Thai University Students’ Prior Knowledge About P-waves Generated During Particle Motion

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ABSTRACT

The goal of this study is to identify Thai students’ prior knowledge about particle motion when P-waves arrive. This existing idea significantly influences what and how students learn in the classroom. The data were collected via conceptual open-ended questions designed by the researchers and through explanatory follow-up interviews. Participants (n = 171) were freshmen in science, engineering, agricultural sciences, and medicine fields enrolled in a university in Thailand. The major categories of Thai students’ prior knowledge about particle motion at P-wave arrival are (1) the belief that particles spread in all directions, like water waves, when P-waves arrive, (2) the belief that particles move forward with a sine wave motion, and that these particles travel with the propagating wave energy to the P-wave’s final destination, (3) the belief that particles vertically move back and forth at P- wave arrival. These beliefs are the alternative conception held by more than three-quarter of our study population. The other held the scientific conception (category 4) that particles in a medium vibrate in the same direction as the propagating wave energy when P-waves arrive, coupled with recognition that particles do not travel with the propagating energy. Recognizing the existence of this prior knowledge is vital to creating teaching strategies to promote the conceptual change approach, which is based on both historical Piagetian learning theory and the new trend “knowledge in pieces”, about particle motion and seismic energy, in particular, as well as earthquakes, in general.

INTRODUCTION

Earthquake Teaching and Learning in Thailand

Science teaching and learning in Thailand is geared towards helping students acquire knowledge and skills on their own, with the purpose of encouraging students to think like scientists about authentic problems. However, by the last decade some basic science concepts, such as earthquakes, were not contained in the national science curriculum standards for Thai elementary to secondary school students. Earthquakes have been one of the basic science concepts that all secondary school students in Thailand are expected to learn starting in 2001. The main sub-topics for an earthquake concept are the definitions of an earthquake, focus, and epicenter, characteristics of earthquakes, causes of earthquakes, seismometers, seismic waves, Richter magnitude scale and Mercalli intensity scale, safety procedures from earthquakes, history of earthquakes in Thailand, active faults and risk areas of earthquakes in Thailand, and Tsunamis and safety procedures from Tsunamis (IPST, 2008). Therefore, this earthquake concept is not only a new concept for the teaching experience of some Thai teachers, but also a new concept for Thai secondary school students. That inspires the authors to consider in the light of helping Thai students learn about this new concept.

Prior Knowledge

Ausubel’s (1968) well known maxim has stated that “The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly” (p. vi). This concerns the role of existing knowledge in the light of constructivist philosophical frameworks of learning theories (Mbajiorgu et al., 2007). Furthermore, it is evident that what students already know is the primary resource for teaching strategies (diSessa, 1993; Hewson and Hewson, 1983; Posner et al., 1982; Villani, 1992). Consequently, to help Thai students learn about the earthquake topic, our preliminary study focuses on what students already know about earthquakes.

Generally, students’ prior knowledge has originated from the everyday experiences of students, (diSessa, 1993; Mak et al., 1999; Posner et al., 1982). Prior knowledge was first documented by Piaget in 1929, however systematic research into prior knowledge really began in early 1970s (Gregg, 2001; Posner et al., 1982; Villani, 1992). Research into students’ prior knowledge has a long history. Previously, coupled with the term “prior knowledge” are the broad labels “preconception”, “children’s science”, “naive knowledge”, “children’s belief”, “intuitive idea” as well as other names (Berg and Brouwer, 1991; Clark, 2006; diSessa, 1993; Dreyfus et al., 1990; Linder, 1993; Pines and West, 1986; Stenhouse, 1986;). To avoid confusion with differing definitions for these terms, we choose the generic term “prior knowledge” to represent conceptions held by our study population. The students’ prior knowledge provides an indication of the alternative conceptions as well as the scientific conceptions possessed by the students (Driver and Easley, 1978; Hewson and Hewson, 1983).

Implications of Prior Knowledge to Instruction

Prior knowledge plays a major role in the initial stage of conceptual change, and influences how and what students learn (Berg and Brouwer, 1991; diSessa, 1993; Dreyfus et al., 1990; Hewson and Hewson, 1983; Libarkin and Kurdziel, 2001; Marques and Thompson, 1997; Posner et al., 1982; She, 2002; Wagner, 2006). The implications of prior knowledge in instructions depend on the theoretical approaches to conceptual change that instructors use. Until now, there are two major theoretical approaches to conceptual change evidenced by two groups of conceptual change researchers that are considered (1) knowledge-as-

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theory and (2) knowledge-as-elements (Özdemir and Clark, 2007). In the same meaning, Elby (2000) viewed these two perspectives from the point of a constructivist and called them (1) misconceptions constructivists and (2) fine-grained constructivists.

(1) The knowledge-as-theory perspective (misconceptions constructivists)

These researchers considered structural properties of students' knowledge as a coherent unified framework of theory-like character. Prior knowledge is organized into theory, schema, or frame forms. This perspective came from Piagetian learning theory. Researchers represented conceptual change approach by using Piaget's concepts of assimilation and accommodation and Kuhn's (1962 concepts of normal science and scientific revolution (Özdemir and Clark, 2007). This was defined by Posner et al. in 1982. To change students' prior knowledge in instructions, students' alternative conceptions were used as instruments to construct cognitive conflicting situations between old and new knowledge. If students are dissatisfied with prior knowledge, and find that a new conception is intelligible, appears initially plausible and fruitful, students' conceptual change is likely to occur. Students' alternative conceptions will be replaced by scientific conceptions (Goldberg and Bendall, 1995; Hewson and Hewson, 1983; Posner et al., 1982). Since a prior knowledge structure is like a theory or a model, it can be replaced by other models in the appropriate situations of a cognitive conflict.

Historically, the knowledge-as-theory perspective was a well known perspective suggesting the prior knowledge structure and the conceptual change strategy. Many conceptual change researchers agree with this idea (Berg and Brouwer, 1991; Dreyfus et al., 1990; Libarkin and Kurdziel, 2001; Marques and Thompson, 1997; She, 2002; Vosniadou, 1994; Vosniadou and Brewer, 1992). However, more recently (1990s) some researchers are questioning the nature of the students' prior knowledge structure, especially the coherence of prior knowledge. These researchers suggest that student reasoning is fractured and not as theory-based, robust, coherent, and/or stable across time and contextual as some theories prescribe. Since prior knowledge is not independent from the cognitive artifacts within a learners' conceptual ecology, it is highly resistant to change (Clark, 2006; diSessa 1993; diSessa et al., 2004; diSessa and Sherin, 1998; Hamza and Wickman, 2008; Smith et al., 1993; Wagner, 2006). Interestingly, this is also consistent with Strike and Posner's (1992) suggestion, which stated that "These epistemological assumptions suggest that the basic problem of understanding cognitive development is to understand how the components of an individual's conceptual ecology interact and develop and how the conceptual ecology interacts with experience" (p. 155-156).

(2) The knowledge-as-elements perspective (fine-grained constructivists)

In contrast with the knowledge-as-theory perspective, this group of researchers considered students' knowledge structure as quasi-independent elements. Prior knowledge is a collection of quasi-independent simple elements within a larger conceptual ecology that are loosely connected into larger conceptual networks without an overarching structure (Clark, 2006; diSessa, 1993; Özdemir and Clark, 2007; Smith et al., 1993; Wagner, 2006). This perspective came from diSessa's (1993) idea called "knowledge in pieces". diSessa (1993) suggested 4 parts of a knowledge system: (1) elements—describe the size and character of the knowledge structures involved, (2) cognitive mechanism—provides an image of the operation of the prior knowledge system, (3) development—understanding the genesis and development of the system, and (4) systemticity—describes the level and kind of relatedness of the elements in the system. diSessa (1993) defined a term "phenomenological primitive" (or p-prim for short) to describe a small knowledge structure (an element). Moreover, diSessa (1993) explained possible characters of p-prims such as, self-explanatory - something happens "because that's the way things are". P-prims constitute a rich vocabulary through which people remember and interpret their experience. P-prims are consistent over time for individual contexts, but have high contextual sensitivity.

Prior knowledge is a collection of elements (p-prims), which are loosely connected, so adding new elements, reorganizing connection, and/or modifying current elements through an evolutionary process will promote conceptual change. In other words, the underlying idea for constructing conceptual change strategies is the fine-grained analysis of student reasoning. Since a prior knowledge structure is like loosely connected elements, its elements can be reorganized in the connection by using several appropriate contexts, in order to build more complex and stable formal knowledge (scientific conception) (Clark, 2006; diSessa, 1993; Redish, 2004; Smith et al., 1993; Ueno, 1993).

Although these two perspectives consider prior knowledge structures and conceptual change approaches in different ways, they consistently agree that students' prior knowledge come from students' daily experiences, and it influences students' learning. Thus prior knowledge is well established as the primary source to promote conceptual change strategy as aforementioned.

How to Survey Students' Prior Knowledge

Studies to identify and analyze student prior knowledge have most commonly utilized interviews, concept mapping, and open-ended tests or multiple-choice tests (Schmidt, 1997; Tan et al., 2002). Each approach has different advantages and disadvantages. Generally, multiple-choice tests are widely used as quantitative assessments for investigations of large courses or populations. Qualitative methods, like interviews and open-ended tests, are used to elicit richer information about how students think. These can be time-consuming to collect, interpret and use, but yield particularly valuable data. Often, qualitative data are used in the development of quantitative tools. For our preliminary study, we aim to explore students' prior knowledge about a previously unstudied topic, prompting use of open-ended tests and interviews.

Geoscience Research into Students' Prior Knowledge

During the last decades, much research into students' prior knowledge has been conducted in various disciplines of science, including geosciences (e.g., *Physics:* Clement, 1982; Maloney et. al., 2001, *Chemistry:* Griffiths and Preston, 1992; Wheeler and Kass, 1978, *Biology:* Brumby, 1984; Trowbridge and Mintzes, 1988, *Astronomy:* Zeilik et al., 1998, and *Geosciences:* Dodick, 2007; Nussbaum and Novak, 1976; Philips, 1991). Research into students' conceptions in the discipline of geosciences has gradually grown, resulting in significant work across a wide range of concepts. For example, Earth's structure (Blake, 2005; Kortz et al, 2008; Libarkin and Anderson, 2005; Libarkin et al., 2005; Lillo, 1994; Marques and Thompson, 1997; Nussbaum, 1979; Nussbaum and Novak, 1976; Petcovic and Ruhf, 2008; Sharp et al., 1995; Sibley, 2005), Earth's materials such as rocks, and minerals (Blake, 2005; Kortz et al, 2008; Libarkin et al., 2005), Earth's processes such as mountains, volcanoes, earthquakes, weathering, and erosion (Blake, 2005; Dal, 2005 ; Dove, 1997; Kortz et al, 2008; Libarkin et al., 2005; Petcovic and Ruhf, 2008; Ross and Shuell, 1993; Sharp et al., 1995), and the geological time (Ault, 1982; Hume, 1978; Libarkin et al., 2005; Petcovic and Ruhf, 2008; Trend, 1998) have all been investigated in significant detail. However, student conceptions of earthquakes and related phenomena have been investigated in only a small number of studies.

Earthquake Facts and Terms in Our Study

Earthquakes are vibrations within the Earth caused by the rupture and sudden movement of the lithosphere—the outer, rigid shell of the Earth above the asthenosphere (modified from Lillie, 1999). The study of earthquakes is important for scientific, social and economic reasons. Earthquakes attest to the fact that dynamic forces are operating within the Earth. They also provide crucial data about the deep interior of the Earth because seismic waves are changed as they travel through the Earth. Interpretation of the thickness, structure and composition of the crust, mantle and core can be made from the types and speeds of seismic waves moving past each zone. The main types of seismic waves are (1) body waves that can be either primary waves (P-waves) or secondary waves (S-waves), and (2) surface waves that can be either Rayleigh waves or Love waves (Richter, 1958; Fowler, 2005). When earthquakes occur, P-waves propagate as particles in media vibrate parallel to the direction of wave energy (compression), and transfer seismic energy from the focus along the ray path. P-waves move faster than other waves (called the first earthquake waves), providing a non-destructive sign of earthquake activity, with the potential for more destructive seismic waves to follow.

Students' Prior Knowledge about Earthquakes

Research into students' prior knowledge about earthquakes has identified several key significant alternative conceptions that may impede learning. For example, Leather (1987) found that over 50% of the 11 and 14 year olds UK students in his study believed that earthquakes occur only in hot countries and those earthquakes are caused by heat. This is consistent with the results from Sharpe et al. (1995), which conducted informal interviews with 9 to10 year old students in Devon, England about causes of earthquakes and found that these students believed that earthquakes occur mostly in hot countries and are caused by heat inside the earth. Overall, students of all ages hold ideas about earthquake causes that are quite different from the consensus view of scientists; that is, that most large earthquakes occur near tectonic plate boundaries. Furthermore, Ross and Shuell (1993) found that students have trouble understanding the natural cause of earthquakes. Very few students considered plate movement to be a cause of earthquakes. They also confused unrelated concepts, including confusion between earthquakes, other natural disasters, and weather conditions. Similarly, although Libarkin et al. (2005) found that most college students can write the term "plate tectonics or fault" when describing the cause of earthquakes; students were unable to explain the meaning of these terms when probed by interviews. In addition, Whitney et al. (2004) found that some students erroneously believed that earthquake occurrence can be easily predicted by unusual animal behavior or changes in weather.

In addition to earthquake causes, previous research has identified students' prior knowledge about earthquake locations, magnitude and intensity. For example, Oberhofer (1991) found that students commonly believed that a change of one magnitude on the Richter scale corresponds to a difference in released energy of 10 times (e.g., a difference of two magnitudes would be 100 times more energy). These students focused on orders of magnitude, instead of seismic energy; it is unclear whether students recognized a difference between magnitude and energy. Moreover, Oliver and Hannafin (2001) found that students often have trouble in earthquake engineering classes because these students did not know how seismic waves travel through the ground. Interestingly, Kortz et al. (2008) found that after finishing their Lecture Tutorial class, students exhibited the lowest absolute gains on earthquake intensity and magnitude topics evaluated by the Geoscience Concept Inventory (GCI). In contrast, these same students showed moderate absolute gains on the topic of earthquake location and other topics of geosciences.

RESEARCH PURPOSE

To help Thai students learn about the earthquake topic, in particular, as a first step in investigating the essential underlying cause of student difficulty with seismic wave motion, our study focuses on the prior knowledge of P-waves related particle motion. Accordingly, the objective of this study is to identify Thai students' prior knowledge about P-waves generated particle motion. Open-ended questions designed by the authors and interviews were used to identify students' prior knowledge. Moreover, we use these results to suggest implications for the design of instructional strategies based on what students bring to the classroom, both in the perspective of knowledge-as-theory and knowledge-as-elements.

METHODS

Instrumentation: Developing the open-ended conceptual questions

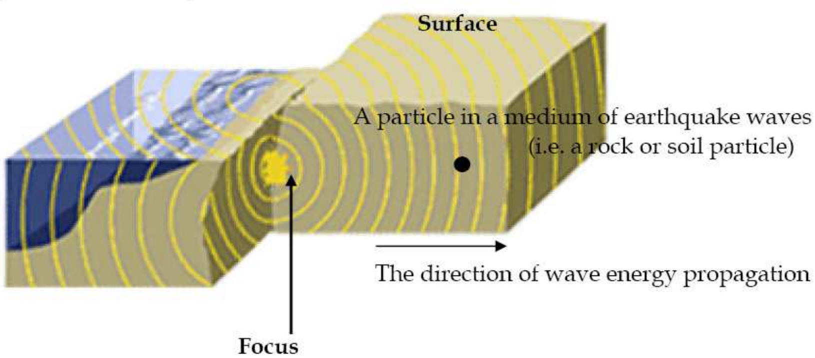
To identify Thai students' prior knowledge about the particle motion during P-wave propagation, open-ended conceptual questions were constructed. These questions were measured for content validity by using the Rovinelli and Hambleton's (1977) formula called Index of Item-Objective Congruence. Five experts, who had at least five years experience in investigating or teaching about seismic waves, were invited to judge the item objective congruence. We constructed a table for each expert to use during the item validation. Each expert assessed the agreement of each item with the stated purpose for the item, and marked: agree (+1 point), in which the item and its purpose correlate, not sure (0 point), or disagree (-1 point), in which the item and its purpose do not correlate. We averaged the scores from all experts for a given item. Rovinelli and Hambleton (1977) have suggested for the guidelines for interpretation that the number of content experts be considered when determining a criterion for item acceptance. In this situation in which five content experts are being used to assess a set of items, a minimal criterion might be the index value that would be attained if a minimum of four of five experts classified an item as a perfect match to an objective (+1 point), while one of five are not able to make a decision (0 point). Clearly, if five experts are used, a value of approximately 0.80 might be used as an accepted value. However, Turner and Carlson (2003) suggested that although the cutoff value is a floating criterion, a generally accepted value might be a minimum of 0.75.

Thus our items with Index of Item-Objective Congruence ≥ 0.80, equivalent to overall agreement that the item matches its stated objective, were selected for inclusion on the questions. We also modified our questions based upon expert suggestions. Finally, these pilot questions were administered to 71 pilot secondary school students who have studied an earthquake topic (not included in the study population). To check students' interpretations of items that matched researcher intentions, we then analyzed these students' responses and found that all of those matched the item objective (not considered scientific or alternative conceptions). The 3 open-ended questions ultimately used in our study are shown in figure 1. Question 1(Q1) and question 2 (Q2) were used to ask all study population (n=171) to draw and write about particle motion at P-wave arrival**.** Question 3 (Q3) was used to interview some study population (n=38) in the same concept.

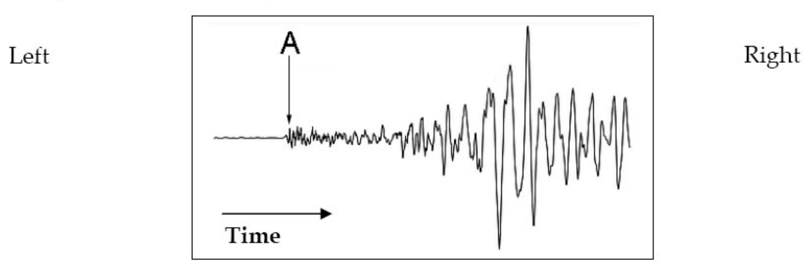
Context: University students in Thailand

All participants were Thai freshmen (mean age 19 students enrolled in science, engineering, agricultural sciences, and medicine at a university in the northeast part of Thailand. Although these students had not taken geosciences in the university, they had studied the P-wave

Q1. Consider a particle in a medium of earthquake waves (i.e. a rock or soil particle) (shown by a dot " ● " in the following figure).**Draw the particle motion (at the dot)** when the first earthquake wave arrives. (The direction of wave energy propagation is shown by the arrow below)



Q2. Consider the position A on the following seismogram. It is the first earthquake wave signal recorded on the seismogram. Assume that the direction of wave energy propagation is from the left to the right hand side of the figure; **describe the particle motion** when the first earthquake wave arrives.



Q3. When the first earthquake wave propagates through a soil or rock particle, it will shake the particle like what other kinds of waves?

FIGURE 1. The Three Open-Ended Questions About Particle Motion At P-Wave Arrival Constructed By The Authors

concept in prior secondary school instruction. The instruction took various forms, including traditional lecture, lecture with demonstration via internet animations, cookbook experiments, student presentations, and problem-solving. Finally, all students in this study had taken a first-semester introductory physics course that included the topic mechanical waves.

Procedure

In the first step, this study employed two open-ended conceptual questions (Q & Q2), completed by 171 students (about 57% female). Participants were asked to complete the "earthquake conceptual survey" that included these two questions, in addition to eight other open-ended or multiple-choice earthquake questions unrelated to this study, at the beginning of Physics Laboratory at the middle of second semester. In general, students took 10-15 minutes to complete this survey.

Both Q1 and Q2 were used to characterize students' ideas about particle motion at P- wave arrival. We found both similarities and differences in the shape of students' drawings in Q1, thus we grouped them into a structurally similar categories group. For the group of drawings we were unable to category, we invited those students to explain the meaning of their drawings. In the same way, we randomly selected a few students in each structurally similar categories group to explain the meaning of their drawings. Ultimately, there were thirty-eight students (about 60% female), who were invited to the individual interviews. After these students explained their drawings' meanings in Q1, they were given Q3 to confirm their responses again. The individual interview took 3-4 minutes per student and the researcher took note of students' responses. In brief, the final number of participating students in this study was 171 students (38 students in the interview process came from the same population). The main procedure of this study was represented again in figure 2.

Analysis

The collected data, including drawings from Q1, explanations from Q2, and interview responses from Q3, were analyzed by grouping main ideas. This involves classifying students' drawings from Q1, identifying keywords in students' explanations from Q2 and grouping students' responses in the individual interviews from Q3. This analysis was measured the intercoder reliability by the authors by using the Holsti (1969) method. It revealed more than 80% of the intercoder reliability between the authors. This means that the authors were in agreement more than 80% of the data analysis, which is shown in Table 1, and 2. In particular,

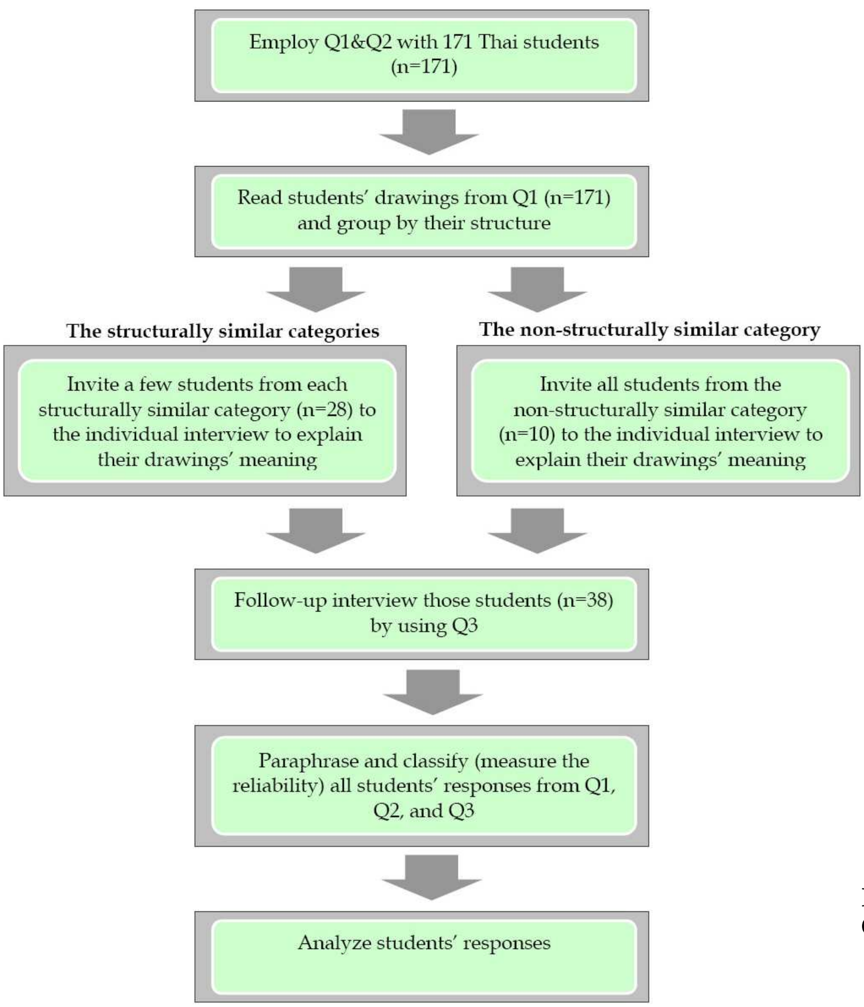


FIGURE 2. The Main Procedures Of This Study

data were analyzed by:

Step 1: Reading students' drawings (Q1) or explanations (Q2) carefully to identify their main ideas.
Step 2: Grouping the same structural drawings from Q1 in a given category.
Step 3: Inviting a few students in each category to individual interview, coupled with all students who drew different structural drawings in Q1,
Step 4: Interviewing all students in Step 3 by using Q3.
Step 5: Splitting scientific and alternative conceptions from Q1, Q2, and Q3's responses.
Step 6: Paraphrasing and classifying alternative responses from Q1, Q2, and Q3.
Step 7: Measuring the intercoder reliability for the paraphrasing and classifying in Step6.
Step 8: Grouping similar alternative responses into a category.
Step 9: Analyzing each alternative responses category from Q1, Q2 and Q3, including the scientific group

RESULTS

This study identifies common ideas held by Thai freshmen about particle motion at P-wave arrival as probed by Q1, Q2, and Q3. In this section, we discuss each group of students' drawings from Q1 and students' explanation from Q2, as well as descriptions in more details. Moreover, we show the agreement of interview responses with categories of Q1 and Q2.

Drawings of Particle Motion (Q1)

Students (n =171) were asked to provide a drawing to expose their ideas about particle motion at P-wave arrival. We identified a range of prior knowledge from students' responses to this question, and found the 5 categories of students' drawings as shown in Table 1. These 5 categories of the drawings represented different prior knowledge that are (1) the belief that particles spread in all directions at P-wave arrival, (2) the belief that particles move forward like a sine wave motion at P- wave arrival, (3) the scientific idea that particles horizontally move back and forth at P-wave arrival, (4) the belief that particles vertically move back and forth at P- wave arrival, and (5) other beliefs such as particles move forward, or particles go up when P-waves arrive.

Nearly half of these students (Group 1 in Table 1) believed that particles will spread in all directions when affected by P-waves. These students represented the idea in several different ways. The most common drawing was that of a series of concentric circles surrounding a central dot (1(a) in Table 1), followed by a drawing of arrows spreading in all directions from a common origin (1(b) in Table 1). A third, less common drawing mixed concentric circles and arrows (1(c) in Table 1). Interview responses indicate that all three drawing types were indicative of the same alternative conception. For example, students explained each of these drawings, respectively, by stating, "the particle spreads in all directions at the first earthquake wave arrival like water waves when I throw the rock down", "the particle moves in all directions", and "the particle spreads in all directions".

This was an example dialog between the researcher and a student in the individual interview. The researcher asked a student to describe the meaning of his drawing and followed-up with giving Q3. Eventually, the researcher was able to both identify a student's drawing and know the alternative conception about particle motion at P-wave arrival. A student's drawing in the following case was grouped into Group 1 (Table 1).

Starting the dialog
The researcher: (show the student's drawing in Q1)…Is this your drawing for Q1?
A student: Yes.
The researcher: Please describe the meaning of your drawing.
A student: It means when an earthquake occurs, its medium spreads in all directions. Like when we throw a bulk of rock down in a pool, water will spread in all directions.
The researcher: (point to student's drawing)….What do these expanding circles refer to?
A student: It means positions of media. Media expanded from here to here (point at a small circle and a larger circle).
The researcher: Well…so your arrows point the motion direction of the media, right?
A student: Yes.
The researcher: When the first earthquake wave propagates through a soil or rock particle, it will shake the particle like what other kinds of waves?
A student: Um…I think it is like water waves.

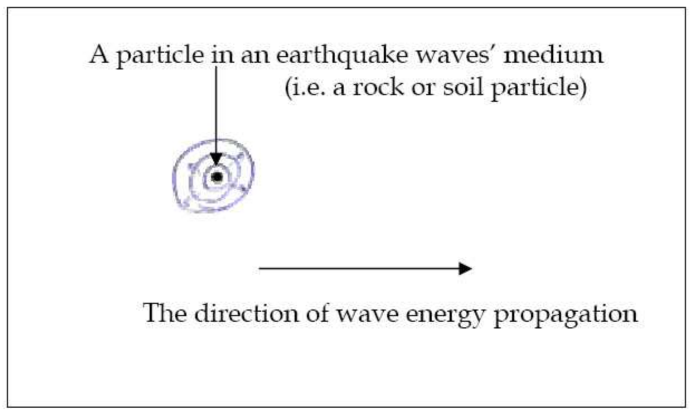
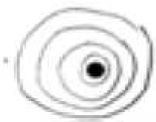
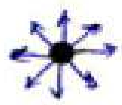
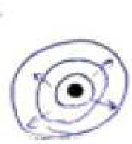
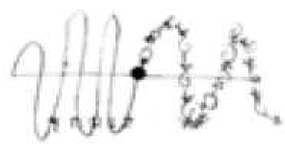
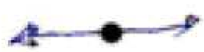
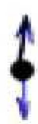
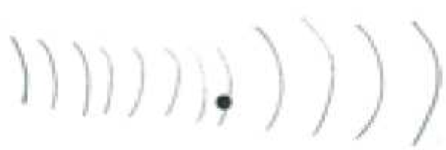


FIGURE 3. A Drawing of a Student Who Was Invited to the Individual Interview

A second category of prior knowledge held by the students in this study is the belief that particles move forward in sine wave-like motion when P-waves arrive (Group 2 in Table 1). Most students drew the head arrow pointing towards the destination direction, possible representing the moving path of the particle. Some drawings depicted a series of short rays bending from the particle to the destination. From interviews, we found that students used both drawings (2(a) and 2(b) in Table 1) to

TABLE 1. FIVE CATEGORIES OF STUDENTS'S DRAWINGS ABOUT PARTICLE MOTION AT P-WAVE ARRIVAL (RESULTS FROM Q1)

Group	Students' Drawings	Students' Ideas	% of students
1#	 1(a)  1(b)  1(c)	Students believe that particles spread in all directions at P-wave arrival, and also move along their wave energy. *(alternative conceptions)*	47%
2#	 2(a)  2(b)	Students believe that particles move forward like a sine wave motion when P- waves arrive, in which these particles move together with their energy. *(alternative conceptions)*	20%
3		Students' scientific idea is that particles horizontally move back and forth at P-wave arrival. (*the scientific conception*)	16%
4		Students believe that particles vertically move back and forth at P- wave arrival. This concept belongs to the S-wave concept, other type of body seismic waves, not for P-waves. *(alternative conceptions)*	11%
5	 5(a)  5(b)  5(c)  5(d)	Miscellaneous responses *(alternative conceptions)*	6%

Note: Here is the direction of wave energy propagation.

identify the same idea about particle motion at P-wave arrival.

Only sixteen percent of students in this study drew scientific conception drawings representing particle motion at P-wave arrival (Group 3 in Table 1). Interestingly, Group 3 is mostly populated by freshmen majoring in medicine. These students described particles that vibrate along the direction of wave propagation, but do not move with the wave energy. Most of the students in this group gave examples of waves, such as sound waves or compressional waves on a slinky, which move in the same way as P-waves.

Eleven percent of students drew figures similar to those represented by Group 4 (Table 1). The interview responses suggested that students held different types of prior knowledge. Most of these students believed that P-waves may be the same as transverse waves, such that particles in a medium vibrate perpendicular to energy wave propagation. When these students were reminded in interviews that P-waves are longitudinal waves, most were able to accurately draw and explain the scientific conception about particle motion at P-wave arrival. They also affirmed that the particle did not move along with the wave energy. In contrast to this majority, a few students were still unable to provide a scientific drawing or explanation, even after being prompted to think about P-waves as longitudinal waves. A student in this group said "I know that the first earthquake waves are the longitudinal waves, such that a particle in a medium should move in the same direction of waves, which means that the particle should vibrate only up and down because of it doesn't move along its waves, so my drawing is like this."

Students' drawings that were unclassifiable relative to the former four groups were placed into Group 5 (Table 1). Some drawings in this group may represent a combination of ideas represented by the other four groups. For example, the shape of drawings in 5(a) is similar with a half structure of drawings in 1(a). It is possible that these drawings are a combination of each other. The most popular drawing in Group 5 was 5(c) in Table 1.

Explanations of Particle Motion (Q2)

Students (n=171) were asked to write an explanation about particle motion at P- wave arrival. These explanations were paraphrased, intercoder reliability tested, and grouped into five main ideas as shown in Table 2. This table shows the five groups with English titles, the percentages of students in each explanation group, and an example from each group in both the original Thai and in an English translation.

Overall, students' explanations were easily grouped into the five main categories. For example, "the particle will vibrate along the direction of the arrow shown in the figure", "the particle horizontally vibrates like sound waves", and "the

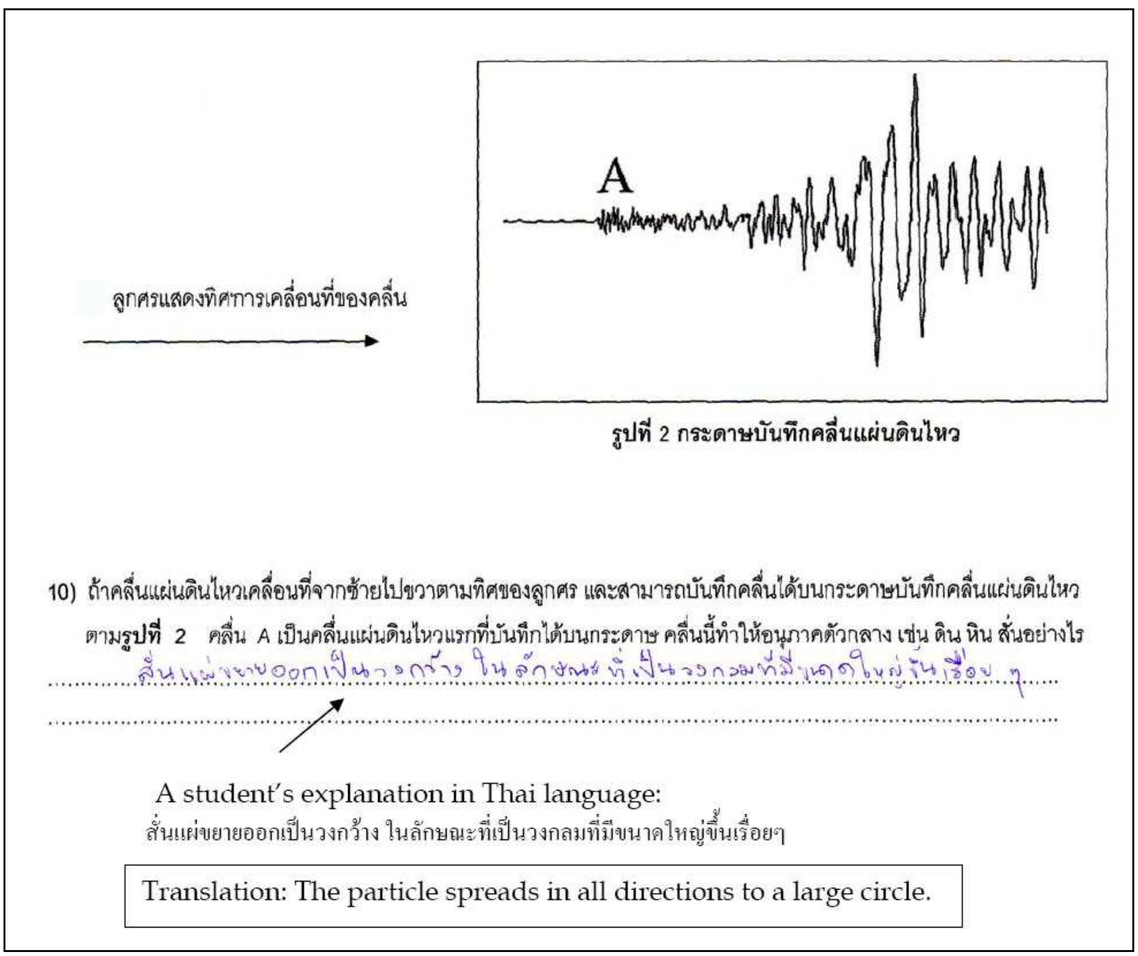


FIGURE 4. An Example of Students' Explanation in Q2 Discussion

TABLE 2. FIVE CATEGORIES OF STUDENTS' EXPLANATION ABOUT PARTICLE MOTION AT P-WAVE ARRIVAL (RESULTS FROM Q2)

Group	Students' Explanations	Examples		% of students
		Thai Language	Translation	
1#	Particles move like the signal recorded on the seismogram /move forward like a sine waves motion. *(alternative conceptions)*	น่าจะสั่นแบบ 	The particle probably vibrates like this 	55%
2	Particles vibrate back and forth /vibrate in the same direction of the wave propagation/ vibrate like longitudinal waves, like sound wave. *(the scientific conceptions)*	การสั่นของอนุภาคจะมีทิศตามทิศของลูกศร	The particle will vibrate along the direction of the arrow shown in the figure.	14%
3	Particles vertically move back and forth/ vibrate like transverse waves, waves on a string, light. *(alternative conceptions)*	ทำให้อนุภาคตัวกลางสั่นตามขวาง ตามลักษณะที่คลื่นเคลื่อนที่ไป	The particle vertically vibrates with the wave movement	12%
4#	Particles spread in all directions / moves like water waves. *(alternative conceptions)*	การสั่นของอนุภาคตัวกลาง เช่น ดิน หิน จะเหมือนกับคลื่นน้ำ	The particle, such as a rock or soil particle, will similarly vibrate with that of water waves.	12%
5	Particles violently vibrate with high frequency / Particles quake some buildings and collapse them. Particle vibration generates the Tsunami. / Particles vibration depends on the type of the medium. *(alternative conceptions)*	อนุภาคตัวกลางจะสั่นเล็กน้อย และเพิ่มขนาดขึ้นเรื่อยๆ จนหมดความแรงคลื่น	The particle will increasingly vibrate in magnitude until the strange of waves is lost.	7%

particle vibrates in the same direction of the wave propagation" were clustered into the same idea (Group 2 in Table 2), which was the scientific conception. These explanations were paraphrased to group by their authentic meaning. However, some students' explanations were unable to group because of obscurity, irrelevance and meaningless. They were mixed in Group 5 (Table 2). For example, "the particle vibrates with high frequency", "the particle quakes some buildings and collapses them", "the particle vibration depends on the type of the medium." were explanations in Group 5 (Table 2). The most popular explanation was that at P-wave arrival particles move with a sine wave motion, similar to the seismogram shown in Q2 (Group 1 in Table 2).

The students' responses to Q3 are the same with both Q1 and Q2. We found that 36% of these students believed that P-waves will shake the particle in a medium like that of water waves. The others 29%, 16%, and 10% of them believed that P-waves will shake the particle in a medium like that of waves on a string, sound waves, and light respectively.

Our study utilized open-ended questions constructed by the authors to identify Thai university students' prior knowledge about particle motion at P-wave arrival. Q1 and Q2 were administered to 171 students, as well as from the same study population we invited 38 students for the individual interview by using Q3. We paraphrased and classified students' drawing in Q1, their explanations in Q2, and interview responses in Q3. We ultimately grouped their ideas into five common categories for both Q1 and Q2 based on strong confirmation from interviews.

Drawings of Particle Motion (Q1)

Some students' drawings (Group 1 in Table 1) are similar to the picture illustrating in Q1. It is possible that this picture relates to students' thinking. This is consistent with Podolefsky and Finkelstein's (2008) study that found that for physics concepts pictures, graphs, gestures or other external representations play key roles in cognitive function, as students' interpretation of the meanings and applying meanings to these representations. Moreover, the picture illustrated in Q1 is similar to a common picture showing the way in which seismic energy propagates after an initial break, that appears in common geology textbooks or instructional websites (e.g., Lillie, 1999; Bolt, 2004 and the others, and website: USGS). A dot contained in these images represents an earthquake focus, but represents a particle in a medium in our Q1. The idea about pictures, graphs, or other representations may shape students interpretations of concepts is in line with Elby's (2000) cognitive mechanism called What-You-See-Is - What-You-Get (WYSIWYG). Elby suggested that WYSIWYG is one of several prior knowledge elements contributing to a "naive" interpretation of a visual representation. The students' drawings in the second group (Table 1) are closely aligned with that of waves on a string as depicted in common physics textbooks in explanations of transverse waves (e.g., Cutnell and Johnson, 2005; Giancoli, 2004; Halliday et al., 2001). Generally, these textbooks start with discussions of mechanical waves by focusing on the transverse wave, and using waves on a string to illustrate transverse energy motion. It is possible that these students recall only depictions and illustrations, not whole concepts, owing to people are generally better at memorizing the pictures than at memorizing words (Koran and Koran, 1980). In this study, we found that a mismatch existed between students depictions of a concept in their drawings and the related written explanation of that concept.

This study shows that less than a quarter of freshman Thai students hold the scientific conception related to this concept (Group 3 in Table 1), despite pre-college instruction and prior physics coursework. The interview responses suggest that most students in this group have a strong understanding of mechanical waves, including P-waves. This strong understanding is illustrated by the high degree of accuracy portrayed in drawings and written explanation. At the same time, one student in this group stated "I am not sure about the type of the first earthquake waves, but I guess it should be the longitudinal waves, and then I draw this". Overall, it reflects the low learning outcome about the mechanical wave concept, especially seismic waves, in Thai secondary schools.

Although students in the fourth group (Table 1) exhibited a single drawing type, they held complicated alternative conception about both the direction of wave propagation and the motion of particles in a medium. Most students have learned about the particle motion of longitudinal and transverse waves, but forgot which type P-waves are classified into; students may also have been unacquainted with the concept of P-waves, although all had engaged in pre-college instruction about earthquakes. Some students were able to memorize the definition of longitudinal waves, but could not depict this definition in a drawing. It is possible that these students learned by rote, which is problematic when trying to apply knowledge to authentic phenomena (Elby, 1999; Heller et al., 1992).

Most students in the fifth group (Table 1) lacked basic understanding of wave motion. For example, "the particle should move forward at the first earthquake wave arrival", "I don't know much about that, but I think the first earthquake waves should carry their particles to the destination" , and "I forgot about that, and then I draw like this drawing" were used by students to explain drawings in this group . It is possible that students in this group held a wide range of prior knowledge on many topics related to mechanical waves as revealed by previous researchers (Eshach and Schwartz, 2006; Houle and Barnett, 2008; Wittmann et al., 1999). Furthermore, some drawings in this group may represent a combination of ideas represented by the other four groups. For example, the shape of drawings in 5(c) is similar with a half structure of drawings in group 3. This is possible to reveal incomplete ideas of students' prior knowledge elements, if these drawings are a combination of each other.

Explanations of Particle Motion (Q2)

We classified the drawings in Q1 and identified four categories of ideas, plus one of the miscellaneous ideas. Interestingly, paraphrasing of the written explanations (Q2) produced the same four categories, plus one of the miscellaneous ideas. These groups are listed in Tables 1 and 2 based on the commonality of response. As an example, the drawings in Group 1 in Table 1 have the same meaning as the explanation in Group 4 in Table 2; these students indicated that P-waves are similar to water waves during the interviews. The drawings in Group 2 in Table 1 have the same meaning as the explanation in Group 1 in Table 2, and were described as waves on a string in interviews. Interestingly, we found different percentages of students between their drawings and explanations of these groups (groups with "#"). Most students (47%) in this study drew drawings in group 1 (e.g., a series of concentric circles surrounding a central dot), which means particles move like water waves at P-wave arrival, to answer Q1 about particle motion at P-wave arrival. In contrast, for the same concept but different contexts (Q2) only twelve percent of students in our study stated that particles move like water waves when P-waves arrive. Furthermore, only twenty percent of students in our study drew drawings in group 2 for Q1, which means particles move like a sine wave motion when P-waves arrive. But in Q2 most students (55%) stated that particles move like the signal recorded on the seismogram or a sine wave motion at P-wave arrival. Since the picture of "a series of concentric circles surrounding a central dot" and the picture of "a seismogram" are illustrated in Q1 and Q2, respectively, they may shape students' interpretations of the meanings and applying the meanings to these representations (Elby, 2000; Podolefsky and Finkelstein, 2008). Unfortunately, these students behaved like novices who focused on surface features, thus they faced difficulty in understanding such a concept (Chi et al., 1981). However, this prior knowledge element obviously revealed its property about the high contextual sensitivity (Clark, 2006; diSessa, 1993; Özdemir and Clark, 2007; Smith et al., 1993; Wagner, 2006). In other words, students' responses to Q1 and Q2 depended on the contexts in the question, although both Q1 and Q2 asked students about the same concept.

In this study, we were able to both identify students' prior knowledge about particle motion at P-wave arrival, and also showed that drawings and written explanations provided similar information about conceptions. Although, some students in this study appear to respond differently to the same conceptual questions in multi contexts, suggesting, for example, that P-waves are similar to water waves, waves on a string, and sound waves, without any indication that the student recognizes these as different kinds of energy propagation. This variability in students' responses suggests that while this questionnaire was a useful tool for understanding the range of student ideas, additional survey questions are needed to fully reveal the thinking underlying the identified categories of students' concepts of particles at P-wave arrival. In brief, this questionnaire was a useful instrument for surveying prior knowledge elements about particle motion at P-wave arrival.

In our study, only fourteen percent of students wrote a scientific explanation of particle motion at P-wave arrival (Group 2 in Table 2). This is quite similar to the sixteen percent of students who were able to provide scientific drawings (Group 3 in Table 1). It is possible that these students understand the scientific conception of particle motion at P-wave arrival, and they use this knowledge to reason about particle motion regardless of the specific problem scenario.

IMPLICATIONS OF INSTRUCTION

Our study revealed Thai students prior knowledge about particle motion at P-wave arrival. Prior knowledge is considered to be a basic source for the conceptual change approaches for both the knowledge-as-theory perspective and the knowledge-as-elements perspective as aforementioned. Since the views of the nature of structural prior knowledge of these two perspectives are different, the instructional designs for classroom conceptual change strategies of them are also different.

In the light of knowledge-as-theory, the main goal of a conceptual strategy is a cognitive conflict. Instructors have to engage students to confront their prior knowledge. In other words, instructors should provide students with scenarios or questions that cannot be explained with common alternative conceptions. In this situation, students will be dissatisfied and learn why their current ideas must be abandoned, often deciding to abandon these ideas on their own. Ultimately, that alternative conception will be replaced by the scientific conception (Hewson and Hewson, 1983; Posner et al., 1982).

Although constructivism views students' prior knowledge as a primary source for learning, erasing alternative conceptions with a replacement of the scientific conception is inconsistent with constructivism (Özdemir and Clark, 2007; Smith et al., 1993). Smith et al. in 1993 stated that "Our central claim is that many of the assertions of misconceptions research are inconsistent with constructivism. Misconceptions research has emphasized the flawed results of student learning. Constructivism, in contrast, characterizes the process of learning as the gradual recrafting of existing knowledge that, despite many intermediate difficulties, is eventually successful. It is difficult to see how misconceptions that (a) interfere with learning, (b) must be replaced, and (c) resist instruction can also play the role of useful prior knowledge that supports students' learning. If we take constructivism seriously, we must either reconsider the solely mistaken character of misconceptions or look for other ideas to serve as productive resources for student learning" (p. 123-124). However, from this theoretical debate Elby (2000) distinguished constructivists into two flavors such as misconceptions constructivists, and fine-grained constructivists.

So in the light of knowledge-as-elements, to promote a conceptual change approach instructors should focus on how prior knowledge elements are activated in appropriate contexts. For the same concept instructors should encourage students to confront with various contexts. The fine-grained analysis of student reasoning suggests that conceptual change requires restructuring, editing, and reorganizing the loosely connection of prior knowledge elements (Clark, 2006; diSessa, 1993; Özdemir and Clark, 2007; Smith et al., 1993; Wagner, 2006).

In our study we found students' prior knowledge about particle motion at P-wave arrival, which is likely to change in different contexts. This revealed not only a highly contextual sensitivity property of elements but also pointed out a pathway to bridge such loosely linked elements in order to be concrete elements of a scientific conception. Students should experience in multiple contexts to reorganize their prior knowledge elements. For example, to promote conceptual change about particle motion at P-wave arrival guided by the prior knowledge in our study, instructors may ask questions in different contexts or show different demonstrations in this concept. Instructors may use a demonstration wave spring, coupled with a red string stuck on its helix to demonstrate the particle motion at P-wave arrival. Instructors may throw a rock in a pool and ask students to look at the movement of leaves floating on that pool. Instructors may introduce students to play human waves or act like a particle of waves' medium. Moreover, instructors may use a simple seismograph to teach about seismic waves concepts. It is possible that these various contexts may help students to reorganize their loosely connected existing ideas into larger conceptual networks and ultimately go to the network of a scientific conception.

CONCLUSIONS

The research presented here suggests that Thai freshmen hold a variety of prior knowledge about particle motion at P-wave arrival. This has originated from their everyday experiences. It is possible that the images in textbooks and educational websites may influence students' recall. However, the main categories of the prior knowledge are (1) the belief that particles spread in all directions, like water waves, when P-waves arrive, (2) the belief that particles move forward with a sine wave motion, and that these particles travel with the propagating wave energy to the P-wave's final destination, (3) the belief that particles vertically move back and forth at P- wave arrival. These beliefs are the alternative conception held by more than three-quarters of Thai freshmen in our study. The other held the scientific conception (category 4) that particles in a medium vibrate in the same direction as the propagating wave energy when P-waves arrive, coupled with recognition that particles do not travel with the propagating energy. Furthermore, these students' prior knowledge elements varied in different question contexts. However, these multi contexts may be used to design a conceptual change strategy which is based on the knowledge-as-elements perspective, in which prior knowledge is a collection of quasi-independent simple elements within a larger conceptual ecology that are loosely connected into larger conceptual networks without an overarching structure. Since scientific ideas require the reorganizing and restructuring of the connection of prior knowledge elements, multiple contexts are required. Indeed, this prior knowledge is still the primary source of cognitive conflict to promote a conceptual change strategy in the light of knowledge-astheory perspective. In brief, the prior knowledge implications for classroom instruction depend on how instructors think about the nature of structural prior knowledge, including its conceptual change approach.

In future work, the results of this study will be used to construct a teaching module for encouraging conceptual change of Thai secondary school students. This teaching module will contain problems in various contexts guided by this prior knowledge. Earthquake news, online earthquake data from educational websites and real seismograms from local seismometers will be used to engage students in classrooms. Students will perform experiments by using a simple seismometer to learn about seismic wave motion.

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