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Facilitating Changes in Ninth Grade Students' Understanding of Dissolution and Diffusion through DSLM Instruction

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Abstract

This study examines the nature and process of ninth grade students' conceptual change regarding their mental model of dissolution and diffusion as a result of instructions using the Dual Situated Learning Model (DSLM). The dual situated learning events of this model are designed according to the students' ontological viewpoint of the science concepts as well as the nature of these concepts. Moreover, these events serve two functions by creating dissonance with the pre-existing knowledge and providing new schema for constructing a more scientific view of the concept. The concepts of dissolution and diffusion were chosen to examine students' conceptual change process because they involve the understanding of both invisible and process attributes. Results indicate that about 76%–90% of the students successfully underwent a change in their understanding of the concepts of dissolution and diffusion after instruction using dual situated learning events. Moreover, about 75% of the students successfully applied their previous mental sets into the challenging situated learning event. This current study demonstrates that DSLM indeed facilitates the processes of conceptual change and knowledge acquisition involving concepts of dissolution and diffusion, clarifying the nature of conceptual change involving science concepts of both an invisible and a process nature.

Key Words: conceptual change, dissolution and diffusion, dual situated learning model

Previous researchers have shown that students' misconceptions in science are highly resistant to change through classroom instruction because the students have difficulty understanding that the concepts are involved with the attributes of process (Chi, Slotta, & deLeeuw, 1994) or with invisible molecules (Brook, Briggs, & Driver, 1984; Gabel, Samuel, & Hunn, 1987). In the past decade, science educators have studied misconceptions held by students and how to bring about conceptual change. However, there is still a lack of sufficient empirical study to support any instructional approach that would contribute to students' conceptual change. This study employed the Dual Situated Learning Model (DSLM; She, 2001, 2002, 2003, 2004) to examine the changes in understanding of science concepts, involving the understanding of both invisible and process attributes. The concepts of dissolution and diffusion were chosen for examining the change process because they involve the understanding of both invisible molecules and process, which can be categorised as radical change according to Chi et al. (1994). Moreover, many other studies have reported that students had difficulty understanding the concepts of dissolution and diffusion from a scientific point of view (Westbrook & Marek, 1991; Haidar & Abraham, 1991; Odom & Barrow, 1995).

Theoretical Framework

In the last two decades, many studies in science education and cognitive psychology have proposed introducing different perspectives concerning the nature of the scientific concepts in order to achieve conceptual change. Carey (1985, 1986) suggested that the key criterion for distinguishing between radical and weak restructuring is whether the concepts central to the theories are inter-translatable.

Chi et al. (1994, p. 34) proposed that the difficulty experienced in learning scientific concepts "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.). They further defined conceptual change as the reassignment of a concept to an ontologically distinct category, such as from matter to process.

Using case studies of scientific revolutions, Thagard (1992) built a model which described various types and different degrees of scientific conceptual changes. In his analysis of scientific conceptual systems, he divided scientific concepts into tree-like structures. These structures include kind-relations (birds, mammals and reptiles are all kinds of animals) and part-relations (birds have feathers and beaks), as well as relations between concepts, and rules that link concepts (whales eat sardines), which are in turn parts of the concept itself. He used these notions to create a "hierarchy of change types."

Exactly how the nature of scientific concepts would contribute to conceptual change process remains unclear. However, there seems to be a common consensus among researchers that the nature of scientific concepts would be a main factor determining whether conceptual change would occur based upon the studies described above.

The early literature on conceptual change concentrated on categorising scientific misconceptions held by students, that is, what they actually believed about a subject (Nussbaum, 1979; Nussbaum & Novak, 1976). As researchers began to explore how to help students move from their alternative notions to more scientifically accepted conceptions, they relied on Piaget's theory of disequilibrium, in which accommodation plays major roles (Posner, Strike, Hewson, & Gertzog, 1982). Researchers believed that in order for a change to take place, disequilibrium must arise in the form of dissatisfaction with the current model (Posner et al., 1982). They further believed that once being dissatisfied, the students must find the new concept intelligible, plausible and fruitful.

On the other hand, instead of dissatisfaction, Rea-Ramirez and Clement (1998) examined the role of dissonance in the process of conceptual change, pointing out that dissonance should not necessarily be equated with elimination or harsh didactic confrontation. They further proposed that certain carefully chosen discrepant events may actually arouse the students' dissatisfaction with their initial model as well as encouraging them to go beyond the previous model they held. Berlyne (1965) believed that an optimal degree of cognitive dissonance would lead to curiosity and motivate exploration. People have traditionally regarded dissonance as conflict;

however, with a broader definition of dissonance, we can possibly envision other instances where dissonance exists without harsh confrontation. It is important to note that the use of dissonance should not be so strong as to cause conflict, but should be just strong enough to upset the equilibrium of students, driving them to engage in internal struggle and to seek changes. The DSLM therefore places an emphasis on creating dissonance with students' pre-existing knowledge and to move beyond their pre-existing knowledge.

Learning transfer refers to whether some knowledge learned in one situation will be utilised in another. Sternberg and Frensch (1996) put forward four mechanisms involved in learning transfer, namely encoding specificity, organisation, discrimination, and provision of mental set. Encoding specificity Tulving and Thomson (1973) stated that whether or not an item can be retrieved depends on the way in which the item was encoded; while organisation states that whether or not retrieval will occur depends on how information is organised in the memory. Discrimination affects transfer by tagging an item as either relevant or non-relevant to a new situation to which that item might be applied (Anderson & Bower, 1973; Sternberg & Bower, 1974). A mental set refers to a certain way of seeing a task or situation that may carry over to other tasks or situations, whether or not it is appropriate. The idea is that whether transfer occurs will depend in part upon whether the individual has a mental set to achieve transfer (Sternberg & Frensch, 1996). The mental set applies during the stages of encoding, storage, retrieval and deals with the state of mind one needs to obtain transfer. Thus, transfer is enhanced when one actively seeks to transfer what one has learned (Sternberg & Frensch, 1996).

This theory provides the concepts for the design of DSLM events, which are required to create dissonance and help students move beyond their old conceptions to structure new mental sets. Basically, between the process of creating dissonance and building up a new mental set, students would need to encode information specifically, organise their pre-knowledge, and discriminate between relevant and non-relevant information in order to build up new mental structures. These studies described above shed light on the development of DSLM.

The Dual Situated Learning Model

The DSLM is comprised of the following six major stages that aim to help students restructure their science concepts: (1) Stage 1 – examining the attributes of the science concept. This stage provides information about which essential mental sets are needed to construct a scientific view of the concept; (2) Stage 2 – probing students' misconceptions of the science concept. This involves probing the students' beliefs concerning the science concept; (3) Stage 3 – analysing which mental sets the students lack. This would provide information about which mental sets students specifically lack for the construction of a more scientific view of the concepts; (4) Stage 4 – designing dual situated learning events. The design of dual situated learning events is based on Stage 3 results, related to which mental sets students lack. If there are two mental sets needed for helping students construct a more scientific view of the concepts, it might be necessary to design at least two dual situated learning events; (5) Stage 5 – instructing with dual situated learning events. This emphasises giving students the opportunity to make predictions, provide explanations, confront dissonance, and construct a more scientific view of the concepts; (6) Stage 6 – instructing with a challenging situated learning event, this is to provide an opportunity for the students to apply the mental sets they have acquired to a new situation in order to ensure that successful conceptual change has occurred.

This DSLM has been shown to have the potential to promote students' conceptual change. Situated learning means that the process of conceptual change should be situated in the nature of science concepts and students' beliefs of the science concepts in order to determine what essential mental sets are needed for constructing a more scientific view of the concepts. "Dual" means that this model has two functions in many of its facets. First, conceptual change should be built upon the elements of situated learning discused. Second, the conceptual change process should create dissonance with students' pre-existing knowledge, and provide a new mental set for them to achieve a more scientific view of the concept, which can be either a revision of the old model or the construction of a new one. Third, the process of creating dissonance needs to both arouse students' motivation and challenge their beliefs of the concepts. Fourth, the process of conceptual change needs to challenge students' ontological and epistemological beliefs of science concepts (She, 2004).

Features of the DSLM

As described previously, one of the major features of DSLM emphasises that the process of conceptual change should be situated on the nature of science concepts and students' beliefs about these science concepts in order to determine which essential mental sets are needed to construct a more scientific view of the concepts. Identifying the nature of the science concept would determine which and how many mental sets are needed to construct a more scientific view of the concept. Probing students' beliefs about the particular science concept may achieve a deeper understanding of students' misconceptions and what causes these misconceptions. The information obtained from probing would help pinpoint which and how many particular mental sets the students lack for restructuring the science concept. It would further help science educators design specific situated learning events to overcome such deficiencies and to foster conceptual change. She (2002) proposed that the concepts at a higher hierarchical level subsume more essential underlying concepts, thus making it more difficult for conceptual changes to occur. The number of dual situated learning events required would depend on the number of mental sets that students lack for constructing a more scientific view of the concepts.

Second, DSLM requires the creation of dissonance with students' pre-existing knowledge in order to arouse students' curiosity and interest, as well as challenge their beliefs about the science concepts. Once they are motivated to engage in event prediction and to visualise what actually happens, the possibility of restructuring their beliefs about the concepts may increase.

Third, providing the new mental set should be the platform where knowledge reconstruction can occur. As suggested by Posner et al. (1982), the students must see the new mental set as intelligible, plausible and fruitful in order for conceptual change to occur. This can be fostered by many types of instructional activities, such as analogy, modeling, discrepant events and inquiry activities, as long as they fulfill the suggestions of Posner et al. to provide students with opportunities to visualise what actually happens in order to construct new mental sets.

The last feature provides an opportunity to challenge students to see whether they can actually apply the mental sets that they have revised or constructed to another situation, thus achieving a successful conceptual change. The design of challenging situated learning events needs to consider all of the particular mental sets that students lack before any intervention.

Invisible and Process Concepts

Previous research has shown that students' misconceptions in science are highly resistant to change through classroom instruction because students have difficulty understanding process attributes (Chi et al., 1994) and invisible attributes of molecules (Brook et al., 1984; Gabel et al., 1987). The term invisible molecule indicates that the viewpoint of a molecule is not visible from the students' naked eyes. However, it has been suggested that the students' grasp of the nature and structure of molecules is essential to the understanding of chemistry. For example, the kinetic molecular theory, which describes that all matter is composed of tiny particles that are constantly in motion, provides a basis for understanding the invisible molecular events underlying natural phenomena as well as explaining the observable aspects of these same phenomena (Lee, Eichinger, Andderson, Berkheimer, & Blakeslee, 1993). Many studies have consistently reported that students have great difficulty explaining the nature of substances and observable changes of substances (Bar, 1989; Osborne & Cosgrove, 1983; Stavy, 1988; Stavy & Stachel, 1985). In addition, students have even greater difficulty understanding the basic properties of invisible molecules and explaining changes of state in terms of molecules (Brook et al., 1984; Gabel et al., 1987). Haidar and Abraham (1991) further pointed out that the understanding and use of atomic and molecular concepts are essential in teaching chemistry. More importantly, students tend to see phenomena at the macroscopic level, whereas chemistry requires them to think at the microscopic level. In order to be fully able to understand the concepts of dissolution and diffusion, students need to possess the molecular level schema of water and solute. Moreover, students also see the process attributes of the concepts of dissolution and diffusion only with difficulty, instead tending to view dissolution and diffusion as the attributes of matter. Chi et al. (1994) have proposed that the mismatch of ontological categories for students' intuitive concepts has recently being used to explain why some concepts are more difficult to construct or reconstruct, such as reassignment of a concept from matter to process. Many other studies also have reported similar results, indicating that students have difficulty understanding the concepts of dissolution and diffusion from a scientific point of view (Westbrook & Marek, 1991; Haidar & Abraham, 1991; Odom & Barrow, 1995) because students lack either the molecular concepts or the process attributes of these concepts.

The use of DSLM has been shown to successfully foster students' conceptual change for concepts of air pressure, buoyancy, thermal expansion and heat transfer (She, 2002, 2003, 2004). She suggested that the hierarchical level of scientific concepts would determine how easy or difficult it is to bring about conceptual change. Concepts of higher hierarchical level subsume more essential underlying concepts, thus making it more difficult for conceptual changes to occur. The number of dual situated learning events required would depend on the number of mental sets that students lack for constructing a more scientific view of the concepts (She, 2002). That research provided evidence that the concept of buoyancy is at a higher hierarchical level than air pressure, therefore, more mental sets and dual situated learning events are needed for buoyancy than for air pressure. Though She's study demonstrated that use of the DSLM instructional approach could bring about conceptual change even for difficult concepts (She, 2004) or those of a higher hierarchical level (She, 2002, 2003), it would be significant to know whether this model can contribute to restructuring of concepts that involve the understanding of invisible molecule and process attributes, such as dissolution and diffusion.

Objectives

DSLM has been shown to successfully facilitate students' conceptual change involving the attributes of higher hierarchical concepts, such as air pressure, buoyancy, thermal expansion and heat transfer (She, 2002, 2003, 2004). In addition, it would be of interest to investigate whether DSLM would promote conceptual change involving both invisible and process attributes. Therefore, this study examines the nature and process of ninth grade students' conceptual change in their mental models of dissolution and diffusion, through the use of DSLM. The concepts of dissolution and diffusion were chosen for examining students' conceptual change process because they involve the understanding of both invisible as well as process attributes, which can be categorised as radical change according to Chi et al.'s theory (1994).

Method

Participants

Twenty-two Grade 9 students (age 14–15), randomly selected from an average achievement class, were enrolled for this study (11 boys and 11 girls). All the participants had been taught the concept of dissolution and diffusion in their Grade 8 physical science and Grade 7 biology course.

Instruction with the Dual Situated Learning Model

DSLM (She, 2001, 2002, 2003, 2004), which involves six stages was employed to examine how the model would foster the occurrence of conceptual change even for concepts of both invisible and process nature.

Stage 1 (S1). Examining the attributes of the science concepts

A panel of eight experts, including science educators, scientists, and middle school physical science teachers, was involved in examining the attributes of dissolution and diffusion. These two concepts involve the understanding of both invisible (molecular level) as well as process attributes. According to the evaluation of the panel experts, in order to construct a more scientific view of the notion of dissolution, two mental sets are needed. The mental set can be considered as something possessed by an individual who can approach a task successfully, based on having the specific set of related knowledge. Mental Set 1 views dissolution as an interaction of solute and solvent at the molecular level, with the solute dissolving within the solvent because the water molecules have spaces in between. Mental Set 2 sees dissolution as a dynamic process beginning with slow movement within the solvent until the solute is finally distributed evenly.

As for diffusion, in addition to the molecular structure of water (Mental Set 1), the students need to acquire two key schemata in order to obtain a more scientific perspective of the concept. First, the diffusion process is dynamic, with the dye molecule moving randomly from high to low concentration areas (Mental Set 3), and second, such a process would result in an even distribution of the dye molecules among the water molecules (Mental Set 4).

Stage 2 (S2). Probing misconceptions of the science concept

Immediately after Stage 1, the researcher begins to design the interviewing task to probe students' misconceptions. The interview-about-events technique (Gilbert, Osborne, & Fensham, 1982) was used here to examine students' beliefs about the concept of dissolution and diffusion. Each student interview lasted for 30 minutes. Each student was presented with the event for dissolution individually without demonstration (Table 1). They were asked to predict what would happen if sugar was put into water and to provide possible reasons. In addition, students were asked to draw their mental image of sugar dissolving in water. This was used to detect the students' knowledge about Mental Sets 1 and 2. We also presented the students with an event for diffusion without demonstration and asked them to predict what would happen if a drop of dye was added into the water and to provide possible reasons (Table 2). Students also were requested to draw their mental image of the diffusion of dye in water. This is to detect the students' knowledge about Mental Sets 3 and 4. This qualitative method allowed us to probe the students' understanding of a semantically rich concept (Goetz & Lecompte, 1984). In addition, the students were asked to draw

Table 1
Probing Student's Misconception of Dissolution.

Ask students to predict what would happen if we dissolve sugar into water? Explain why? And also ask students to draw their mental structure about sugar dissolving in water.

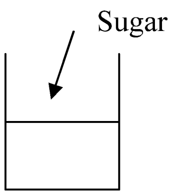
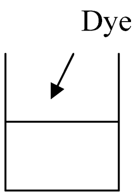


Table 2
Probing Student's Misconception of Diffusion.

Ask students to predict what would happen if we add a drop of dye into water? Explain why? And also ask students to draw their mental structure of the diffusion of dye in water.



an illustration of their mental model in accordance with what they understood about the concepts. The entire process of the interviews was recorded on 11 videotapes, which were then transcribed for further analysis.

Stage 3 (S3). Analysing the attributes of concepts that students lack

Analyses of the results from Stages 1 and 2 show that about 80% of the students lacked Mental Set 1 for restructuring the notion of dissolution at the molecular level, with the solute dissolving within the solvent because the water molecules have space in between (Table 3). About 60% of the students lacked Mental Set 2, because they did not see dissolution as a dynamic process beginning with slow movement within solvent until the solute is finally distributed evenly (Table 4). As for diffusion, 80% of the students lacked Mental Sets 3 and 4 since they believed that either the dye molecules would spread out or move randomly (Table 6).

Stage 4 (S4). Designing dual situated learning events

Designing of the dual situated learning events was based on the results from Stages 1, 2 and 3, which showed that students lacked Mental Sets 1, 2, 3 and 4. Therefore, the expert panel tried to design a series of dual situated learning events to specifically help students reconstruct their Mental Sets 1, 2, 3 and 4.

In this study, two dual situated learning events concerning dissolution were chosen to help students construct Mental Sets 1 and 2 (Appendix 1) in addition to creating dissonance. For diffusion, two dual situated learning events concerning diffusion were chosen to help students construct Mental Sets 3 and 4 (Appendix 1) in addition to creating dissonance. The presentation of analogy was designed to help students visualise that there is space in between the water molecules (Mental Set 1 – molecular level of dissolution) (Appendix 1, Event 1). The real event (visualising the process of brown sugar dissolving in water) was chosen to aid students in comprehending the dynamic process of dissolution as well as the final even distribution of sugar molecules (Mental Set 2 – dynamic process of dissolution) (Appendix 1, Event 2).

The water molecule schema (Mental Set 1) has already been constructed through the instruction on dissolution. The real event (visualising a drop of dye dropping into water) chosen for the teaching of diffusion focused on helping students construct the dynamic process of diffusion, wherein the dye molecules move from high to low concentration (Mental Set 3) (Appendix 1, Event 3). The analogy of fragrant air diffusion was designed to help students understand that the dye molecules would move from a high to a low concentration area (molecular level of diffusion) and finally be distributed evenly (Mental Set 4) (Appendix 1, Event 4).

Stage 5 (S5). Instructing with dual situated learning events

The interview-about-events technique (Gilbert et al., 1982) was employed to probe the students' understanding about the concepts before and after instruction with each dual situated learning event. All of the four real dual situated learning events were presented to each student individually. The instructions given to students were: (1) Step 1 – students were asked to predict what would happen and also provide the explanation for their prediction before the dual situated learning events were presented; (2) Step 2 – present the analogy and discrepant event to show students what is really happening; (3) Step 3 – after the presentation, the students were asked again to conclude whether their results fitted their predictions, and to provide a possible explanation (Appendix 1). In order to understand how conceptual change occurs as a result of the dual situated learning event instruction, the students were asked to "think aloud." The overall instructional process of predicting, explaining, visualising analogy and discrepant events, confronting dissonance, and providing possible explanation were videotaped. Each student took about 60–80 minutes to finish the whole process. All of the video tapes were transcribed into written files, which were combined with students' drawings in order to categorise students' mental models of dissolution and diffusion. All of the students' descriptions of their mental models of dissolution and diffusion were initially categorised into different categories. The percentage of each category was obtained from grouping students descriptions according to their category.

Stage 6 (S6). Challenging situated learning events

The challenging situated learning event (Appendix 1) served to check whether students had acquired the mental sets required for understanding the notions of dissolution and diffusion. The design of the event illustrating the diffusion of a drop of dye in different concentrations of sugar water would require students to know that the water molecules have space between them (Mental Set 1), and the process of diffusion at the macroscopic level (Mental Set 3) and at the microscopic level (Mental Set 4). The students were instructed to predict what would happen if a drop of dye were added into three different solutions: water, 10% sugar water, and 20% sugar water, and explain why. Students' predictions and explanation were videotaped. Moreover, they also were required to draw their image or pictures of what would happen if a drop of dye were added into water, 10% sugar water, or 20% sugar water. The transcripts of the interview videotapes and students drawings were used to categorise students' mental models of the event.

Results

Dissolution

Dual Situated Learning Event 1 (DSLE 1)

Table 3 shows the percentage of students' presenting each mental model before the use of DSLE 1. As can be seen, most of the students lacked the molecular level schema and only 20% of the students held the schema of even distribution. However, as seen in Table 2, after the dual situated learning event, 40% of the students acquired the concept that the sugar molecules would dissolve within the water molecules and be distributed evenly. The remaining 60% of the students thought that the sugar molecules would combine with the water molecules, and only 20% of them believed that it would finally be distributed evenly. As shown in their representative mental models, 100% of the students employed Mental Set 1 to represent the molecular structure of water in their drawing after the presentation of the first dual situated learning event – the water molecule analogy (Table 4). In other words, presenting the water molecule analogy indeed helps students recognise the molecular perspective of dissolution. In addition, it helps 60% of the students to understand that the sugar molecules would finally be distributed evenly in water (Mental Set 2) after the use of DSLE 1.

Table 3
Students' Mental Model of Dissolution before Dual Situated Learning Event 1.

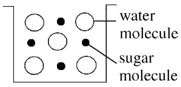
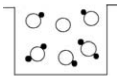
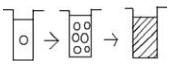
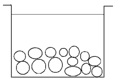
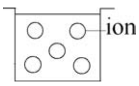
Concept	Representative mental model	Percentage
1.1. The sugar molecules would mix with the water molecules and be distributed evenly.		20
1.2. The sugar molecules would combine with the water molecules.		25
1.3. The sugar would break up into smaller molecules and distribute in water.		25
1.4. The sugar would distribute in water unevenly, with higher concentration at the bottom of the beaker.		15
1.5. The sugar would either dissolve or precipitate at the bottom while it mixes with water.		10
1.6. The sugar would break into molecules, then become ions.		5

Table 4
Students' Mental Model of Dissolution after Dual Situated Learning Event 1.

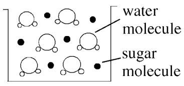
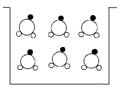
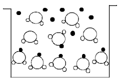
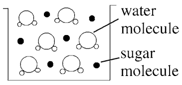
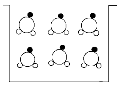
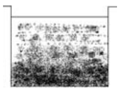
Concept	Representative mental model	Percentage
1.1. The sugar molecules would dissolve within the water molecules and be distributed evenly.		40
1.2. The sugar molecules would combine with water molecules and be distributed evenly.		20
1.21. The sugar molecules would combine with the water molecule and precipitate at the bottom, thus the concentration of sugar would be higher at the bottom of the beaker.		40

Table 5
Students' Mental Model of Dissolution after Dual Situated Learning Event 2.

Concept	Representative mental model	Percentage
1.1. The sugar molecules would dissolve within the water molecules and be distributed evenly (three students emphasized that stirring would foster even distribution).		50
1.2. The sugar molecules would combine with water molecules and be distributed evenly.		40
1.4. The sugar molecules would distribute in water randomly and be hard to differentiate, with the higher concentration at the bottom of the beaker.		10

Dual Situated Learning Event 2 (DSLE 2)

Table 5 shows the students' mental model of dissolution after the use of DSLE 2. As can be seen, about 50% of the students believed that the sugar molecules would dissolve within the water molecules and 40% of the students thought that the sugar molecules would combine with the water molecules. About 90% of the students believed that the sugar molecules would finally be distributed evenly. From the students' representative mental model shown in Table 3, 90% of the students continued to use the molecular structure of water (Mental Set 1) in their illustrations, even after the second dual situated learning event. More important, the percentage of students who believed in the even distribution of sugar molecules (Mental Set 2) also increased from 60% to 90%.

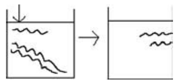
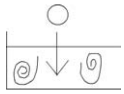
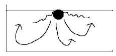
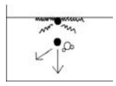
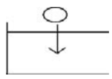
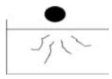
In summary, the percentage of students acquiring a more scientific view of dissolution indeed increased as instruction progressed from the first to the second dual situated learning event.

Diffusion

Dual Situated Learning Event 3 (DSLE 3)

Table 6 shows the students' mental model before the use of DSLE 3. As can be seen, only 19% of the students held the concept that the dye would move from high to low concentration, and only half of those students believed the dye would finally be

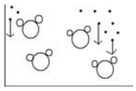
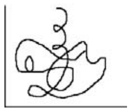
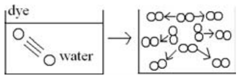
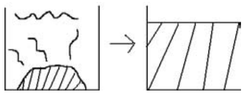
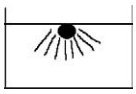
Table 6
Students' Mental Model of Diffusion before the Dual Situated Learning Event 3.

Concept	Representative mental model	Percentage
1.1. The dye molecules would move from high concentration to low concentration and be distributed evenly.		9.5
1.2. The dye molecules would move from high to low concentration and finally be distributed unevenly.		9.5
1.3. The dye molecules would move randomly.		19
1.4. The dye molecules would finally be distributed evenly.		19
1.5. The dye molecules would combine with the water molecules and spread out randomly.		14
1.6. The dye molecules would move to the bottom because of gravity and then spread out.		14
1.7. The dye molecules would move from dye area to non-dye area.		14

distributed evenly. Some students believed that the dye would move randomly; while others thought that the dye would move either from the dye area to the non-dye area or to the bottom because of gravity, and then spread out. Among the remainder, 14% of the students believed that the dye molecules would combine with water molecules and spread out randomly.

Table 7 shows the students' mental model after the use of DSLE 3: the real event of the diffusion process. As can be seen, about 43% of the students (an increase of 24%) viewed the process of diffusion as the movement of the dye from high to low concentration at the macroscopic level. There is an increase of 19% of the students (14% to 33%) who perceived that the dye would move from top to bottom because of gravity and then spread out. About 14% of the students maintained the same mental model of the dye molecules combining with the water molecules, with only slight change in their belief that the dye would finally be distributed evenly. This clearly indicates that about 43% of the students acquired Mental Set 3 after the use of DSLE 3.

Table 7
Students' Mental Model of Diffusion after Dual Situated Learning Event 3.

Concept	Representative mental model	Students
1.12. The dye molecules would move from high to low concentration.		43
1.3. The dye molecules would move randomly.		5
1.5. The dye molecules would combine with the water molecules and be distributed evenly.		14
1.6. The dye molecules would move from top to bottom because of gravity, and then spread out.		33
1.7. The dye molecules would move from dye area to non-dye area and be distributed evenly.		5

Dual Situated Learning Event 4 (DSLE 4)

As seen in Table 8, before DSLE 4, about 85% of the students described their mental model of fragrant air molecules moving from high to low concentration, and finally becoming evenly distributed, so that persons in different locations in a room would eventually smell the same fragrant air. About 5% of the students believed that the fragrant air would finally be distributed evenly, but they only focused on describing the process of molecule collision. Only about 5% of the students thought that a person closer to the fragrant air would smell more fragrance than the others who were more distant from the source.

Table 9 shows students' mental models of what would happen when adding a drop of dye into water, after the use of the DSLE 3 and 4; the analogy of diffusion at the macroscopic and microscopic level. As can be seen, 76% of the students described their mental model of the diffusion process at the microscopic level as the dye molecules moving from high to low concentration and becoming finally even distributed. Among the rest, 14% of the students still described the phenomena observed, that is, the dye molecules moving from the dye to non-dye area and be evenly distributed finally. About 5% of the students changed to focus on describing the process of diffusion as dye molecules colliding and spreading out. Only 5% of the students retained the same mental model that the dye would move randomly, before and after

Table 8
Students' Mental Model before Dual Situated Learning Event 4 (Who Would Smell More Fragrant Air after a While?).

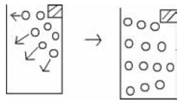
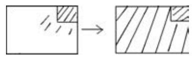
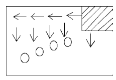
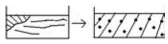
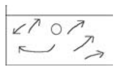
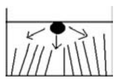
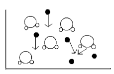
Concept	Representative mental model	Percentage
1.1. All of them smell the same eventually because the fragrant air molecules would move from high concentration to low concentration.		85
1.8. Those who sit close to the fragrant air source would smell more fragrant air than the others.		5
1.9. All of them smell the same eventually because of the fragrant air molecules would collide and then spread out.		5
1.10. All of them smell the same eventually because the fragrant air molecules would move up. When the concentration at the top is higher, they would move toward the bottom.		5

Table 9
Students' Mental Model of Diffusion after Dual Situated Learning Event 4.

Concept	Representative mental model	Percentage
1.1. The dye molecules would move from high to low concentration and finally be distributed evenly.		76
1.3. The dye molecules would move randomly.		5
1.7. The dye molecules would move from dye area to non-dye area and distribute evenly.		14
1.8. The dye molecules would collide and then spread out.		5

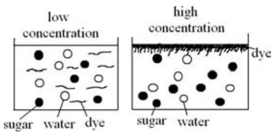
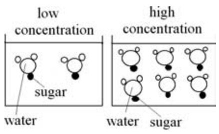
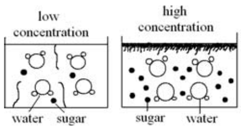
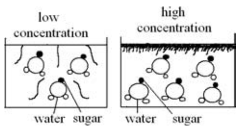
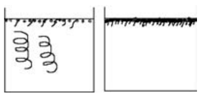
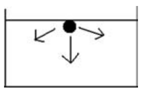
instruction on diffusion using the third and fourth DSLE. This clearly shows that after the use of DSLE 3 and 4, about 76% of the students actually acquired the Mental Set 4 in addition to the Mental Set 3.

Challenging Situated Learning Event

In order to examine whether students had already acquired all of the mental sets involved in dissolution and diffusion, a challenging situated learning event was provided; wherein the students were asked to predict how the rate of diffusion varied among different concentrations of sugar water.

Table 10 displays the mental models of how students accounted for the variation in diffusion rate in two different concentrations, 10% and 20%, of sugar water. About

Table 10
Students' Mental Model before Challenging Situated Learning Event (Diffusion Rate with Different Concentrations of Sugar Water).

Concept	Representative mental model	Percentage
1.1. The sugar molecules would take up a lot of space, leaving little room for diffusion to occur.		5
1.2. The sugar molecules would combine with the water molecules, higher concentration would prevent the dye molecules from combining with the water molecules.		30
1.3. The higher concentration of sugar water leaves little room for the dye molecules, therefore diffusion rate is much slower.		35
1.4. More sugar molecules cause more collision and therefore more resistance.		5
1.5. Higher concentration of sugar water results in different density of sugar water, so dye would float on sugar water.		15
1.6. There is no difference between high and low concentration of sugar water.		5
1.7. Do not know.		5

90% of the students believed that the higher concentration of sugar water would leave much smaller spaces for the dye molecules to diffuse, or allow a smaller amount of water for the dye molecules to combine with, or lead to higher density of sugar water, thus increasing the chance for the drop of dye to float. As seen in the students' representative mental model, about 75% of the students actually described the process of diffusion at the molecular level (Mental Set 4), and 15% of the students' mental model of the diffusion process still remains at the macroscopic level (Mental Set 3). About 75% students depicted the water molecules similar to what was presented earlier in Mental Set 1, indicating that 90% of the students successfully predicted and explained the challenging situated learning events. More importantly, it clearly demonstrates that 75% of the students acquired Mental Sets 1, 3 and 4; and about 15% of the students acquired Mental Set 3, successfully applying the models to the challenging situated learning event.

Conclusions and Educational Implications

Our results indicated that the use of dual situated learning events indeed facilitates students' conceptual change involving science concepts with both invisible and process attributes. The analysis of the students' ontological view of dissolution and diffusion shows that more than 90% of the students originally held misconceptions. The use of DSLM successfully brought about conceptual change with respect to dissolution and diffusion for between 76%–90% of the students.

The students' mental models were carefully examined after the presentation of the challenging situated learning event. It was found that 75% of students successfully employed what they had learned from instruction concerning the molecular level of understanding of diffusion and put that understanding into use for explaining the variation in diffusion rate in different concentrations of sugar water. In particular, the illustrations of the students' mental model (water, sugar, and dye molecules) provide evidence of the students' ability to apply what they have acquired from one situation to another.

Overall, it is clearly demonstrated that the design and use of analogy as one of the DSLM events in scaffolding students' understandings of dissolution and diffusion at a molecular level indeed promoted students' conceptual change involving concepts with invisible attributes. The design and use of real events as DSLM events also allows students to visualise the process of dissolution and diffusion which indeed fosters students' conceptual change involving concepts with process attribute at the macroscopic level. This shows that the use of these dual situated learning events indeed helped students change their preconception and successfully apply four mental sets to the situation. In particular, the explanations offered by the students provide further evidence of how students are able to apply the concepts that they have constructed from one situation to the next.

Results of this study demonstrate that this DSLM instructional model can foster conceptual change, even for concepts with invisible and process attributes, which were classified as difficult concepts by many previous studies. This is because the unique characteristics of DSLM are: (1) Provide students with the essential mental sets and concrete understanding of the concepts, as well as creating dissonance with their ontological view concerning dissolution and diffusion; (2) The dual situated learning events help students visualise observable changes of the concepts; (3) The number of dual situated learning events required would depend on the number of mental sets that students lack for constructing a more scientific view of the concepts; (4) The previous dual situated learning events can serve as the scallfolding for the next events since they are all closely related to each other.

This study clarifies the process of conceptual change among students through the use of DSLM. Though this study employed DSLM in an interview-based instruction, the model also has successfully brought conceptual change through classroom-based instruction (She, 2003), so it would be worthwhile putting the model into actual classroom practice. The following are implications for teachers regarding how to apply this model to classroom teaching: (1) The teacher can provide students with specific questions or events and require students to write down or draw what they think of the concepts from their ontological view; (2) Teachers can use the analyses of specific attributes of chemistry concepts that students lack as the bases for designing appropriate dual situated learning events for conceptual change. Particularly, if the concepts possess invisible attributes, using analogy to help students visualise the actual structure is highly recommended. If the concepts involve process, then it would be wise to design a real event which would allow students to comprehend the process; (3) When presenting the dual situated learning events, teachers need to intervene continuously with students and ask them to write down as well as draw what they believe before and after each event; (4) The way of employing this model is quite flexible since the teacher can either perform it with the whole class or a group of the students, allowing them to discuss and argue with each other. When employing this model, teachers need to continuously monitor and interact with students to make sure that students finally acquire a more scientific view of the concepts; (5) More importantly, teachers need to prepare a challenging situated learning event to make sure that conceptual change in their students is feasible.

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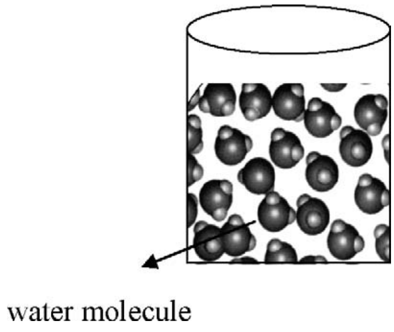
Appendix 1. Dual Situated Learning Events for Instruction on Dissolution and Diffusion

(1). Dual Situated Learning Event 1 (DSLE 1) for Dissolution

Step 1. Ask students to predict what would happen if we dissolve sugar into water? Explain why? And also ask students to draw their mental image/picture of sugar dissolving in water.

Step 2. Present the water molecule analogy to help them construct the molecular structure of water (Mental set 1).

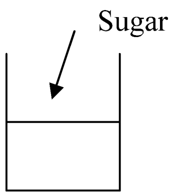


Step 3. After presenting the water molecule analogy, ask the students to provide explanation what would happen if we dissolve sugar into water? And also ask students to draw their mental image/picture of sugar dissolving in water.

(2). Dual Situated Learning Event 2 (DSLE 2) for Dissolution

Step 1. Ask students to predict what would happen if we dissolve sugar into water? Explain why? And also ask students to draw their mental image/picture of sugar dissolving in water.

Step 2. Actually demonstrate the real event of putting sugar into water (Mental set 2).

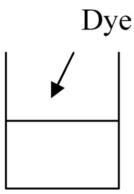


Step 3. After presenting the real event of putting sugar into water, then ask students to explain what would happen if we dissolve sugar into water? And also ask students to draw their mental image/picture of sugar dissolving in water.

(3). Dual Situated Learning Event 3 (DSLE 3) for Diffusion

Step 1. Ask students to predict what would happen if we add a drop of dye into water? Explain why? And also ask students to draw their mental image/picture of the diffusion of dye in water.

Step 2. Actually demonstrate the real event of adding a drop of dye into water (Mental set 3).

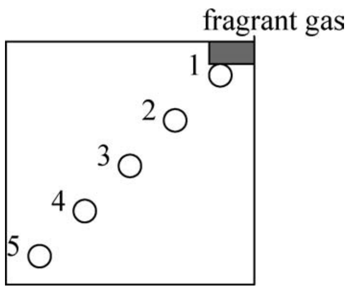


Step 3. After presenting the real event of adding a drop of dye into water, then ask students to explain what would happen if we add a drop of dye into water? And also ask students to draw their mental image/picture of the diffusion of dye in water.

(4). Dual Situated Learning Event 4 (DSLE 4) for Diffusion

Step 1. Ask students to predict what would happen if we spread fragrant gas from the right corner of the classroom, then who would smell it first, and how it spreads out in the classroom? Explain why? And also ask students to draw their mental image/picture of the diffusion of fragrant gas in the classroom.

Step 2. Present the fragrant air diffusion analogy to help students construct the dynamic process of diffusion and the final even distribution of fragrant air (Mental set 4).



Step 3. After presenting the fragrant air diffusion analogy and then ask students to explain what would happen if we add a drop of dye into water? And also ask students to draw their mental image/picture of the diffusion of dye in water.

Appendix 2. Challenging Situated Learning Event

Step 1. Ask students to predict what would happen if we add a drop of dye into three different solutions: water, 10% sugar water, and 20% sugar water, respectively? Explain why? Ask students to draw their mental image/picture of the diffusion of dye in water, 10% sugar water, and 20% sugar water.