SOLO Taxonomy: Increased Complexity of Conceptual Understanding about the Interconnection between Convection and Natural Disasters Using Hands-On Activities

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Abstract
Convection is an underlying concept that explains the occurrence of natural disasters such as storms, earthquakes and Tsunamis. However, in the middle school science curriculum of Thailand, convection and natural disasters are rather taught in isolation. In addition, hands-on activities that show the link between convection and the occurrence of natural disasters do not exist in the curriculum. Therefore, this study aims to develop a set of cost-effective hands-on activities to promote students' conceptual understanding and their ability to link these concepts together. There were 101 ninth graders taking part in this pre-post experimental study. The result shows that based on a conceptual test, there was a statistically significant increase in the students' mean scores after participation in the developed activities compared to before participation. In addition, there was an increase in complexity of conceptual understanding as there was a statistically significant shift towards a positive direction of complex understanding along the continuum of the SOLO taxonomy. It is therefore suggested to implement the developed hands-on activities in the middle school science curriculum to enhance students' understanding of convection related to the occurrence of natural disasters.
Keywords: Convection, Natural disasters, Hands-on, SOLO taxonomy

Convection
Heat is thermal energy which can be transferred from one place to another by three distinctive modes, composing of conduction, radiation and convection. First, conduction is the transfer of heat between two solid objects which depends on the difference in temperature of the hot and cold parts through solids. Second, radiation takes place when two bodies are at different temperatures and separated by distance. This mode of transfer does not rely on any contact between the heat source and the heated object, but through empty space by thermal radiation. The third form of heat transfer which is focused in this study is convection. This occurs when liquids and gases are heated. The heated fluids expand as the particles move faster. As a result, the particles take up more volume. In other words, they are less dense than fluid particles in cold areas, so that they rise to the cooler parts. The denser cold fluid falls into the warm areas.

Convection and Natural Disasters

Convection, heat transfer by mass motion of a fluid such as air and water (Bejan, 2013), and the occurrence of storms, earthquakes and Tsunamis, do not exist in isolation. In fact, the occurrence of these natural disasters can be explained by the scientific concept of convection (Tackley, 2000). Storms occur because of fast-moving winds flowing between two surface areas that have a great difference in temperature. More specifically, the difference in temperature causes different density of the air above the surface. Above the hotter surface, the air becomes less dense. This leads to the flow of the air from the cooler surface which has higher density to replace the rising hotter air. The flow of the air from the cooler surface to the hotter surface here is the flow of the wind. And this motion of the air is convection. The greater the difference of the temperature between the two surfaces, the stronger the wind flows. This is called storms (Smithsonian Science Education Center, 2006).

Earthquakes are also caused by convection. Inside in the earth, there is energy in the form of heat that causes the motion of mantle under the plates. The heat does not disperse equally inside the earth, causing different temperature in different parts. The deeper parts have high temperature than the shallower parts. This different temperature causes the motion of the mantle from the cooler part to the hotter part. This convection of mantle causes the movement of plate tectonics which causes geological changes. When plate tectonics clash in certain strength, earthquakes occur (Tackley, 2000). When an earthquake happens near water, Tsunami can occur as a result. Tsunamis happen when subduction occurs. Subduction is a process that larger plates under the sea slide under a lighter plate. The lighter plate suddenly shifts upward and causes the strong movement of the sea, known as big waves (Lario et al., 2016).

Hands-on Activities about Convection in the Liquid

According to the standard science curriculum of Thailand, heat transfer including convection is taught in Science 1 for grade 7 students; while, natural disasters are taught in Science 2 for grade 7 students. In Science 1, there are two main experiments to support the concept of convection. The first experiment (Figure 1, left) is to observe the rising temperature and the upward movement of the colour of potassium permanganate ($KMnO_4$) after putting the heat on. In this experiment, grade 7 students will see the direction of the movement of $KMnO_4$ which moves away from the source of heat in an upward direction. Therefore, students can observe the pattern of convection. However, some students might not be able to tell what actually causes convection and might not see how different temperature involves in this process. In addition, some students may have misconceptions that convection only occurs in the direction moving from the hotter area to the cooler area. The second experiment (Figure 1, right) is to sense the rising temperature of water through time after putting a bottle of hot water in the bath filled with water. In this experiment, students will learn that heat can be transferred in water as the water molecules move away from the source of heat.

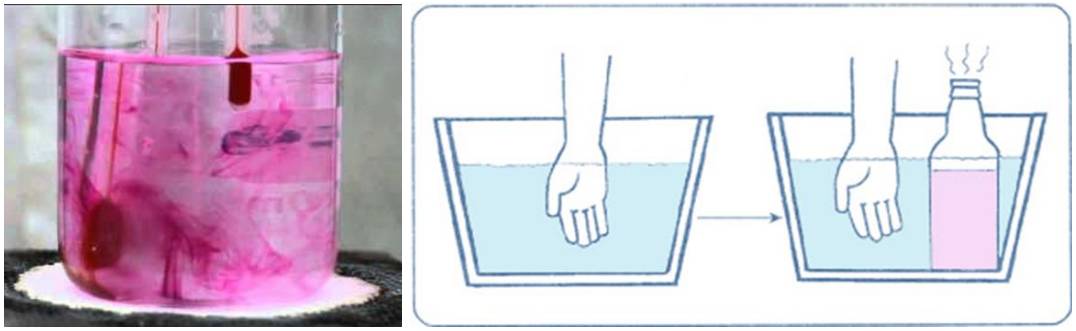

Figure 1 Convection in liquid activity

Based on these two experiments, convection is introduced to middle school students as a standalone concept, with no attempts to draw a link to the following lessons in Science 2 on natural disasters. In addition, there are no hands-on activities for natural disasters in the current form of the national science. It seems that this topic is mainly delivered by a tradition teaching method in which teachers summarise different types of natural disasters and simply explain to students how they occur. Therefore, there remain problems in this learning setting. First, the experiments on convection in Science 1 limit to convection in water only, not in the air, nor other forms of fluid. In addition, they focus only basic understanding about convection which is not applicable to real life. Second, the class activities about natural events in Science 2 are rather passive. There is no hands-on work or connection to the concept of convection. Therefore, in order to improve the current teaching of convection and natural disasters, there has to be the development of useful hands-on and minds-on activities that can help students to understand the mechanism of convection more profoundly and enable them to see the link between convection and the occurrence of natural disasters.

Hands-on Activities about Convection in the Air

There is no experiment on convection in the air in Thailand's textbooks. However, few can be found elsewhere. The first set of hands-on activity is to demonstrate convection in the air, called convection box by NASA (Figure 2, left). It consists of a shoe box, two kitchen towel tubes located at two opposite sides, kitchen towel, a candle and clay. In this activity, learners are to observe the movement of the smoke between the two towel tubes after putting the candle on the kitchen towel. However, it is difficult to observe the movement of the smoke, especially when the smoke is saturated. In addition, using kitchen towel with fire can be dangerous to young learners. Another set of convection kit is developed by Science and Technology Concepts by Smithsonian, STC (Figure 2, right). It uses glass columns, plastic tube, thermometer, candle, incense. It aims to observe the movement of the smoke between the columns and the tube after putting the candle on. Although this is considered to be a well-designed kit, it is very expensive and currently available at a relatively high cost. It is fragile as made by glass columns. After all, this kit is not available in Thailand.

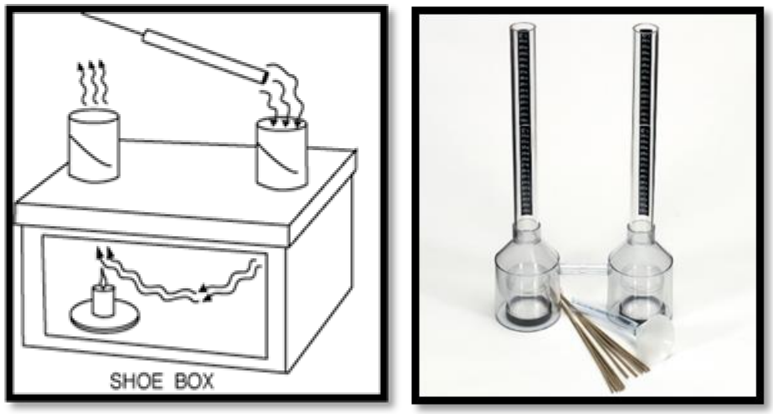

Figure 2 Convection in the air activity

The Importance of Hands-on Activities

It is believed that an effective teaching of science subject has to be in the form of active learning. The key idea for active learning is that students are not passive participants in their learning; rather, they are engaged and active in the learning process (Huerta, 2007). Research shows that there are a number of benefits of active learning. For example, it can improve cognitive and psychomotor skills of students simultaneously (Woodley, 2009), as well as promote positive attitudes towards science (Prince, 2004). In addition, as Woodley (2009) points out, through hands-on activities students are able to build a bridge between what they can see and handle (hands-on) and scientific ideas that account for observations (minds-on). Also, Bennett et al. (2007) points out that real-world connections offer teachers the chance to help students see science in the world around them and put science into a context that is meaningful to students.

SOLO Taxonomy

The structure of observed learning outcomes (SOLO) taxonomy is a model that describes levels of increasing complexity in student's understanding of subjects (Wells, 2015). In other words, it can be used to see how students can draw connections between science concepts in a single phenomenon. The model consists of five levels of understanding (Figure 3). First, the least developed level of understanding is called prestructural in which students develop no understanding of the topic that they are studying. Second, some students may have superficial understanding of a single concept which is called unistructural. Third, some students may express their understanding on several relevant topics, called multistructural. However, this understanding is in isolation and that they cannot find useful connection between the topics. Fourth, relational concerns students’ ability to connect different ideas in a single phenomenon and are able to integrate the ideas into a coherent concept. This is perhaps the main goal of science teaching in middle school level. Finally, in some certain contexts, students are expected to be able to apply the integrative concept that they learn to another context. This highest level of complex understanding is called extended abstract (Wells, 2015).

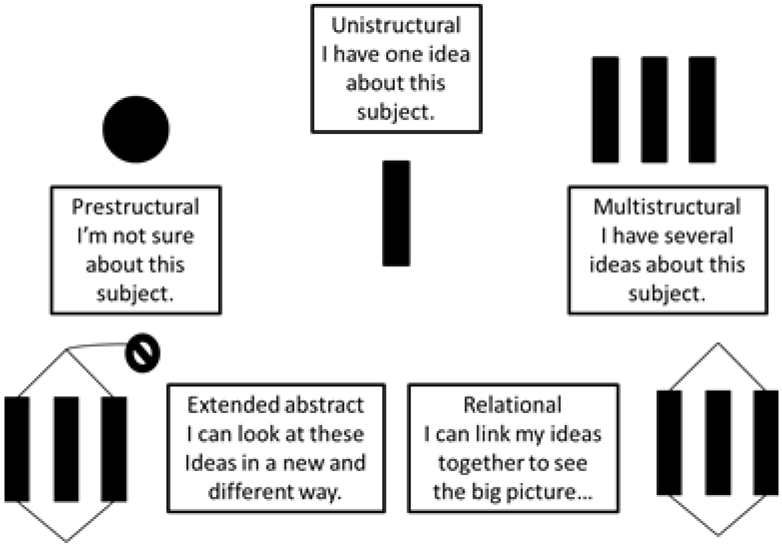

Figure 3 SOLO taxonomy

Research Objective

In order to fill the aforementioned gaps, this study sets three research objectives, aiming to (1) develop a set of hands-on activities on convection in fluid that illustrate the occurrence of storms and plate tectonics for middle school students, (2) to measure learning achievement of student participants in conceptual understanding of convection in fluid that causes storms and plate tectonics by comparing pre-test and post-test scores, and (3) to investigate changes in level of complexity of understanding along the continuum of the SOLO taxonomy of student participants between before and after doing the activities.

The Developed Hands-on Activities

Two sets of hands-on activities were developed in this study, alongside the use of a guided inquiry-based learning. The first set represents convection in the air that causes winds and storms (Activities 1-3). The second set represents convection in fluid that causes earthquakes and Tsunamis (Activity 4). Alongside these hands-on activities, questions and scenarios are used to promote minds-on engagement.

Activity 1: Convection in the air

In the first activity, a set of materials are composed of a plastic bottle (1.5 ml), incense, candle and ice. In this activity, students are able to do a set of hands-on and minds-on tasks as follows (Figure 4). Incense is needed to be lit to generate smoke for observation. The aim is to lead students to understand a general concept of convection which occurs according to different temperatures, leading to different density of the air above the different surfaces.

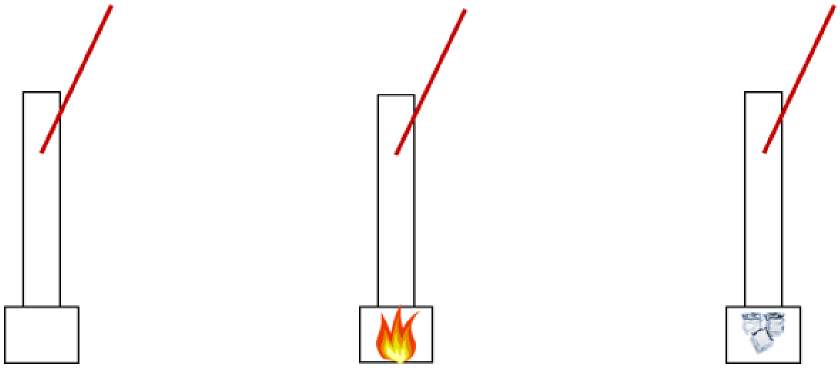

Figure 4 A study kit for direction of air convection

Task	Hands-on	Minds-on
1	-	Students are asked to think about the direction of smoke and discuss what happens if the incense is put in the column with no candles or ice
2	-	Students are asked to think what happens if the incense is put in the hot column and in the cold column
3	Students try to put the incense in the normal column and then observe the direction of the smoke (left picture)	Students discuss the results that they can observe.
4	Students try to put the incense in the hot column and observe the direction of the smoke (middle picture)	Students discuss the results that they can observe.
5	Students try to put the incense in the cold column and observe the direction of the smoke (right picture)	Students discuss the results that they can observe.

Activity 2: The occurrence of winds

The second set of the hands-on and minds-on tasks are related to the link of the concept of convection and the occurrence of winds. A set of materials are composed of two plastic bottle (1.5 ml), a straw, incense, candle and ice. According to Figure 5, two plastic bottles are required to connect with a clear straw near the top. Candle is put at the bottom of one plastic bottle and ice is at the other. Incense is needed to be lit to generate smoke for observation.

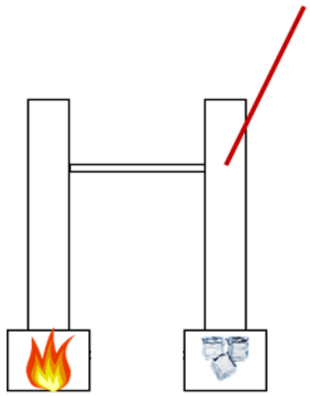

Figure 5 A study kit for the occurrence of winds

Task	Hands-on	Minds-on
1	-	Students are asked to think what happens if the hot and cold columns are connect with a tube. They are allowed to discuss their prediction until possible answers emerge
2	Students perform the experiment by connecting the two columns with a tube (on the top) and put the incense in the cold column and observe the results.	Students discuss the results that they can observe.
3	-	Students are asked to think what happens if they put the incense in the hot column. Will the result be different?
4	Students perform the experiment by putting the incense in the hot column (see figure below) and observe the results.	Students discuss the results that they can observe.
5	-	Students discuss about the occurrence of wind and sea breeze according to the observations.

Activity 3: The occurrence of storms

The third set of hands-on and minds-on tasks is for understanding the occurrence of storms. A set of materials are composed of two plastic bottle (1.5 ml), two straws, incense, candle and ice. According to Figure 6, two plastic bottles are required to connect with two clear straws. One is near the top (the same position with the previous activity). The other is near the bottom. Candle is put at the bottom of one plastic bottle and ice is at the other. Incense is needed to be lit to generate smoke for observation. It should be noted that this set of experiment has to be done quickly. There are two reasons for this. The first reason is to avoid the exposure of the plastic bottle with fire from the candle which can melt the bottle when the heat is kept for over 5 minutes. The second is to avoid the saturation of smoke which make it difficult to observe the flow of the smoke.

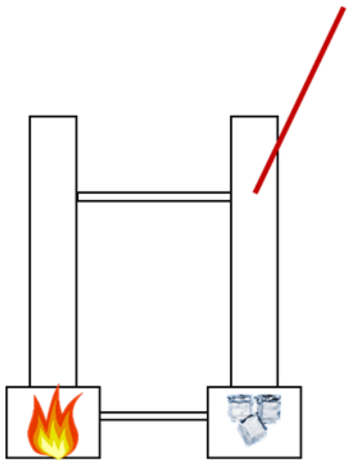

Figure 6 A study kit for the occurrence of storms

Task	Hands-on	Minds-on
1	-	Students are asked what happens if one more tube in the bottom is put in the bottom of the two columns.
2	Students perform the experiment by putting another tube in the bottom (see figure below) between the two columns and put the incense in the cold column and observe the results. They can also try to put the incense in the hot column too.	Students discuss the results that they can observe, especially the difference in the speed of the smoke between the two tubes.
3	-	Students discuss about the occurrence of storms.

Activity 4: Convection in fluid

In this activity, a set of materials are composed of a small tank, washing-up liquid, plastic sheets and candles (Figure 7). To perform this experiment, students pour some washing-up liquid in the small tank. Then they are asked to put small pieces of plastic sheets on the surface of the washing-up liquid. After that, they are asked to put candles to heat up one side of the tank and then observe the movement of the washing-up liquid and the plastic sheets. Students perform a minds-on task which is to link this set of materials with the occurrence of earthquakes and Tsunamis and discuss about this issue.

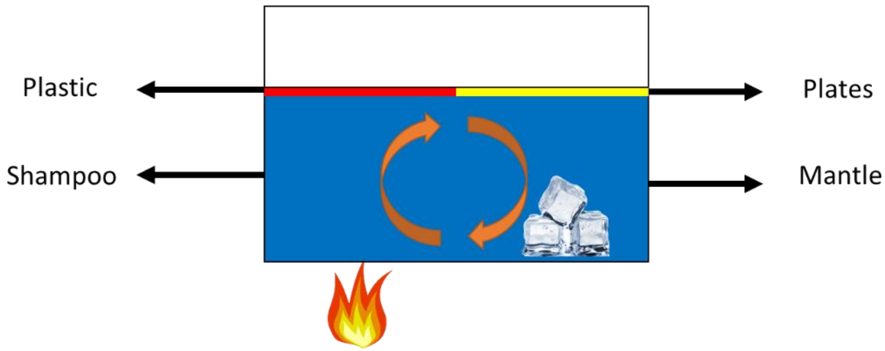

Figure 7 A study kit for the occurrence of convection in fluid

Data analysis

The participants of this study were 101 grade nine students who voluntarily took part. The research design followed these three steps. First, after being informed about their rights to participate as well as to withdraw from this study, the student participants were asked to do a pre-test which composes of 15 multiple-choice items and 3 open-ended questions. This was taken about 30 minutes. Second, the student participants were divided into small groups in order to do the developed activities from 1 to 4. This took about 2 hours. Third, the student participants did a post-test which for about 30 minutes.

In order to measure students' learning achievement, the mean scores of the student participants achieved from the pre-test and the post-test were calculated, based on 15 multiple-choice questions. A paired t-test was used to compare the means at the significant level of 0.05 (Johnson & Christensen, 2008). In order to investigate changes in level of complexity of understanding, the written responses were classified into different levels according to the SOLO taxonomy using a given criterion (Wells, 2015). The change in levels was statistically analysed both in the level of descriptive and inferential statistics. The statistically significant change in levels was measured by a Wilcoxon signed-rank test which is a non-parametric test used when comparing categorical values of two related samples (Johnson & Christensen, 2008).

Research Results

Students' mean scores of the pre-test and the post-test were calculated. According to Table 1, the mean score of the pre-test of the total of 101 student participants was 8.23; whereas the mean score of the post-test increased to 11.20 (out of 15). A statistical difference of these mean scores was analysed using a paired t-test. The result shows that there was a statistically significant increase in the mean score the students achieved in the post-test compared with the pre-test.

Table 1 Students' mean scores in the pre-test and the post-test

	Mean	**N**	**Std. Deviation**	**Std. Error Mean**
Post-test	11.20	101	1.6311	.1623
Pre-test	8.23	101	2.1349	.2124

Students' written answers were analysed. As shown in Table 2, over 90% of the student participants had some prior knowledge about this topic before joining the learning activity as nobody was found to be in the prestructural level. However, their prior knowledge was found to be in isolation. Considering their responses in the pre-test, almost 18% expressed in their understanding in the unistructural level, whereas 72.3% in the multistructural level. More specifically, students were able to answer what convection means and how natural phenomena occur superficially. Nonetheless, when it comes to the integration of these two concepts, many of them were unable to see their link. Only about 10% exhibited their advanced levels of understanding: the relational and extended abstract levels. In the post-test, over 60% of the student participants exhibited their advanced levels of understanding: 23.8% and 37.6% were categorised in extended abstract and relational, respectively. About 35% remained in multistructural, while only 3% were found to be in unistructural. The improvement in the complexity of the conceptual understanding can be viewed as the result of the learning within the interactive environment using the developed hands-on and minds-on activity.

Table 2: Students' levels of understanding according to the SOLO taxonomy

SOLO level	**Pre-test**		**Post-test**	
	number	**percent**	**number**	**percent**
prestructural	0	0	0	0
unistructural	18	17.8	3	3.0
multistructural	73	72.3	36	35.6
relational	9	8.9	38	37.6
extended abstract	1	1.0	24	23.8
Total	101	100.0	101	100.0

A Wilcoxon signed rank test was used in this study to analyse whether the overall shift in the levels across the SOLO taxonomy is statistically significant or not. The five SOLO levels were converted to an ordinal scale ranging from 1 to 5, representing the prestructural to the extended abstract levels, respectively. It shows that 62 participants exhibited their positive shift (changing from a lower to a higher level of SOLO understanding), while 3 out of 101 participants exhibited a negative shift. Out of the total number, 36 were found to remain unchanged throughout the learning activity. The analysis shows that the shift in the levels was statistically significant after participating in this learning activity. The overall shift can be expected by about 1 level towards a more advanced level of the SOLO taxonomy.

Discussion

This study reaches its aims to develop a cost-effective hands-on activities on the interconnection of convection and the occurrence of natural disasters, in particular storms, earthquakes and Tsunami. It clearly shows that the student participants gained better understanding of the concepts as expressed by the increased mean score. The effectiveness of this is understood to be resulted from both the hands-on activities as well as the inquiry nature of the lessons that prompted the participants to think along the way. The interaction of their thoughts and their action brings about this effective outcome of learning.

In the first set of activities on convection in the air, students are able to learn the direction of the convection current through the observation of the movement of smoke. The expected direction is the movement from the cooler part to the hotter part. This is due to the fact that the air participles in the hotter part become less dense so they rise. After students get this fundamental idea, they begin to apply this to the occurrence of wind. The occurrence of wind can be simply seen from the activity that air moves from one place to another. The activity shows that when putting two plastic bottles together, one with candle which is hotter and the other with ice which is cooler, students can see the direction of smoke from the incense that it moves from the cooler bottle to the hotter one. The smoke pass through the tube that connects the two plastic bottles. This movement of the air can simulate the occurrence of wind or sea breezes in general which basically occur due to a difference in temperature between two areas.

Furthermore, when students perform the third activity of convection in the air, they can compare the speed of smoke between the two tubes that connect the two plastic bottles. One tube place near the source of heat, while the other place near to top (far the source). By this setting, it allows the lower tube to be a channel for a stronger and faster movement of the air because a great difference in temperature between the two bottles. In comparison to the above tube, the air around this area between the two plastic bottles has more-or-less the same temperature, or lesser difference. Therefore, the speed of the movement of the smoke is slower. This prompts students to think that the greater the difference in temperature between the two bottles, the stronger the movement of the air. This shows how storms occur when a great difference in temperature (air pressure) exists.

Finally, the simulation of the activity on convection in fluid using washing-up liquid helps students connect convection to the occurrence of earthquakes and Tsunamis. To simulate this, students have to first imagine that plastic sheets placed on the surface of the washing up liquid are the earth's plates. Now they can observe what causes the plates to move and that is because of convection in the washing up liquid which represents magma under the earth. The convection is set to run simply by putting candle in one side of the tank so that unequal heat is generated. Once convection of the plates start, movements of the plastic sheets can be then observed. There are times when these plastic sheets collide, and this is an appropriate point where earthquake can be explained in the light of convection. Earthquakes are caused by tectonic movements in the Earth's crust. The main cause is that when tectonic plates collide, one rides over the other. Further, this can be linked how Tsunamis occur. Although this activity does not clearly simulate how they actually occur, the advantage of minds-on questions can take their role to generate some thinking and understanding.

In addition, it shows that students do not come to class empty. On the other hand, they have some prior knowledge. This claim is made on the ground that the student participants acquire some understanding about the concept of convection and natural disasters. However, this prior knowledge is shown in an isolation form in which little is known about the existing link between convection and the occurrence of natural disasters. This study shows that in order to build the link, it is only the matter of making the link explicit through hands-on activities. The students can actively construct their knowledge right after they see the link with their own eyes.

The action above is referred to by Bretz (2001) as meaningful learning, after Piaget's model of constructivism, in which individual knowledge, actions, and experiences are brought into a setting of learning. In this learning environment, students cognitively organize new knowledge by simply adding it or making connection into their existing knowledge, the process known as assimilation, or modifying it into a new knowledge structure, known as accommodation. The characteristics of cognitive process in meaningful learning are less arbitrary and more substantive. Therefore, modern education should put it emphasis on this aspect of learning.

Let us turn the discussion to the complexity of understanding about the connection between convection and natural disasters from a lower to a high level after doing the hands-on activities. This positive result confirms the effectiveness of the developed hands-on activities which aim for students to do the tasks and think about the tasks in order to develop their conceptual understanding. In addition, the developed hands-on activities can help students see the clear link between convection and natural disasters (storms, earthquakes and Tsunamis) as most of the students were identified in the relational level after doing the activities. Although 3 students were found to move backward, this does not violate the statistical finding of this study. An in-depth analysis was then carried out to figure what possible causes were. First, we found that all of the three students did better in the post-test using the conceptual test. However, their written responses were less informative compared to their previous response. This might be due to time constraints which did not allow them to complete their written answer as they possibly wanted it to be.

This also shows some educational implication. An aim of science education is to allow students to see natural phenomena as a whole, not in isolation. Therefore, reaching the level of relational should be considered as the least step of scientific literacy, if not extended abstract. Of course, there is no intention to deny the importance of multistructural in which various concepts of science are understood. However, it is essential to let students draw possible links of these concepts into a coherent and holistic fashion. Although this aim cannot be achieved in every lesson thorough hands-on activities, it cannot be denied that student discourses and discussions can bring students to the point of being aware of the links. Therefore, it is suggested here that SOLO taxonomy should be used as a main framework for lesson design as well as setting learning outcomes. It is possible to spend some class periods to build up scientific understanding of multiple concepts. However, there should be a point where these are brought together. And the best place where these are met is sit in the context of actual phenomena such as the occurrence of natural phenomena as shown in this research.

Conclusion

Hands-on activities can be used to make abstract concepts of science tangible. In addition, they can bring about possible connections of scientific concepts into practice. This study develops a set of hands-on activity to vertically foster students' in-depth understanding of convection as well as the occurrence of natural phenomena such as storms, winds, earthquakes and Tsunami. Also, it aims to horizontally broaden students' perspective of the interconnection of the scientific concept of convection as the underlying mechanism of the occurrence of the natural disasters. The results of this study were promising in both the vertical and horizontal dimensions. While the vertical knowledge is believed to be built by a series of inquiry-based learning using the hands-on activities, the horizontal knowledge is linked up by questions and scenarios that prompt students to see the existing link between different science concepts in a real-life situation.

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