ecological diversity.

REFERENCES

Atwater, B. F. (1987). Evidence for great Holocene earthquakes along the outer coast of Washington State. *Science*, *236*(4804), 942-944.

Atwater, B. F. (1999). *Surviving a tsunami--lessons from Chile, Hawaii, and Japan* (Report No. 1187). Geological Survey (USGS).

Atwater, B. F., Musumi-Rokkaku, S., Satake, K., Tsuji, Y., Ueda, K., & Yamaguchi, D. K. (2016). *The orphan tsunami of 1700: Japanese clues to a parent earthquake in North America.* Seattle, WA: University of Washington Press.

Atwater, B. F., & Yamaguchi, D. K. (1991). Sudden, probably coseismic submergence of Holocene trees and grass in coastal Washington State. *Geology*, *19*, 706-709.

Baytiyeh, H., & Naja, M. K. (2014). Can education reduce Middle Eastern fatalistic attitude regarding earthquake disasters? *Disaster Prevention & Management, 23*, 343-355. doi:10.1108/DPM-12-2013-0219

Becker, J. S., Paton, D., Johnston, D. M., & Ronan, K. R. (2013). Salient beliefs about earthquake hazards and household preparedness. *Risk Analysis: An International Journal, 33*, 1710-1727.

Bell, B., & Cowie, B. (2001). The characteristics of formative assessment in science education. *Science Education, 85*, 536-553.

Berg, B. L., & Lune, L. H. (2012). *Qualitative research methods for the social sciences*. Saddle River, NJ: Pearson.

Bernard, E. N. (2005). The US National Tsunami Hazard Mitigation Program: A successful state—federal partnership. In E.N. Bernard (Ed.), *Developing tsunami-resilient communities* (pp. 5-24). Dordrecht, Netherlands: Springer.

Black, P. J. (1993). Formative and summative assessment by teachers. *Studies in Science Education, 21*, 49-97. doi:10.1080/03057269308560014

Black, P. J. (1998). Formative assessment: Raising standards inside the classroom. *School Science Review, 80*(291), 39-46.

Black, P. J., & Wiliam, D. (1998). Assessment and classroom learning. *Assessment in Education, 5*(1), 7-74.

Bråten, I., Britt, M. A., Strømsø, H. I., & Rouet, J. F. (2011). The role of epistemic beliefs in the comprehension of multiple expository texts: Toward an integrated model. *Educational Psychologist*, *46*(1), 48-70.

Brown, D. (2014). Students' conceptions as dynamically emergent structures. *Science & Education, 23*, 1463-1483. doi:10.1007/s11191-013-9655-9

Brown, D., & Hammer, D. (2008). Conceptual change in physics. In Vosniadou, S. (Ed.), *International handbook of research on conceptual change* (pp. 127-154). New York, NY: Routledge.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher, 18*(1), 32-42.

Butler, R.F. (2018). Cascadia earthquake science and hazards. In C. V. Fletcher & J. Lovejoy (Eds.), *The really big one: Risk, health, and environmental communication.* Landham, MD: Rowman & Littlefield. Manuscript submitted for publication.

Cheek, K. A. (2010). Commentary: A summary and analysis of twenty-seven years of geoscience conceptions research. *Journal of Geoscience Education, 58*(3), 122-134.

Chi, M. T. (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *The Journal of the Learning Sciences*, *14*(2), 161-199.

Chi, M. T. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In In Vosniadou, S. (ED.), *International handbook of research on conceptual change* (pp. 89-110). New York, NY: Routledge.

Chi, M. T. H., Slotta, J. D., & de Leeuw, N. (1994). From things to processes: A theory of conceptual change for learning science concepts. *Learning and Instruction, 4*(1), 27-43.

Chi, M. T., Roscoe, R. D., Slotta, J. D., Roy, M., & Chase, C. C. (2012). Misconceived causal explanations for emergent processes. *Cognitive Science*, *36*(1), 1-61.

Clague, J., Yorath, R., Franklin, R., & Turner, B. (2006). *At risk: Earthquakes and tsunamis on the west coast*. Tricouni Press.

DeLaughter, J. E., Stein, S., Stein, C. A., & Bain, K. R. (1998). Preconceptions abound among students in an introductory earth science course. *Eos Transactions, American Geophysical Union, 79*, 429.

Dengler, L. (2005). The role of education in the national tsunami hazard mitigation program. *Natural Hazards, 35*, 141-153.

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition & Instruction, 10*(2-3), 105.

diSessa, A. A., Gillespie, N. M., & Esterly, J. B. (2004). Coherence versus fragmentation in the development of the concept of force. *Cognitive Science, 28*, 843-900. doi:10.1016/j.cogsci.2004.05.003

diSessa, A. A., & Sherin, B. L. (1998). What changes in conceptual change? *International Journal of Science Education, 20*, 1155-1191. doi:10.1080/0950069980201002

Donovan, M. S., & Bransford, J. D. (2005). Scientific Inquiry and how people learn. In Donovan, M. S., & Bransford, J. D. (Eds.), *How students learn: History, mathematics, and science in the classroom*. Washington, DC: The National Academies Press.

Driver, R., & Easley, J. (1978). Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education*, *5*, 61-84.

Duit, R. (2008). Bibliography STCSE: Students' and teachers' conceptions and science education. Kiel, Germany: IPN-Leibniz Institute for Science Education. Retrieved from http://www.if.ufrj.br/~marta/aprendizagememfisica/fv09.pdf

Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education*, *25*, 671-688.

Federal Emergency Management Agency. (2008). *Strategic plan for the national earthquake hazards reduction program*. Retrieved from https://www.nehrp.gov/pdf/strategic_plan_2008.pdf

Geist, E. L. (2005). *Local tsunami hazards in the Pacific Northwest from Cascadia subduction zone earthquakes*. Menlo Park, CA: United States Geological Survey. Retrieved from https://pubs.usgs.gov/pp/pp1661b/pp1661b.pdf

Goetz, T., Frenzel, A. C., Pekrun, R. ,Hall, N. C., & Ludtke, O. (2007). Between-and within-domain relations of students' academic emotions. *Journal of Educationl Psychology*, *99*, 715-733.

Goldfinger, C., Ikeda, Y., Yeats, R. S., & Ren, J. (2012). Superquakes and supercycles. *Seismological Research Letters*, *84*(1), 24-32.

Hofer, B. K. (2001). Personal epistemology research: Implications for learning and teaching. *Educational Psychology Review*, *13*, 353-383.

Hofer, B. K. (2006). Domain specificity of personal epistemology: Resolved questions, persistent issues, new models. *International Journal of Educational Research*, *45*(1), 85-95.

Hofer, B. K., & Pintrich, P. R. (1997). The development of epistemological theories: Beliefs about knowledge and knowing and their relation to learning. *Review of Educational Research*, *67*(1), 88-140.

Horan, J., Ritchie, L. A., Meinhold, S., Gill, D. A., Houghton, B. F., Gregg, C. E., . . . Johnston, D. (2010). Evaluating disaster education: The National Oceanic and Atmospheric Administration's TsunamiReady™ community program and risk awareness education efforts in New Hanover County, North Carolina. *New Directions for Evaluation*, 2010, 79-93.

Inokuma, A., & Nagayama, D. (2013). The 2011 Great East Japan earthquake, tsunami and nuclear disaster. *Civil engineering*, *166*(4), 170-177.

Ioannides, C., & Vosniadou, S. (2002). The changing meanings of force. *Cognitive Science Quarterly*, 2*(1)*, 5-62.

Johnson, V. A., Ronan, K. R., Johnston, D. M., & Peace, R. (2014). Evaluations of disaster education programs for children: A methodological review. *International Journal of Disaster Risk Reduction*, *9*, 107-123.

Johnston, D., Paton, D., Crawford, G. L., Ronan, K., Houghton, B., & Bürgelt, P. (2005). Measuring tsunami preparedness in coastal Washington, United States. In E. N. Bernard (Ed.), *Developing tsunami-resilient communities* (pp. 173-184). Dordrecht, Netherlands: Springer.

Jonientz-Trisler, C., Simmons, R., Yanagi, B., Crawford, G., Darienzo, M., Eisner, R., . . . Priest, G. (2005). Planning for tsunami-resilient communities. *Natural Hazards, 35*(1), 121-139.

Katada, T., & Kanai, M. (2008). *Implementation of tsunami disaster education for children and their parents at elementary school.* Paper presented at the Proc. of the Solutions to Coastal Disasters Congress 2008, Turtle Bay, HI. doi: 10.1061/40978(313)4

Kaya, H. (2010). Metaphors developed by secondary school students towards "earthquake" concept. *Educational Research and Reviews, 5*, 712-718.

Kienhues, D., & Bromme, R. (2011). Beliefs about abilities and epistemic beliefs: Aspects of cognitive flexibility in information-rich environments. In Elen, J., Stahl, E., Bromme, R., & Clarebout, G. (Eds.), *Links between beliefs and cognitive flexibility* (pp. 105-124). Dordrecht, Netherlands: Springer.

Khishfe, R., & Lederman, N. (2007). Relationship between instructional context and views of nature of science. *International Journal of Science Education*, *29*, 939-961.

King, C. (2000). The earth's mantle is solid: Teachers' misconceptions about the earth and plate tectonics. *School Science Review, 82*(298), 57-64.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge: Cambridge University Press.

Libarkin, J. C. (2005). Conceptions, cognition, and change: Student thinking about the earth. *Journal of Geoscience Education, 53*, 342-342.

Mason, L. (2007). Introduction: Bridging the cognitive and sociocultural approaches in research on conceptual change: Is it feasible? *Educational Psychologist*, *42*(1), 1-7.

McCloskey, M. (1983). Naive theories of motion. In Gentner, D., & Stevens, A. L. (Eds.), *Mental models* (pp. 299-324). Hillsdale, NJ: Lawrence Erlbaum Associates.

Muis, K. R., Bendixen, L. D., & Haerle, F. C. (2006). Domain-generality and domain-specificity in personal epistemology research: Philosophical and empirical reflections in the development of a theoretical framework. *Educational Psychology Review*, *18*(1), 3-54.

National Oceanic and Atmospheric Administration. (2013). *National Tsunami Hazard Mitigation Program 2013 - 2017 strategic plan*. Retrieved from http://nws.weather.gov/nthmp/documents/NTHMPStrategicPlan.pdf

National Research Council. (2011). *National earthquake resilience: research, implementation, and outreach*. Washington, D.C.: National Academies Press. Retrieved from https://www.nap.edu/read/13092/chapter/1

National Research Council. (2011). *Tsunami warning and preparedness: An assessment of the U.S. tsunami program and the nation's preparedness efforts*. (2011). Washington, DC: National Academies Press. Retrieved from http://www.nap.edu/download.php?record_id=12628

Noble, T., DiMattia, C., Nemirovsky, R., & Barros, A. (2006). Making a circle: Tool use and the spaces where we live. *Cognition and Instruction*, *24*, 387-437.

Norris, F. H., Friedman, M. J., Watson, P. J., Byrne, C. M., Diaz, E., & Kaniasty, K. (2002). 60,000 disaster victims speak: Part I. An empirical review of the empirical literature, 1981–2001. *Psychiatry: Interpersonal and Biological Processes*, *65*(3), 207-239.

Oregon Seismic Safety Policy Advisory Commission (OSSPAC). (2013). *The Oregon resilience plan: Reducing risk and improving recovery for the next Cascadia earthquake and tsunami*. Retrieved from http://www.oregon.gov/oem/Documents/Oregon_Resilience_Plan_Final.pdf

Paton, D., Houghton, B. F., Gregg, C. E., McIvor, D., Johnston, D. M., Bürgelt, P., . . . Horan, J. (2009). Managing tsunami risk: Social context influences on preparedness. *Journal of Pacific Rim Psychology, 3*, 27-37. doi:10.1375/prp.3.1.27

Pekrun, R., & Stephens, E. (2010). Achievement emotions: A control-valve approach. *Social and Personality Psychology Compass*, *(4)*, 238-255.

Philips, W. C. (1991). Earth science misconceptions. *Science Teacher, 58*(2), 21-23.

Piaget, J. (1964). Part I: Cognitive development in children: Piaget development and learning. *Journal of Research in Science Teaching, 2*, 176-186. doi:10.1002/tea.3660020306

Piaget, J., & Cook, M. T. (1954). *The construction of reality in the child*. New York, NY: Routledge.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227.

Reiner, M., Slotta, J. D., Chi, M. T., & Resnick, L. B. (2000). Naive physics reasoning: A commitment to substance-based conceptions. *Cognition and instruction*, *18*(3), 1-34.

Ronan, K. R., Crellin, K., & Johnston, D. (2010). Correlates of hazards education for youth: a replication study. *Natural Hazards, 53*, 503-526.

Ross, K., & Dargush, A. (1992). *Investigating teacher knowledge of earthquakes.* Paper presented at the Tenth World Conference on Earthquake Engineering, Madrid, Spain.

Ruiz-Primo, M. A., & Furtak, E. M. (2007). Exploring teachers' informal formative assessment practices and students' understanding in the context of scientific inquiry. *Journal of Research in Science Teaching, 44*(1), 57-84.

Sadler, T. D., Barab, S. A., & Scott, B. (2007). What do students gain by engaging in socioscientific inquiry? *Research in Science Education, 37*, 371-391. doi:10.1007/s11165-006-9030-9

Sawaji, O. (2012). Education and disaster reduction. *The Japan Journal*, 6-10.

Shaw, R., Shiwaku, H., Kobayashi, K., & Kobayashi, M. (2004). Linking experience, education, perception and earthquake preparedness. *Disaster Prevention and Management: An International Journal, 13*(1), 39-49.

Sherin, B. L., Krakowski, M., & Lee, V. R. (2012). Some assembly required: How scientific explanations are constructed during clinical interviews. *Journal of Research in Science Teaching*, *49*, 166-198.

Sibley, D. F. (2005). Visual abilities and misconceptions about plate tectonics. *Journal of Geoscience Education, 53*, 471-477.

Slotta, J. D. (2011). In defense of Chi's Ontological Incompatibility Hypothesis. *Journal of the Learning Sciences*, *20*, 151-162.

Slotta, J. D., & Chi, M. T. (2006). Helping students understand challenging topics in science through ontology training. *Cognition and Instruction*, *24*, 261-289.

Slotta, J. D., Chi, M. T., & Joram, E. (1995). Assessing students' misclassifications of physics concepts: An ontological basis for conceptual change. *Cognition and Instruction*, *13*, 373-400.

Sinatra, G. M., Broughton, S. H., & Lombardi, D. (2014). Emotions in science education. In Pekrun, R., & Linnenbrink-Garcia, L., (Eds.), *International handbook of emotions in education*. New York, NY: Routledge.

Sinatra, G. M., Kienhues, D., & Hofer, B. K. (2014). Addressing challenges to public understanding of science: Epistemic cognition, motivated reasoning, and conceptual change. *Educational Psychologist*, *49*, 123-138.

Strike, K. A., & Posner, G. J. (1985). A conceptual change view of learning and understanding. In L. H. West & A. L. Pines (Eds.), *Cognitive structure and conceptual change* (pp. 189-210). Orlando, FL:Academic Press, Inc.

United Nations Office for Disaster Risk Reduction (2005). ISDR Hyogo framework for action 2005-2015: Building the resilience of nations and communities to disasters. In *Extract from the final report of the World Conference on Disaster Reduction (A/CONF. 206/6)* (Vol. 380). Retrieved from https://www.unisdr.org/2005/wcdr/intergover/official-doc/L-docs/Hyogo-framework-for-action-english.pdf

United States Geological Survey (1994). *The Loma Prieta earthquake professional papers*. (USGS Publication No. 1551). Retrieved from https://pubs.usgs.gov/pp/pp1551/

van Zee, E. H., Iwasyk, M., Kurose, A., Simpson, D., & Wild, J. (2001). Student and teacher questioning during conversations about science. *Journal of Research in Science Teaching, 38*, 159-190.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. *Learning and Instruction, 4*(1), 45-69.

Vosniadou, S., & Brewer, W. F. (1992). Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology, 24*, 535.

Vosniadou, S. & Kempner, L. (1993). *Mental models of heat*. Paper presented at the Biennial Meeting of the Society for Research in Child Development, New Orleans, LA.

Vosniadou, S., & Mason, L. (2012). Conceptual change induced by instruction: A complex interplay of multiple factors. In Harris, K. R., Graham, S. E., Urdan (Eds.), *APA educational psychology handbook* (pp. 221-246). American Psychological Association.

Vosniadou, S., & Skopeliti, I. (2014). Conceptual change from the framework theory side of the fence. *Science & Education, 23*, 1427-1445. doi:10.1007/s11191-013-9640-3

Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., & Papademetriou, E. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction*, *11*, 381-419.

Washington State Seismic Safety Committee. (2012). *Resilient Washington state: A framework for minimizing loss and improving state recovery after an earthquake*. Retrieved from http://www.dnr.wa.gov/Publications/ger_ic114_resilient_washington_state.pdf

White, M., & Epston, D. (1990). *Narrative means to therapeutic ends*. New York, NY: WW Norton & Company.

Wiser, M., & Amin, T. (2001). "Is heat hot?" Inducing conceptual change by integrating everyday and scientific perspectives on thermal phenomena. *Learning and Instruction*, *11*, 331-355.

Zeidler, D. L., & Nichols, B. H. (2009). Socioscientific issues: Theory and practice. *Journal of Elementary Science Education*, *21*(2), 49.

APPENDICIES

Appendix A

Student Booklets and Interview Protocol

Name ______________________________________ **Date _________________________**

Earthquake Booklet for Students

In this booklet, you will be writing and drawing to show what you think about earthquakes.

It is OK if you are not sure of your responses to any item. This is not a test, and your work will not be graded. The purpose of this booklet is to show what you think about earthquakes.

Your responses will help us learn better ways to teach students about earthquakes.

1. Describe what you think causes earthquakes to occur.

If you are not sure of your response, that is OK. Just describe what you think *might* cause earthquakes to occur.

Go to the next page. →

2. Based on your response to **Number 1**, draw and label a diagram that shows what you think causes earthquakes to occur.

Go to the next page. →

3. Describe what you think are some of the effects of earthquakes.

If you are not sure of your response, that is OK. Just describe what you think *might* be some of the effects of earthquakes.

Go to the next page. →

4. Based on your response to **Number 3**, draw and label a diagram to show what you think are some of the effects of earthquakes.

Go to the next page. →

5. Do you think an earthquake will ever occur in this area? Why do you think this?

6. Describe some of the ways people can prepare for an earthquake.

If you are not sure of your response, that is OK. Just describe some of the ways you think people *might* prepare for an earthquake.

Go to the next page. →

7. Suppose you experience an earthquake in the future. What do you think you would do during the earthquake? Why would you do this?

8. Suppose you experience an earthquake in the future. How do you think you would feel during the earthquake? Why would you feel this way?

9. Suppose a friend asked you the following question:
"Do you think people can know when and where an earthquake will occur?

What would you tell your friend?

Thank you for taking the time to complete this booklet!

Please return your completed Earthquake Booklet for Students to your teacher.

Thank You!

Name _______________________________________ Date __________________________

Tsunami Booklet for Students

In this booklet, you will be writing and drawing to show what you think about tsunamis.

It is OK if you are not sure of your responses to any item. This is not a test, and your work will not be graded. The purpose of this booklet is to show what you think about tsunamis.

Your responses will help us learn better ways to teach students about tsunamis.

1. Describe what you think causes tsunamis to occur.

If you are not sure of your response, that is OK. Just describe what you think *might* cause tsunamis to occur.

Go to the next page. →

2. Based on your response to **Number 1**, draw and label a diagram that shows what you think causes tsunamis to occur.

Go to the next page. →

3. Describe what you think are some of the effects of tsunamis.

If you are not sure of your response, that is OK. Just describe what you think *might* be some of the effects of tsunamis.

Go to the next page. →

4. Based on your response to **Number 3**, draw and label a diagram to show what you think are some of the effects of tsunamis.

Go to the next page. →

5. Do you think a tsunami will occur along the coast of Oregon? Why do you think this?

6. Describe some of the ways people can prepare for a tsunami.

If you are not sure of your response, that is OK. Just describe some of the ways you think people *might* prepare for a tsunami.

Go to the next page. →

7. Suppose in the future you were somewhere at the coast. How would you know whether or not a tsunami was coming?

8. Suppose in the future you were at the coast and you thought a tsunami was coming. What do you think you would do? Why would you do this?

9. Suppose a friend asked you the following question:
"Do you think people can prevent tsunamis from occurring?

What would you tell your friend?

Thank you for taking the time to complete this booklet!

Please return your completed Tsunami Booklet for Students to your teacher.

Thank You!

Semi-Structured Individual Student Interview Protocol

- The interviews will be conducted within one week after students have completed their responses in the *Earthquake Booklet for Students* and the *Tsunami Booklet for Students*.
- The interview questions are in reference to the student's responses to the **Number 1 - Number 9** prompts in the *Earthquake Booklet for Students* and the **Number 1 - Number 9** prompts in the *Tsunami Booklet for Students*. The interviewer and the student will be able to refer to the student's original responses in the two booklets during the interview.
- The interviews will be conducted by an OSU doctoral candidate as the interviewer.
- The interviews will be conducted at the school that the students attend during school hours in a location and at a time established by the teacher.
- The interview sessions will be between the interviewer and one student.
- The interview session will begin with the interviewer introducing himself/herself to the student and briefly explaining the purpose of the interview.
- The interview questions below are the planned questions to be asked of each interviewee. As a semi-structured interview, the interviewer may ask further questions related to the original question based on the interviewee's responses to further probe the interviewee's knowledge and beliefs.
- The interview will be video recorded.
- Each interview is anticipated to take approximately 45 minutes to complete.

Brief Introductory Statement by the Graduate Student Interviewer
Hello. How are you today? (pause) My name is _________________. I am a graduate student at Oregon State University, and I am helping to conduct a research study. This study will help us to better understand what students think about earthquakes and tsunamis and help us to become better teachers.

I would like to interview you and ask some questions about your responses in the *Earthquake Booklet for Students* and the *Tsunami Booklet for Students* that you completed on _________ and ________. This is not a test, and your responses in the booklets and during the interview will not be graded. The purpose of the interview is to learn what you think about earthquakes and tsunamis and not to find out if your answers are right or wrong. If you don't want to be interviewed, you can choose not to be interviewed. If there is a question you do not want to answer during the interview, we can skip that question. Would you like to continue with the interview?

(If YES): OK, let's get started. I am going to turn on the video camera now to begin our interview.
(If NO): That's OK. Thank you for talking with me.

Planned Interview Questions

Q1. Let's first look at your *Earthquake Booklet for Students*. Can you describe for me what your diagram in **Number 2** is showing about what causes earthquakes to occur?

Q2. Can you describe for me what your diagram in **Number 4** is showing about the effects of earthquakes?

Q3. How sure are you about your descriptions of the causes and effects of earthquakes? For example, are you *very sure*, *somewhat sure*, *just a little bit sure*, or *not sure at all*?

Q4. Can you tell me how each of the ways you described in **Number 6** will help people prepare for an earthquake?

> *Possible follow-up question: Is there any other way you can think of for people to prepare for an earthquake?*
> *Possible follow-up question: Which of the ways you have described to prepare for earthquakes could you or your family do?*

Q5. For **Number 7**, you answered that you would _________________ if an earthquake occurred in the future. Suppose an earthquake occurred right now, what would be the best thing for you to do?

> *Possible follow-up question: Why do you think this would this be the best thing for you to do?*

Q6. **Number 9** was about what you would tell your friend if they asked whether people can know when and where an earthquake will occur. You said you would tell your friend ________________________. What reasons would you give for your answer to your friend?

Q7. Let's now look at your *Tsunami Booklet for Students*. Can you describe for me what your diagram in **Number 2** is showing about what causes tsunamis to occur?

Q8. Can you describe for me what your diagram in **Number 4** is showing about the effects of tsunamis?

Q9. How sure are you about your descriptions of the causes and effects of tsunamis? For example, are you *very sure*, *somewhat sure*, *just a little bit sure*, or *not sure at all*?

Q10. Can you tell me how each of the ways you described in **Number 6** will help people prepare for a tsunami?

Possible follow-up question: Is there any other way you can think of for people to prepare for a tsunami?
Possible follow-up question: Do you think you or your family would ever need to prepare for a tsunami?

Q11. **Number 9** was about what you would tell your friend if they asked whether people can prevent tsunamis from occurring. You said you would tell your friend ________________________. What reasons would you give for your answer to your friend?

Q12. We have been talking a lot about earthquakes and tsunamis. Where have you learned about earthquakes and tsunamis and where do your ideas come from?

Q13. Do you think your knowledge about earthquakes and tsunamis will change in the future, and why do you think this way?

Q14. Who do you think is most responsible for helping people be prepared for earthquakes and tsunamis?

Q15. Suppose a friend asked you the following question:
"If earthquakes and tsunamis can be so destructive to people and buildings, why do you think they happen at all?" What would you tell your friend?

Possible follow-up question: What reasons would you give for your answer to your friend?

Brief Closing Statement by the Graduate Student Interviewer
Thank you for talking with me during this interview. Your responses are greatly appreciated, and they will help us to better understand what students think about earthquakes and tsunamis. I am going to turn off the video camera now.

Appendix B

Introductory Script

Introductory Script Read by the Teacher
Before Passing Out the Earthquake Workbooks

Later this month, we will begin a unit to learn more about earthquakes and tsunamis.

Before we begin the unit, I have an Earthquake Booklet for you to complete today and then a Tsunami Booklet for you to complete on Thursday. Next week, Mr. Lownsbery will begin interviews with those participating in the research study for OSU. Even if you are not participating in the study, everyone will be completing the workbooks as a class assignment.

The workbooks are not tests, and your work will not be graded. However, it is important for you to answer each prompt thoughtfully and to express your ideas clearly so others can understand what you are thinking. Keep in mind that the workbooks are not to find out if you know or don't know a right answer; they are to find out what you think at this time. This is an opportunity to express your ideas even if you are not sure of an answer. Just describe what you think might be the answer.

After I pass out the workbooks, we will read through the prompts together to see if you have any questions. Then you should complete the Earthquake Workbook on your own without talking with your neighbor.

When you are done, bring me your workbook and then work quietly on ___________________ until everyone is finished.

Appendix C

Coding Scheme and Guidelines

Codes for Science Knowledge
Student responses that demonstrate knowledge of the geophysical causes and effects of earthquakes and tsunamis are coded with one code as evaluated by the coder.

Science Knowledge		code knowledge of the geophysical causes and effects of earthquake and tsunami as evaluated by coder
N	naïve	scientifically incorrect, from phenomenological or sociological perceptions prior to, or without direct connection to, science instruction and learning
S	synthetic	combines aspects of naïve or prior knowledge with scientifically correct knowledge
I	imprecise	imprecisely represents scientific knowledge
A	accepted	consistent with scientifically accepted understandings

Codes for Preparedness Knowledge
Student responses that demonstrate knowledge of preparedness for earthquake and tsunami are coded with one code as evaluated by the coder. Preparedness Knowledge includes: 1) knowledge related to the risks to humans and the built environment from the natural phenomena; and 2) knowledge related to human behaviors in response to those risks. Preparedness Knowledge refers to knowledge of risks and behaviors before, during, and after an earthquake or tsunami.

Preparedness Knowledge		code knowledge of risks to humans and the built environment and knowledge related to human behaviors in response to risks (before, during, after) as evaluated by coder
N	naïve	incorrect, from phenomenological or sociological perceptions prior to, or without direct connection to, preparedness instruction and learning
S	synthetic	combines aspects of naïve or prior knowledge with correct preparedness knowledge
I	imprecise	imprecisely represents preparedness knowledge
A	accepted	consistent with accepted preparedness understandings

Codes for Epistemic Beliefs

Certainty		only code Certainty if degree of certainty is explicitly stated by student
CL	low certainty	e.g., “I guess,” “don’t know,” “not sure,” “maybe,” “possibly,” “could be”
CM	moderate certainty	e.g., “I think,” “pretty sure,” “most likely”
CH	high certainty	e.g., “know for sure,” “I am positive, “definitely”

Simplicity		code Simplicity as evaluated by coder, only code for Science Knowledge or Preparedness Knowledge
SS	simplistic conception	one or two simple facts or components, simplistic does not necessarily mean deficient
SM	moderately complex	multiple components, a relationship between components
SC	complex conception	multiple relationships between multiple components

Source (Origin)		only code Source if explicitly stated by student, may be multiple codes
OE	environment	student ascribes the statement to environmental experience, observation, change
OC	self-constructed	student ascribes the statement to his/her own thinking (e.g., “I think,” “my idea”)
OD	students	
OF	friends	
OI	internet/online/web	
OM	movies/TV/videos/radio	
ON	scientists	
OO	other	any source not included in the categories provided (e.g., “heard somewhere”)
OP	parents/family/siblings	
OR	read/books/magazines	
OS	school	
OT	teachers	
OU	unsure	student states uncertainty about source (e.g., “not sure,” “don’t know”)
OY	community	

Rationale (operational definition for Evidence)		only code Rationale if an explicit rationale/reason/explanation for a claim or statement made by the student is provided without evaluation by coder of the merit of the rationale to support the claim or statement
R	rationale present	

Codes for Ontological Beliefs
Student responses that demonstrate the student’s beliefs about the nature of the geophysical phenomena or the nature of preparedness phenomena are coded with one code as inferred by coder.

Nature of Earthquake and Tsunami Phenomena		code student’s beliefs about the nature of the geophysical phenomena as inferred by coder
T	thing	entity, occurrence, or event that is isolated, unconnected to a

		process
D	direct process	linear, sequential, cause/effect interactions; controlling agent; terminating
E	emergent process	nonlinear, non-sequential collective interactions of many independent agents
S	Superintendent	governing or overseeing process or entity, may be natural order in how things work, may be teleological, purpose driven, or acting with agency

Nature of Preparedness Phenomena		code student's beliefs about the nature of preparedness phenomena as inferred by coder
T	thing	entity, occurrence, or event that is isolated, unconnected to a process
D	direct process	linear, sequential, cause/effect interactions; controlling agent; terminating
E	emergent process	nonlinear, non-sequential collective interactions of many independent agents