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RESEARCH REPORT

Concepts of a higher hierarchical level require more dual situated learning events for conceptual change: a study of air pressure and buoyancy

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This article examines the process of students' conceptual changes in respect of air pressure and buoyancy as a result of instructing with the Dual Situated Learning Model. The dual situated learning events of this model were designed according to the students' ontological viewpoint on the science concepts as well as on the nature of these concepts. Results demonstrated that the notion of buoyancy required more dual situated learning events for conceptual change to occur than that for air pressure. Instead of attributing the difficulty involved in conceptual change to the mismatch of ontological category of the concepts, the author proposes that the hierarchical level of the scientific concepts would determine how easy or difficult it is to bring out a conceptual change. Concepts of higher hierarchical level subsume more essential underlying concepts, thus making it more difficult for conceptual changes to occur.

Introduction

Previous empirical findings have shown that students' misconceptions in science are highly resistant to change through classroom instruction (Osborne and Gilbert 1980, Osborne and Cosgrove 1983, Carey 1986). Several reasons have been proposed to account for this. They include: (1) that students' intuitive concepts are grounded in everyday experiences (Osborne and Freyberg 1985, Driver 1989); (2) that students have difficulty understanding abstract concepts (Murray *et al.* 1990, Brown 1993); and (3) that students have problems perceiving the invisible molecule (Brook *et al.* 1984, Gabel *et al.* 1987). The mismatch of ontological categories for students' intuitive concepts has recently been proposed to explain why some conceptual changes can occur easily while certain alternative conceptions persist from preschool through college (Carey 1991, Thagard 1992, Chi *et al.* 1994). The Dual Situated Learning Model (She 2001) was employed to examine the conceptual change process among students for the concepts of air pressure and buoyancy and to explore the reasons why some concepts are harder to change than others.

Theoretical frameworks

Vosniadou and Brewer (1987) state that there are actually two types of restructuring which can take place during conceptual change, namely weak restructuring and radical restructuring. Weak restructuring allows new information to be accumu-

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lated and new relationships to be formed between existing ideas without changing the core concepts. On the other hand, radical restructuring involves changing both the core concepts and structure of knowledge. Such change is similar to the Kuhnian scientific revolutionary paradigm shifts in science (Kuhn 1970).

Carey's (1985, 1986) theory of change is related to 'weak restructuring'. She argues that a lack of knowledge forces younger children to fall back on the use of a similarity-to-person-as-exemplar model, or to employ the modes of higher level thinking. Tytler's (1998) study tends to support the notion that children's conceptions, rather than being theory-like, are essentially responses to contextual situations. In addition, they are much more layered and complex than previously thought. This implies that conceptual change is better represented as a gradual accretional phenomenon rather than as a Kuhnian scientific revolution.

Major restructuring that required changing the ontological category of a conception has been found to be much more difficult to bring about than simple change within an ontological category (Chi *et al.* 1994). Chi *et al.* (1994) define conceptual change as the reassignment of a concept to another ontologically distinct category, such as from matter to process. They particularly define 'acausal interaction' as a subcategory of process, arguing that many scientific concepts, such as heat, force, mutation, or genetic equilibrium, fall into this subcategory. They suggest that the difficulty children have in learning scientific conceptions 'stems from the existence of a mismatch or incompatibility between the categorical representation that students bring to an instructional context, and the ontological category to which the science concept truly belongs' (p. 34). However, DiSessa (1993) offers a substantial critique of the theory of Chi *et al.*, stating that there are many important concepts in physics that cannot be classified as 'acasual interactions'.

Thagard (1992) uses case studies of scientific revolutions to build a model that describes different types and degrees of scientific conceptual changes. His analysis of scientific conceptual systems involves tree-like structures including kind-relations (birds, mammals and reptiles are all different kinds of animals) and part-relations between concepts (birds have feathers and beaks), and rules that link concepts and are in turn parts of the concepts (whales eat sardines). He uses these notions to create a 'hierarchy of types of changes'.

The studies described above all share the same focus, i.e., there are different categorizations available for science concepts and this would govern whether some conceptual changes are radical, while some are weak. However, these studies fail to support their theory with empirical data, or to suggest how to actually foster conceptual change.

Duit (1995) suggests that conceptual change has to do with restructuring what is already known. His view is supported by Piaget (1974), Toulmin (1972) and Jung (1993). Another view posed by Linder (1993) and Marton (1993) stresses that new ideas are related to the context in which they are used. Duschl *et al.* (1992) suggests that radical restructuring requires the learner to acquire new procedural knowledge with which to re-evaluate existing knowledge before changes can occur. Strike and Posner (1992), in a revision of their original model, emphasize the importance of a student's conceptual ecology in controlling the process of change. A student's conceptual ecology includes a fundamental organization of concepts that serves as the changing conceptual environment in which reconstruction of knowledge occurs (Demastes *et al.* 1995). These findings suggest that conceptual change requires students to re-evaluate their existing knowledge, for students who are provided with context-situated ideas, and a conceptual change environment which motivates them, restructure their concepts.

I have developed a Dual Situated Learning Model (She 2001) for conceptual change. This is built upon well-known theoretical frameworks from science education and cognitive psychology theories (Piaget 1974, Posner *et al.* 1982, Sternberg and Frensch 1996, Steinberg and Clement 1997, Rea-Rramirez and Clement 1998). This approach emphasizes starting both with students' ontological view of the concept and with the attributes of the concept, these serving as the bases for the development of dual situated learning events. Each dual situated learning event has two functions: creating dissonance with students' pre-existing knowledge, providing a new mental set with which to construct more scientific concepts. The new mental set should, as Posner *et al.* (1982) suggest, enable students to see the new concept as intelligible, plausible, and fruitful. The dual situated learning events can be any types of instructional activities, such as analogy, modeling, discrepant events and inquiry activities.

Purpose and participants

This study employs the Dual Situated Learning Model to examine the nature and process of students' conceptual change related to air pressure and buoyancy. The process of restructuring these two different concepts is extended to demonstrate how this model contributes successfully to bringing about the conceptual change, even for concepts categorized as involving the understanding of both matter as well as process.

Twenty 9th grade students (age 14–15) randomly selected from an average achievement class of a Taiwanese middle school participated in this study. All the participants have learned the concept of air pressure and buoyancy at 8th grade physical science course.

Dual situated learning model

The Dual Situated Learning Model involves six stages.

Stage 1 (S1): examining the attributes of the physics concept. The first stage is to examine the attributes of the science concepts. This provides information about which essential mental sets are needed to construct a scientific view of the concepts. Two physics concepts, air pressure and buoyancy, were chosen for this study. A panel of eight was involved, including science educators, scientists, and middle school physical science teachers. These two concepts involved the understanding of invisible and abstract attributes. Both air and water exert pressure and they are made of tiny particles (molecules) that are constantly moving (invisible attribute). For air pressure, students need to understand that air particles exert pressure on all sides of the system including whatever is inside the system. The more you push the system, the more the air particles push against whatever inside the closed system (abstract attribute). The concept of buoyancy is at a higher hierarchical level than air pressure, because it deals with the understanding of more concepts. For instance, it requires the student to know that (1) water particles (invisible attribute) exert pressure on all sides of an object (abstract attribute), and water also exerts a net upward force on the object which is buoyant force (abstract attribute) and (2) this upward buoyant force is equal to the weight of the volume of fluid displaced by the object. In addition, (3) students should also have knowledge of the factors related to the floating and sinking of objects.

Conceptual changes related to air pressure and buoyancy can be categorized as radical changes because these concepts involve the understanding of both matter (for instance, both air and water are made of tiny molecules) as well as process (for instance, air particles move constantly and exert air pressure on all sides of the system and on the object inside; the balance of buoyant force and the weight of water displaced would determine whether an object would sink or float) according to Chi *et al.* (1994).

According to the evaluation of the experts on the panel, in order to construct a more scientific view of the notion of air pressure, two mental sets are needed. Mental set 1 states that air molecules exert pressure within a closed system, while the pressure exerted on the system will reduce the space between air molecules, which in turn changes the air pressure in the system. Mental set 2 states that air pressure exists everywhere within a closed system, and that air pressure has no direction. In order to understand that water molecules exert a net upward buoyant force, students need to know that water molecules exert pressure on all sides of an object which is a concept similar to that they would learn from air pressure events (mental set 1 and 2). Four mental sets are needed to help students constructing their understanding of buoyant force. Mental set 3 states that the buoyancy of an object is not related to its mass. Mental set 4 states that the buoyancy of an object is not related to the presence of air molecules or with cracks or holes inside it. Mental set 5 states that the buoyancy of an object is related to the density of the liquid (water, or other). Mental set 6 states that the buoyancy of an object is related to its volume and that of the displaced liquid (water, or other).

Stage 2 (S2): probing the misconceptions of the physics concept. The second stage involves probing the students' ontological view concerning the concept of air pressure and buoyancy. This study used the interview-about-events technique (Gilbert *et al.* 1982) to elicit students' understanding of the concepts. Each student spent about 30–40 minutes discussing their ontological view of the concepts of air pressure and buoyancy. Almost all of these ninth grade students have learned the concepts of air pressure and buoyant force in eighth grade. Therefore, we decided to present the students with event 2 as described in Appendix 1 without demonstration and to ask them to predict what would happen to the foam rubber if we push the plunger of the syringe and to provide possible reasons. This is to detect the students' knowledge of the attributes of mental sets 1 and 2. We also presented the students with event 1 as described in Appendix 2 without demonstration and asked them to predict whether the object would float, provide a possible explanation and to describe the factors which determine whether the object will float or not. This is to detect the students' knowledge of the attributes of mental sets 3, 4, 5 and 6. This qualitative method allowed us to investigate the nature of students' understanding about semantically rich concepts (Goetz and LeCompte 1984). All these processes were recorded and the 12 videotapes were then transcribed for further analysis.

Stage 3 (S3): analysing the attributes of concepts that students lack. Results from Stages 1 and 2 will indicate which mental sets students specifically lack for the construction of a more scientific view of the concepts, thus providing specific information to teachers for the design of a series of dual situated learning events to promote conceptual change.

Analyses of the results from Stages 1 and 2 show that 70% of the students lack Mental set 1 for restructuring the notion of air pressure since they perceive that air cannot be compressed or exert pressure. About 90% of the students lack mental set 2 because they either believe that air pressure has direction or that it cannot make a substance change shapes. As for buoyancy, 90% of the students lack mental sets 3, 4, 5 and 6 since they believe that buoyancy has to do with the shape and mass of the object or the presence of air, cracks and holes inside the object. The remaining 10% of the students lack mental sets 5 and 6 because they perceive that buoyancy has to do with the object's contact surface with water or its weight.

Stage 4 (S4): designing dual situated learning events. The fourth stage is to design a series of dual situated learning events. Researchers believe that in order for conceptual change to take place, disequilibrium must occur in the form of dissatisfaction with the current model (Posner *et al.* 1982). At the same time, providing a new mental set for students is deemed necessary for conceptual change to occur. Therefore, each dual situated learning event has two functions: creating dissonance with students' pre-existing knowledge; providing a new mental set for them to construct more scientific concepts. Dissonance is aroused by presenting the students with events and asking them to predict what would happen and to provide possible reasons. Then new schema is created by allowing the students to see and experience what actually happens and suggest new explanation. Two dual situated learning events concerning air pressure were chosen to help students construct mental sets 1 and 2 (Appendix 1) as well as to create dissonance. Similarly, three dual situated learning events concerning buoyancy were chosen to help students construct mental sets 3, 4, 5 and 6 (Appendix 2) as well as to create dissonance.

Stage 5 (S1): instructing with dual situated learning events. In this stage, the interview-about-events technique (Gilbert *et al.* 1982) was employed to examine the process of conceptual change. In each dual situated learning instruction event, the students were asked to predict what would happen and also to provide the explanation for their prediction before the events were presented. After the presentation or demonstration of the events, the students were asked to explain why the events were different from their preconceptions and to construct a more scientific view of the concepts according to the events presented. In order to understand the process of conceptual change among students during the instruction, they were asked to 'think aloud'. The whole process of making prediction, providing explanation, confronting dissonance, and then constructing a more scientific view of the concepts, was video-recorded. It took at least 60–90 minutes for each student to finish this process, and these 30 tapes were transcribed for further analysis.

Stage 6 (S6): challenging situated learning events. The last stage is to present the challenging situated learning events which are to provide an opportunity for students to apply the mental sets they have acquired to other situations in order to ensure that successful conceptual change has occurred. Therefore, students were simply asked to predict what would happen and also provide the explanation for their prediction without presenting events.

The challenging situated learning event (Appendix 3) served to check whether students had acquired the mental sets required for understanding the notions of air pressure and buoyancy. The design of the floating dropper is that of a closed system, so that students need to know that air exerts pressure within it (mental set 1) and that air pressure has no direction (mental set 2). The mass of the floating dropper is kept constant (mental set 3) and it always contains the same amount of air (mental set 4). When the bottle is pressed, the water pressure exerted on the floating dropper will reduce the space between the air molecules, as well as the volume of water displaced by the floating dropper (mental set 6), therefore it sinks. This challenging event can also be applied to liquid with different density. It also helps to demonstrate how the density of liquid determines whether the floating dropper will sink float (mental set 5).

Results

Air pressure

Table 1 shows the students' concepts of air pressure before the use of dual situated learning event 1. As can be seen, 75% of the students held the perspective that air inside the syringe could not be compressed. Table 2 shows that after dual situated learning event 1, all the students changed to believe that air inside the syringe could be compressed. About 60% of the students either thought that the air molecules inside could be compressed or there was space between the air molecules.

As seen in table 3, before the use of dual situated learning event 2, 40% of the students believed that the shape of foam rubber would be not changed, 50% of them thought that only the shape of the top and bottom parts would be changed and 10% of them believed that the whole shape would be changed. These 90% of the students either thought that air pressure had to be exerted directly on the objects to change the shape of the foam rubber or that air pressure had direction and changed the shape of the top and bottom parts only. As shown in table 4, after

Table 1. Students' perceptions of air pressure before discrepant events of pressing syringe.

Concepts	%
1. The syringe cannot be pressed	30
1.1. The syringe cannot be pressed because it is full of air that has nowhere to go	20
1.2. The syringe cannot be pressed because air occupies space	5
1.3. Air inside the syringe cannot be pressed because there is air inside the syringe	5
1.4. The syringe cannot be pressed because air pressure exists inside the syringe	10
1.5. The syringe cannot be pressed because the air molecules inside the syringe were already compressed to the extreme level	5
2. The syringe can be pressed	5
2.1. The syringe can be pressed because it is full of air that can be pressed	10
2.2. The syringe can be pressed because it is full of air that can move	5
2.3. The syringe can be pressed because there is still some space inside the syringe	5

Table 2. Students' perceptions of air pressure after discrepant events of pressing syringe.

Concepts	%
2. The syringe can be pressed	25
2.1. The syringe can be pressed and the air molecules become more compressed	35
2.3. The syringe can be pressed because there is still some space inside where air exists	10
2.4. How long the syringe will take to be pressed will depend on the air pressure inside the syringe	10
2.5. The syringe can be pressed because air can escape from the syringe	5
2.6. The syringe can be pressed because air can be compressed	10
2.7. The syringe can be pressed because air can move and can be compressed	5

Table 3. Students' perceptions of foam rubber changes due to air pressure before discrepant events of pressing syringe with foam rubber inside.

Concepts	%
1. The shape of foam rubber will not change	
1.1. The shape of foam rubber will not change because there is air inside the syringe	5
1.2. The shape of foam rubber will not change because when the syringe is pressed, the air molecules inside the syringe will be compressed to the extreme level	25
1.3. The shape of foam rubber will not change because air is saturated inside the syringe or the air pressure inside the syringe creates resistance, so the syringe cannot be pressed any further	10
2. The shape at the top and bottom parts of the foam rubber will change	
2.1. The foam rubber contains space or air occupies space	10
2.2. The foam rubber will be compressed as the volume of the syringe is decreased and air pressure increases (air molecules become compressed)	20
2.3. Air would press the foam rubber when the syringe is pressed	10
2.4. When the syringe is pressed at the top, only the shape of the top and bottom parts of the foam rubber will change	5
2.5. The shape of the foam rubber will change only when the syringe touches the foam rubber	5
3. The shape on all sides of the foam rubber will change	5
3.1. The shape on all sides of the foam rubber will change because air pressure has no direction and it exerts on all sides of the foam rubber	5

the dual situated learning event 2, about 95% of the students began to believe that air exerted pressure on all sides of the foam rubber, making it smaller on all sides.

Buoyancy

As seen in table 5, before the use of dual situated learning event 3, 90% of the students believed that the solid object would sink while the boat-shaped one would float. Among these 18 students, half of them thought that the shape and the presence of cracks and holes determined whether an object would sink or float; while the other half thought that either the submerged volume of the object or its contact

Table 4. Students' perceptions of foam rubber changes due to air pressure after discrepant events of pressing syringe with foam rubber inside.

Concepts	%
1. Only the shape of the top and bottom parts of the foam rubber will change	5
2. The shape of foam rubber will become smaller on all sides	
2.1. The shape of foam rubber will be squeezed on all sides because air would exert pressure on all sides of the foam rubber	45
2.2. The shape of foam rubber will become smaller on all sides because air escapes from the foam rubber when the syringe is pressed	30
2.3 The shape of the foam rubber will change on all sides because air exerts pressure on the foam rubber	20

Table 5. Students' perceptions of buoyancy before discrepant events (the same amount of clay was used to make both the solid and boat-shaped objects).

Concepts	%
1. The solid object will sink, while the boat-shaped one will float	
1.1. The submerged volume of both the solid and boat-shaped objects are different	10
1.2. The greater the contact surface of an object with water, the greater its buoyancy	25
1.3. The boat-shaped object contains empty space, so its volume is greater than the solid one, therefore, the density of the boat-shaped is smaller than that of the solid one	15
1.4. The shape will determine whether the object will float or sink	15
1.5. The boat-shaped object will float because it is empty inside	10
1.6. The boat-shaped object will float because there is air inside	5
1.7. The solid object will sink because of its mass	10
2. Both the solid and boat-shaped objects will float because they have the same mass	5
2.1. The boat-shaped object will sink because it has greater contact surface and thus exerts greater pressure	5

surface with water accounted for its buoyancy. As shown in table 6, after the use of dual situated learning event 3, all the students began to believe that the solid object would sink while the boat-shaped one would float. About 35% of the students held the belief that the object's contact surface with water contributed to the its buoyancy; 45% of them thought that the shape of the object and the presence of cracks and holes within the object governed its buoyancy; and only 10% of them believed that the submerged volume of the object determined whether it would float or sink.

Those 45% of the students who held the belief that buoyancy was governed by the presence of cracks and holes within the object were instructed with dual situated learning event 4. As shown in table 7, before discrepant event 4 was instructed, 15% of the students thought that the sample cans would float, while 30% of them believed that these cans would sink. As seen in table 8, after the use of the dual situated learning event 4, all these 45% of the students changed to believe

Table 6. Students' perceptions of buoyancy after discrepant events (the same amount of clay was used to make both the solid and boat-shaped objects).

Concept	%
1. The solid object will sink, while the boat-shaped one will float	
1.1. The submerged volume of both the solid and boat-shaped objects are different	10
1.2. The greater the contact surface of an object with water, the greater its buoyancy	15
1.21. The greater the contact surface of an object with water, the lower the water pressure	10
1.22. The greater contact surface with water would disperse the mass of the object	10
1.3. The boat-shaped object contains empty space, so its volume is greater than the solid one, therefore, the density of the boat-shaped is smaller than that of the solid one	15
1.4. The shape will determine whether the object will float or sink	15
1.5. The boat-shaped object will float because it is empty inside	10
1.6. The boat-shaped object will float because there is air inside	10
1.7. The solid object will sink because of its mass	5
1.8. The upward water pressure is greater than the mass of the object	5

Table 7. Students' perceptions of the empty can before discrepant events.

Concept	%
1. The empty can will float	10
1.1. The inside of the empty can is filled with air	5
1.2. The empty can will float because of water pressure	5
2. The empty can will sink	5
2.1. The shape will determine whether the empty can will sink or float	5
2.2. The empty can will sink because it looks heavy	10
2.3. The water density will determine whether the empty can will sink or float	5

Table 8. Students' perceptions of the empty can after discrepant events.

Concept	%
1. The empty can in the more concentrated solution (22% salt water) will float	
1.1. The empty can in the more concentrated solution (22% salt water) will float, while that in the less concentrated solution (2% salt water) will sink, because the density of the solutions are different	10
1.2. The empty can will float because its density is lower than that of the salt water	25
1.3. The empty can will sink because it is a closed system. It will float while it is an open system	5
1.4. The empty can will float because of air pressure	5

that the sample cans would float at higher concentration of salt water. About 30% of the students believed that the empty sample can would float because its density was lower than that of salt water.

As seen in table 9, before the dual situated learning event 5, 55% of the students believed that the solid object displaced more volume of water than the boat-shaped one, 35% of them believed otherwise, thinking that the boat-shaped object displaced more volume of water than the solid one, and 15% of them held the belief that both objects displaced the same volume of water. Only this 15% of the students possessed the knowledge that the greater the buoyancy, the greater the volume of water displaced. As shown in table 10, after the use of dual situated

Table 9. Students' perceptions of the volume of water displacement of the solid and boat-shaped objects before discrepant events.

Concept	%
1. The volume of water displaced by the solid object is greater than that by the boat-shaped one	5
1.1. The volume of water displaced by the solid object is greater because it sinks and has a greater submerged volume	45
1.2. The volume of water displaced by the solid object is greater because it sinks	5
2. The volume of water displaced by the boat-shaped object is greater than that by the solid one	
2.1. The greater the buoyancy of an object, the greater the volume of water displaced by it	15
2.2. The greater the volume of an object or the greater the volume of air inside the object, the greater the volume of water displaced by it	15
3. The volume of water displaced by both objects are the same	5
3.1. The volume of water displaced by both objects are the same because they have the same volume	10

Table 10. Students' perceptions of the volume of water displacement of the solid and boat-shaped objects after discrepant events.

Concept	%
1. The volume of water displaced by the boat-shaped object is greater than that by the solid one	
1.1. The volume of water displaced by the object that floats is greater because it exerts greater buoyancy force	65
1.2. The volume of water displaced by the object that sinks is less because its submerged volume is less	10
1.3. The volume of water displaced by the object that floats is greater because it has greater surface area	5
1.4. The volume of water displaced by the boat-shaped object is greater because it contains more air	5
1.5. The volume of water displaced by the boat-shaped object is greater because it contains more air and space than the solid one, thus exerting greater buoyancy force	5
1.6. The volume of water displaced by the boat-shaped object is greater because it has greater volume than the solid one	10

learning event 5, 80% of the students began to believe that the boat-shaped object would have greater displacement of water than the solid one. Among these 80% students, 60% of them would actually explain that the object that floated exerted greater buoyancy, thus displacing greater volume of water.

Challenging situated learning event

In order to examine whether students have already acquired all the schemas concerning air pressure and buoyancy, a challenging situated learning event was provided. The students were asked to predict what would happen to the floating dropper in a bottle (closed system) if the bottle was squeezed on both sides. Their responses were displayed in table 11. As can be seen, all students predicted that the floating dropper would sink. About 65% of them mentioned that the volume of the floating dropper was decreased when the bottle was squeezed from the side. As a result, the density of the floating dropper was increased, thus it sank. Among these students, 25% of them added the view that air inside the floating dropper was compressed when the bottle was squeezed. About 20% of the students believed that the pressure in the bottle would change, and so would that of the floating dropper. The water pressure was increased when the bottle was squeezed. Consequently, the volume of the floating dropper was decreased, thus increasing the density while decreasing the volume of water displacement and the buoyancy. Some other students only predicted that the pressure of the dropper would increase while the volume of water displacement would change or remain the same.

Table 11. Students' explanations of what cause the floating dropper (closed system) to sink or rise.

Concept	%
1. The floating dropper will sink because its density increases	
1.1. The floating dropper will sink because its density increases when it is pressed	10
1.2. The floating dropper will sink because its density increases and its volume decreases when the bottle is pressed	30
2. The floating dropper will sink because its density increases when the air inside it was compressed, resulting in a decrease in air volume	25
3. The buoyancy force will determine whether the floating dropper will sink or rise	
3.1. The floating dropper will sink because of the decrease in buoyancy force due to increase in its density. The density of the floating dropper increases because its volume decreases when the pressure in the bottle changes	15
3.2. The floating dropper will sink because of the decrease in buoyancy force. The decrease in buoyancy force is due to increase in water pressure and decrease in its volume when the floating dropper is compressed	5
4. The pressure will determine whether the floating dropper will sink or rise	
4.1. The floating dropper will sink because its volume changes when the pressure increases	5
4.2. The floating dropper will neither sink or rise because the density remains constant although the pressure increases resulting in volume change	5
5. The floating dropper will neither sink or rise because the water volume remains constant	
5.1. The floating dropper will sink when the bottle is pressed	5

From the predictions offered by the students, we can see that 90% of them have successfully applied the mental sets they have acquired concerning air pressure and buoyancy to the new situation.

Conclusions

The ability of this model to bring about conceptual change can be attributed to its properties. First, the model emphasizes the importance of understanding the nature of physical concepts and students' ontological view of these concepts. These analyses provide teachers with specific mental sets that students lack for constructing specific physical concepts and serve as the bases for designing appropriate dual situated learning events. The design of dual situated learning events should fulfil both requirements: creating dissonance and providing new mental sets to help students construct a more scientific view of the physical concepts.

According to the results, to instruct students whose ontological view of specific science concepts lacks two mental sets, two dual situated learning events are needed for conceptual change to occur. This implies that the number of dual situated learning events required would depend on the number of mental sets the students lack for constructing a more scientific view of the concepts. This finding can provide an alternative explanation why some of the concepts are more difficult to change than others. These relatively more difficult concepts are usually those that subsume more underlying concepts, they are concepts of higher hierarchical level. Previous studies have shown that the mismatch of ontological categories of the science concepts would be the major reason accounting for why some concepts are harder to change than others (Carey 1991, Thagard 1992, Chi *et al.* 1994). Other studies report that students have great difficulty explaining the nature of substances and observable changes of substances (Osborne and Cosgrove 1982, Stavy and Stachel 1985, Stavy 1988, Bar 1989). The hierarchical level of the concept is another crucial factor influencing the relative ease or difficulty students experienced in understanding physical concepts.

This study also sheds light on the process of conceptual change among students. There are two advantages of employing the Dual Situated Learning Model. First, it does provide students with the essential mental sets with concrete understanding of the concepts in addition to creating dissonance with their ontological view concerning air pressure and buoyancy. Second, the events help students understand both the dynamic process and content of the physical concepts. In fact, any other resources can be used as dual situated learning events as long as they achieve the purpose of creating dissonance among students, providing new schemas, as well as helping them to visualize observable changes of substances and understand both the process and matter of physical concepts.

Recent studies have argued that conceptual change in learning is often an incremental process (Duschl and Gitmoer 1991) that may be driven by a range of hot, irrational, social, and motivational forces (Pintrich *et al.* 1993). According to the Dual Situated Learning Model proposed by She (2001), students are motivated to learn science out of curiosity aroused by the events that create dissonance and present a new schema for them.

The limitation of this study is that the Dual Situated Learning Model is employed through individualized interview-about-instance instruction. It would be of interest to put the model into real classroom teaching for further observation.

Solomon (1987) claimed that social factors have significant influence on classroom learning and knowledge construction. In addition, progress in reforming children's intuitive conceptions appears to be most successful when the social milieu of the classroom becomes a platform of the construction of the desired science concepts (Hennessey 1993). It is believed that putting this model into actual classroom teaching, taking into consideration the social factors suggested by Solomon, would result in more successful promotion of knowledge construction among students.

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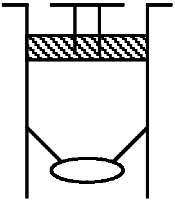
Appendix 1

Dual situated learning events for instruction on air pressure

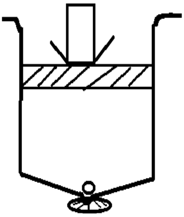
(1) First dual situated learning event for air pressure

Ask students what would happen if we push the plunger of the syringe? Why?



(2) Second dual situated learning event for air pressure

Ask students what would happen to the foam rubber if we push the plunger of the syringe? Why?

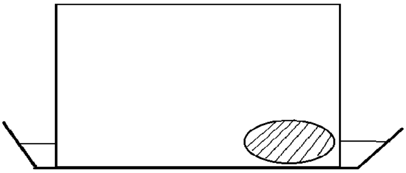


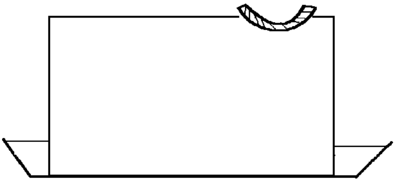
Appendix 2

Dual situated learning events for instruction on buoyancy

(1) First dual situated learning event for buoyancy

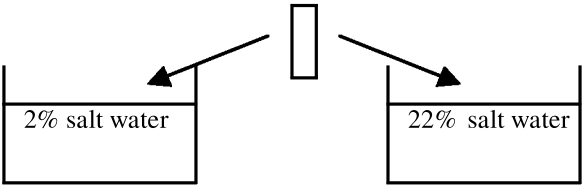
Ask students which object would float? Why? (Both the solid and boat-shaped objects are made of the same amount of clay.)





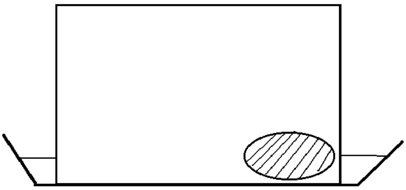
(2) Second dual situated learning event for buoyancy

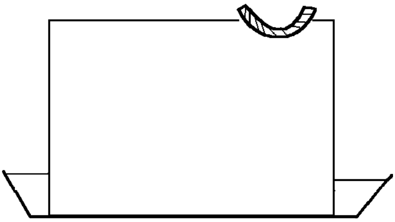
Ask students what would happen if we put the empty can into the 2% salt water and 22% salt water? Why?



(3) Third dual situated learning event for buoyancy

Ask students which object would displace more water? Why? What has buoyancy to do with it?





Appendix 3

Challenging situated learning event

Ask students what would happen to the floating dropper if we push the bottle on both sides? Why?