

Bridging Scientific Reasoning and Conceptual Change Through Adaptive Web-Based Learning

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Abstract: This study reports an adaptive digital learning project, Scientific Concept Construction and Reconstruction (SCCR), and examines its effects on 108 8th grade students' scientific reasoning and conceptual change through mixed methods. A one-group pre-, post-, and retention quasi-experimental design was used in the study. All students received tests for Atomic Achievement, Scientific Reasoning, and Atomic Dependent Reasoning before, 1 week after, and 8 weeks after learning. A total of 18 students, six from each class, were each interviewed for 1 hour before, immediately after, and 2 months after learning. A flow map was used to provide a sequential representation of the flow of students' scientific narrative elicited from the interviews, and to further analyze the level of scientific reasoning and conceptual change. Results show students' concepts of atoms, scientific reasoning, and conceptual change made progress, which is consistent with the interviewing results regarding the level of scientific reasoning and quantity of conceptual change. This study demonstrated that students' conceptual change and scientific reasoning could be improved through the SCCR learning project. Moreover, regression results indicated students' scientific reasoning contributed more to their conceptual change than to the concepts students held immediately after learning. It implies that scientific reasoning was pivotal for conceptual change and prompted students to make associations among new mental sets and existing hierarchical structure-based memory. © 2009 Wiley Periodicals, Inc. *J Res Sci Teach* 47: 91–119, 2010

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Many studies have suggested that a relationship exists between students' alternative conceptions and reasoning ability (Lawson & Thompson, 1988; Lawson & Worsnop, 1992; Oliva, 2003). These studies found that students with better scientific reasoning skills had fewer alternative conceptions and could more easily change their alternative conceptions. Some other studies have proposed that students' understanding of scientific conceptions either hindered or mediated their ability to reason (Duncan & Reiser, 2007; Keselman, Kaufman, Kramer, & Patel, 2007). Oliva (2003) further reported that students with higher levels of formal reasoning tend to change their alternative conceptions more easily. These studies highlight an apparent relationship between conceptual change and scientific reasoning, but the type of relationship between conceptual change and scientific reasoning still remains uncertain. Thus, an empirical study to explore the relationship between conceptual change and scientific reasoning is needed.

The author has developed a conceptual change model, the Dual Situated Learning Model, and has evidenced effective conceptual change in middle school students for the topics of air pressure and buoyancy, thermal expansion, heat transfer, dissolution and diffusion, as well as meiosis and mitosis (She, 2002, 2003, 2004a,b; Tang, She, & Lee, 2005). We believe that there is a great potential to enhance students' conceptual change as well as scientific reasoning ability by uniting scientific reasoning with the Dual Situated Learning Model. Park and Han (2002) suggested that deductive reasoning is a potential factor in helping students to recognize cognitive conflict and to resolve it. Their ideas support our idea that enabling students to recognize

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their own changed ideas and why they would change is very critical for enabling conceptual change. Scientific reasoning certainly plays an important role in doing this. Park and Han (2002) further suggested that students' deductive reasoning is not always activated and used by students in the process of conceptual change. The conceptual change model of the DSLM includes some ideas related to reasoning, and the design of each dual situated learning event leads students to provide explanations before and after events. But it seems that more emphasis on scientific reasoning, particularly in requiring students to recognize their own changed ideas and justify why would they change or retain their original ideas, may both increase the effectiveness of the conceptual change and foster students' scientific reasoning ability.

Thus, this study uses the DSLM (She, 2002, 2003, 2004a,b; Tang et al., 2005) as the basis for developing a Scientific Concept Construction and Reconstruction (SCCR) Project together with a stronger scientific reasoning emphasis. We believe that if students can be involved within an individualized digital learning environment, they will be better able to increase their ability for conceptual change and their scientific reasoning ability. Therefore, this study reports a 3-year digital learning project—SCCR—that was developed based on the Dual Situated Learning Model (DSLM) and scientific reasoning. It is hoped that SCCR can facilitate students' conceptual change as well as scientific reasoning ability. Moreover, this study hopes to uncover the relationship between conceptual change and scientific reasoning.

Literature Review

Reasoning

Reasoning is one of the oldest research areas in psychology. It pertains to the process of drawing conclusions from principles and from evidence (Wason & Johnson-Laird, 1972), moving on from what is already known to infer new conclusions or to evaluate a proposed conclusion. Anderson (1990) refers to reasoning as the mental processes involved in generating and evaluating logical arguments. Reasoning skills include clarification, basis, inference, and evaluation (Ennis, 1987). Clarification skills require identifying and formulating questions, analyzing elements, and defining terms (Schunk, 1999, p. 289). Basis skills address the fact that conclusions about a problem are supported by the information from personal observations, statements by others and previous inferences. It is important to judge the credibility of a source, distinguishing between fact, opinion, and reasoned judgment (Schunk, 1999, p. 290).

Inference skills differ, depending on whether the scientific reasoning involved proceeds inductively or deductively. Induction is the process whereby general rules, principles, and concepts are developed from observation and knowledge of specific examples (Pellegrino, 1985). Inductive reasoning proceeds from specific facts to general conclusions, and it is the main reasoning process used by scientists to arrive at generalizations or scientific laws (Wadsworth, 1996, p. 113). Individuals reason inductively when they extract similarities and differences among specific objects and events, and then arrive at generalizations or conclusions, which are tested by applying them to new experiences or used to predict future specific instances. Individuals retain their generalizations as long as they are effective, and they may modify them when they experience conflicting evidence.

Deductive reasoning is the process of reasoning from one or more general statements on what is known in order to reach a logically certain conclusion (Johnson-Laird, 2000; Rips, 1999). It often involves reasoning from one or more general statements regarding what is known to a specific application of the general statement. Wadsworth (1996, p. 113) noted that deductive reasoning is reasoning from premises to conclusions or from the general to the specific. Inferences or conclusions based on deductive reasoning are necessarily true only if the premises they are derived from are true. When individuals reason deductively, they proceed from general concepts (premises) to specific instances (conclusions) to determine whether the latter follow from the former. A deduction is valid if the premises are true and if the conclusion follows logically from the premises (Johnson-Laird, 1985). Johnson-Laird and Byrne (1991, p. 3) point out that deductive reasoning is a central intellectual ability, which is necessary in order to: formulate plans; evaluate alternative actions; determine the consequences of assumptions and hypotheses; interpret and formulate instructions; develop rules and general principles; pursue arguments and negotiations; weigh evidence and assess data; to decide between competing theories; and as a result to solve problems.

Evaluation skill involves using criteria to judge the adequacy of a problem solution. Evaluation also involves deciding what ought to happen next, which is formulating hypotheses about future events, assuming that one's problem-solving is correct so far. It is very important to ensure that questions are properly posed, that data from adequate sources are available and used to draw inferences, and that relevant criteria are employed for evaluation.

Individuals can use reasoning to analyze complex information efficiently and make associations with existing cognitive structures. This occurs because long-term memory (LTM) networks become more complex and better linked as individuals grow, which in turn reduces the cognitive loading of working memory (WM) (Schunk, 2000, p. 224). Sweller (1988) states that optimum learning occurs in humans when the load on working memory is kept to a minimum, thereby facilitating changes in the long-term memory.

Scientific Reasoning and Conceptual Change

Many researchers have suggested that conceptual change involves deep restructuring, not only in the concepts, but also in the ways of reasoning (Furio, Calatayud, Barcenas, & Padilla, 2000; Gil & Carrascosa, 1994). In general, conceptual changes are associated with other changes, such as viewing phenomena in new ways; and changes in interests, attitudes, or assumed values by the community (Andre & Windschitl, 2003; Chambers & Andre, 1997; Pintrich & Schunk, 1996). These changes also correspond with new ways of reasoning and new approaches for solving scientific problems (Duschl & Gitomer, 1991; Hashweh, 1986). Conceptual change must not be considered merely as a change in content (Hewson & Thorley, 1989). Thus, it is necessary to associate conceptual change with scientific reasoning, because science teaching is usually centered on declarative knowledge (knowing "what") and neglects the procedural and explicative type (knowing "how" and "why") (Kuhn, 1993). Moreover, Park and Han (2002) suggested deductive reasoning as a potential factor in helping students to recognize and resolve cognitive conflict. In short, recognizing their changed ideas, and the reasons for the changes, is critical for conceptual change to occur.

Lawson (2003) has discussed the relationship existing between students' alternative conceptions and their reasoning ability. In order to modify alternative conceptions, students need to be aware of their own alternative conceptions and scientific conceptions, together with the evidence and reasoning that questions the validity of the alternative conceptions. In other words, they must be able to see logically how the evidence supports the scientific conceptions and contradicts the prior alternative conceptions. Lawson and Weser (1990) did a further study to measure pre- to post-instruction change among college students and found that less skilled reasoners were initially more likely to hold a variety of nonscientific beliefs about life and were less likely to change some, though not all, of those beliefs. Lawson and Worsnop (1992) again found that the more skilled reasoners in a sample of high school students were less likely to hold pre-instructional alternative conceptions regarding evolution and special creation.

On the other hand, Oliva (2003) examined the relationship that exists between the degree of structural coherence in students' conceptions (structuralization) and the probability of conceptual change. The results show that students with higher levels of formal reasoning change their alternative conceptions more easily when they display a higher level of initial structuralization. It is possible that students with the highest level of formal reasoning thought may have the necessary cognitive and metacognitive abilities to effect a sudden and global change, in which case structuralization may facilitate this process. In addition, many studies have also noted that those students with higher levels of formal reasoning present with preconceptions that are more structured, though they also tend to change their alternative conceptions with greater ease (Oliva, 2003; Trumper & Gorsky, 1993).

From the other point of view, one of the studies indicated that a group of students that were given critical reasoning and writing activities made progress on both of HIV knowledge and critical reasoning of HIV; however, the group of students that were given critical reasoning about realistic scenarios in the context of HIV activities only made progress on HIV knowledge (Keselman et al., 2007). The authors explain that critical reasoning activities alone did not sufficiently promote students' understanding of scientific conceptions; therefore, they are not able to use their scientific knowledge to reach an accurate conclusion when reasoning about the HIV scenario. This implies that scientific knowledge is crucial for supporting students' ability to reason in the HIV context. The other study also reports a similar idea regarding students' lack of understanding of gene and proteins hindering their ability to reason (Duncan & Reiser, 2007).

Though these studies have either suggested that students with a higher level of scientific reasoning would be able to change their alternative conceptions more easily or students with better understanding of scientific conceptions would mediate their ability of reasoning; there is still a lack of empirical study to confirm the relationship between scientific reasoning and conceptual change. Moreover, none of the previous studies has directly examined whether students' conceptual change and scientific reasoning ability can be promoted through a well-designed conceptual change model with an emphasis on scientific reasoning. Therefore, there are still many unsolved questions: (1) Can students' conceptual change and their scientific reasoning ability be promoted using DSLM with an emphasis on scientific reasoning? (2) What are the relationships among students' conceptual change, scientific reasoning ability, and their knowledge of atoms? (3) Can students' scientific reasoning ability be developed over time?

Perspectives of Conceptual Change and Dual Situated Learning Model (DSLML)

Conceptual change has been a major research area of science education over the past three decades (Duit & Treagust, 2003). As a foundation for this, Posner and Strike's work describing the conditions necessary for conceptual change is the most influential theory in science education (Posner, Strike, Henson, & Herzog, 1982; Strike & Posner, 1985). The focus of Posner et al.'s theory is from an epistemological perspective that explicitly includes student's judgments and opinions about their own conceptions, a perspective that concerns the nature of knowledge and the nature of knowledge acquisition and justification. However, it is possible to facilitate conceptual change from other perspectives, and the ontological perspective is also widely used for studying students' understanding of scientific concepts. Chinn and Brewer (1993) define ontological beliefs as "beliefs about the fundamental categories and properties of the world" (p.17). Similarly, Bliss (1995) describes students' ontological understanding about the world in terms of how they perceive the basic nature of objects and events. Many researchers in cognitive psychology have proposed theories for the ways students develop a conceptual understanding of science concepts from ontological viewpoints (Carey, 1985; Chi, Slotted, & Lieu, 1994; Haggard, 1992; Vosniadou & Brewer, 1987). Though these models differ in many respects, their theories share a similar view of conceptual understanding from ontological perspectives.

Lately, motivational perspectives have become very popular in the field of conceptual change. Vosniadou and Brewer (1994) suggest that various motivational beliefs about the learner and about learning could also act as presuppositions that either facilitate or constrain conceptual change. In contrast, Pintrich (1999) suggested that motivational beliefs might not have a direct influence on conceptual change, although as presuppositions or theories about the learner and the learning, these beliefs may support or constrain conceptual change.

Most studies consider only one perspective of conceptual changes in their model or theory: epistemological, ontological, or social/effective. However, more recently several researchers have studied conceptual change from multidimensional perspectives (Mbajjorgu, Ezechi, & Idoko, 2007; Savinainen, Scott, & Viiri, 2005; She, 2004b; Venville & Treagust, 1998). The Dual Situated Learning Model (DSLML) clearly shares the idea of multidimensional perspectives in terms of epistemology, ontology, and motivation.

Alternative conceptions describe the situation where students hold incomplete or inaccurate understandings of scientific phenomena (Driver & Easley, 1978; Osborne & Cosgrove, 1983). It has been shown to be pervasive, stable and often resistant to change through classroom instruction (Osborne & Cosgrove, 1983; Osborne & Gilbert, 1980). The alternative conceptions indicated the positive respect to the student's self-constructed conceptions and the thought construction process comparing to the term of misconceptions (Clement, 1993). The DSLML considers students' alternative conceptions to be a very important consideration in providing students the opportunity to be actively involved in the process of reconstructing their alternative conceptions and of moving toward a more complete and accurate scientific conception.

The DSLML (She, 2002, 2003, 2004a,b) emphasizes the nature of science concepts and students' ontological together with epistemological beliefs of science concepts, as its major theoretical constructs for conceptual change. In this context (She, 2004a,b), situated learning means that the learning process of conceptual change should be situated in the nature of science concepts and students' beliefs of these science concepts in order to determine what essential mental sets (a mental set is a frame of mind involving an existing model for representing a particular phenomena or information) are needed for constructing a more scientific

view of the concepts. Many scientific concepts are hard to understand (e.g., buoyancy) and tend to need more than one particular mental set for constructing the concept. The term “dual” indicates that two essential components are important for conceptual change to occur and these components are interacting with each other. There are three duals which are critical for constructing each dual situated learning event. The first dual is to consider both the nature of science concepts and students’ beliefs regarding these science concepts. The second dual is to create dissonance with students’ pre-existing knowledge and provide a new mental set for them to achieve a more scientific view of the concept. The third dual is to arouse students’ motivation and to challenge their ontological and epistemological beliefs regarding science concepts.

Though Posner et al.’s conceptual change model and the DSLM share the idea of creating cognitive conflict; however, there are many differences between these two models. The author has pointed out that conceptual change cannot occur simply by creating cognitive dissonance; instead, students must be provided with new mental sets in addition to creating dissonance (She, 2002, 2004a,b). Moreover, students often hold an alternative conception because the concept is at a relatively high hierarchical level that subsumes more essential underlying concepts, and so a series of events are necessary to help students’ conceptual change succeed (She, 2002). On the other hand, Pintrich, Marx, and Boyle (1993) pointed out that Posner et al.’s (1982) conceptual change model is overly rational and focuses only on students’ cognition, without considering the way in which students’ motivational beliefs and the roles of individuals in a classroom learning situation can influence conceptual change. Obviously, Posner et al. did not consider the perspectives of motivation and ontology in conceptual change; and did not consider students actively engaged in the process. In contrast, the DSLM considers the three aspects of epistemology, ontology, and motivation as its main theoretical constructs. The DSLM emphasizes that students should be actively engaged in the conceptual change learning process.

In order to implement this theory, the DSLM has been developed as a six stage learning/instructional model (Table 1). Stage 1: Examining attributes of the science concept, which provides information about the essential mental sets needed to construct a scientific view of the concept. Stage 2: Probing students’ alternative scientific conceptions which require probing the students’ beliefs concerning the science concept. Stage 3: Determining which mental sets students lack for the construction of a more scientific view of the concepts. Stage 4: Designing dual situated learning events, according to stage 3 results showing which mental sets student lack. Stage 5: Instructing with dual situated learning events, to give students the opportunity to make predictions, provide explanations, confront dissonance, and construct a more scientific view of the concepts. Stage 6: Instruction using a challenging dual situated learning event, so the students can apply the mental sets they have acquired to a new situation in order to ensure that successful conceptual change has occurred.

Features of the DSLM

As described previously, one of the major features of the DSLM is to create dissonance with students’ pre-existing knowledge in order to arouse students’ curiosity and interest and challenge their epistemological and ontological beliefs of the science concepts. Motivation is embodied in the design and the learning process of a dual situated learning event, which requires students to actively engage in the event prediction, visualize what actually happens and explain why it is different from their prediction, thereby stimulating their curiosity and interest.

Second, providing the new mental set should be the platform on which knowledge reconstruction can occur. Students must comprehend and believe the new mental set in order for conceptual change to happen. This can be fostered by any type of instructional activity, such as analogy, modeling, discrepant events, and inquiry activities, as long as they provide students with opportunities to visualize what actually happens in order to reconstruct new mental sets.

Third, all of the situated learning events should be designed according to the nature of the science concepts and students’ beliefs of scientific conceptions. In other words, the information on which and how many particular mental sets the students lack for restructuring the science concept would determine which and how many specific dual situated learning events need to be designed to supplement this deficiency and to foster conceptual change. My previous study (She, 2002) proposed that the concepts having a higher hierarchical level subsume underlying concepts, thus making it more difficult for higher-level conceptual

Table 1
Descriptions of dual situated learning model theory

Dual Situated Learning Model	Descriptions	Functional Dimensions of the DSLM Theory
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 concepts	The nature of scientific concepts is the crucial part of DSLM that determines whether conceptual change can be achieved. For instance, some concepts may be classified as process, or higher hierarchical level, or abstract, or invisible, etc. These attributes of science concepts should be analyzed before the planning of dual situated learning events
Stage 2: Probing students' alternative scientific conceptions	This involves probing the students' beliefs concerning the scientific concept	Students' beliefs of scientific concepts are another crucial part of DSLM, which determine whether conceptual change can be successful. These would pinpoint what alternative conceptions students have
Stage 3: Analyzing which mental sets that students lack	It would pinpoint which and how many particular mental sets students lack for restructuring the science concepts based upon the first pair of DSLM theory	The nature of science concepts and students' belief of science concepts provide the basis for determining particular mental sets students need for conceptual change
Stage 4: Designing dual situated learning events	The design of event is based particular mental sets students lack, so a further series of events can be designed. Each event would include the ideas of second and third dual of DSLM theory	The design of each event needs to emphasize creating dissonance with students' original beliefs of science concept, and providing new mental set. Moreover, the design also considers increasing students' motivation and challenging their beliefs of the concepts
Stage 5: Instructing with dual situated learning events	Each event provides students an opportunity to make predictions and provide explanations before and after the event, and to further explain why they changed their conceptions or retained their original conceptions	During the instruction, each event allows students to confront their beliefs of science concepts, and stimulates their curiosity and interest by challenging their epistemological and ontological beliefs of science concepts. Moreover, each event also provides students new mental sets where knowledge reconstruction can occur
Stage 6: Instructing with challenging situated learning event	It provides an opportunity for the students to apply the mental sets they have acquired to a new situation, ensuring that successful conceptual change to occur	The design of a challenging situated learning event needs to combine all of the particular mental sets that students previously lacked and that now have been reconstructed through a series of dual situated learning events

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. More importantly, each dual situated learning event should be connected with the others, and would need to build upon a prior dual situated learning event.

The last feature provides an opportunity for challenging students to see whether they can really apply to another situation the mental sets that they have revised or constructed, thus demonstrating a successful conceptual change. The design of a challenging dual situated learning event requires that, in order to succeed in the challenging event, students must acquire all of the particular mental sets that they previously lacked and that were reconstructed through a series of dual situated learning events.

The application of the DSLM instructional approach has evidenced effective conceptual change in middle school students for the topics of air pressure and buoyancy (She, 2002), thermal expansion (She, 2003), heat transfer (She, 2004b), dissolution and diffusion (She, 2004a), and meiosis and mitosis (Tang et al., 2005).

The design of each dual-situated learning event begins with a driving question targeted to the alternative scientific conceptions commonly found in students. The students are required to provide an answer and an explanation. Followed by the driving questions, various activities such as graphic and text illustrations,

simulated 2D animations, 3D animations, simulated experiments, analogies are provided. The design of these activities must create dissonance and provide students with new mental sets, challenge their ontological and epistemological beliefs, and motivate them to reconstruct the mental sets they lack. The same driving question is asked again, and also requires students to provide an answer and an explanation for the events.

Though the conceptual change model includes scientific reasoning, and the design of each dual situated learning event requests students to provide explanations, whether the DSLM has any impact on students' scientific reasoning ability has not been previously studied. Park and Han (2002) assumed that reasoning plays an important role in conceptual change. However, due to various unknown reasons, reasoning is not always activated and used spontaneously in students' minds in the process of conceptual change. Thus the DSLM may not be efficient for fostering the use of scientific reasoning skills by students. It is clear that the critical point is determining how to make the instructional design able to activate students' scientific reasoning.

Therefore, we have modified the dual-situated learning event to involve an increased amount of scientific reasoning. The students are required to provide an answer and their reasoning for the driving question before proceeding with various activities. The same driving question is asked again after the event to examine the students' conceptual change as well as their reasoning changes. In order to activate students' use of scientific reasoning, therefore, we specifically restructure the process to let students view their answers and the reasoning behind the answers both before and after events, as well as viewing the correct answers. We also further request students to provide a reason why they change or stay with their original concepts after learning the events. This is intended to force students' minds to be spontaneously involved in the process of scientific reasoning and conceptual change. It is predicted that enhancing scientific reasoning to maximize the DSLM more powerfully can facilitate both students' conceptual change and their scientific reasoning ability.

Previous Research on Students' Alternative Conceptions Involving Atoms

Garnett, Garnett, and Hachling (1995) reviewed previous studies on students' alternative conceptions regarding the particulate nature of matter, and specifically pointed out that some students consider atoms to be alive. Harrison and Treagust (1996) reported that high school students consider atoms to be either visible under a microscope or too small to see, are not sure whether all substances contain atoms, consider atoms to be alive like cells and able to grow and divide, consider atoms to be balls or spheres but are not sure about the components inside atoms, view the texture of atoms as being most like a hard polystyrene sphere, are not aware of electron shell or electron clouds, and have a consistent image of atoms as being protected by an outer shell. Lee, Eichinger, Anderson, Berkheimer, and Blakeslee (1993) found similar results about the size of molecules, so that even after instruction, students still believed they could see molecules with a microscope. Lee et al. (1993) showed that students believe atoms to be hard. Griffiths and Preston (1992) reported that students believe all atoms weigh the same, atoms are ball-shaped, there is nothing inside atoms, something exists between atoms, and electrons move within the shell. Overall, these studies have indicated similar alternative conceptions, such as atomic structure, components, shape, size, and properties; arrangement of electrons and its movement; whether all substances contain atoms; that all atoms weighed the same; and the size of molecules. The design of the atomic related Web-based program for atomic structure in this study uses these students' alternative conceptions, found in the previous studies noted above, as one of the major sources for the design of learning events to facilitate students' conceptual change.

Web-Based Learning and Adaptive Learning Technology

Web-based learning has certain unique properties, such as easily accessed and almost unlimited resources, various visual and audio forms of information presentation, and synchronous and asynchronous communication that can overcome temporal and distance constraints on learning. These qualities have led educational researchers and practitioners to consider it as a potential tool for improving teaching and learning, and developments of Web-based learning have also captured the attention of science educators. Except for providing an authentic Web-lab experience, all learning activities seem possible on the Web. Accessing the Web and incorporating Web-based learning into teaching activities are considered fundamental skills of science teachers in the 21st century (Didion, 1997).

In terms of the effectiveness of Web-based learning, some studies report that students gain more in confidence or achievement with computers in a Web-based course (Leasure, Davis, & Thievon, 2000; Marbach-Ad, Rotbai, & Stavay, 2008), while others find that students enrolled in a Web-based course perform worse than conventional students in the final exam (Wang & Newlin 2000). One of the studies using computer assisted instructional materials found that they are effective in reaching comprehension and application levels of cognitive domain, although they are not effective in changing students' alternative conceptions of photosynthesis for an experimental group of students compared to a conventional group (Cepni, Tas, & Kose, 2006). The consensus of the effectiveness for using computer/Web-based learning in education seems varied.

Tuvi and Nachmias (2001), using a taxonomy modified from that of Mioduser, Nachmias, Oren, and Lahav (2000), reviewed 93 Websites focusing on introducing atomic structures and found the following similarities: text was the primary means of presenting information; automatic/human and technical/content-based help were used in less than 18%; less than 6% had interactive images, animation and sound; none of those websites were inquiry-based; and memorizing was the main cognitive process. These studies point out the following critical problems found in most Web-based learning programs designed for science education. First, it is clear that science teaching and learning theories are absent in most of the science Web-learning programs. Second, pedagogical considerations are also not considered in the design of the Web-learning programs. Third, the multimedia capability is not fully used to enhance students' science learning. Therefore, this study attempts to employ the Dual Situated Learning Model (DSLML) and scientific reasoning for the development of a Web-based science learning program in order to facilitate students' conceptual change and scientific reasoning involving atoms.

To be effective, the Web-based learning must not only allow students to navigate between different pages but must help students to better achieve their learning goals. It is also necessary to provide more sophisticated mechanisms that modify the navigation alternatives by a procedure for individual student adaptation. Adaptive learning technology can be useful in any application area where the system is expected to provide people with different learning content or links based on different goals, prior knowledge, and personal features such as age, interests, and preferences (Brusilovsky, 1997). One approach is the adaptive technique of sensitive links which connect hyper-documents whose availability and contents depend on the state of teaching (Brusilovsky & Anderson, 1998). Thereby, the student's knowledge of each concept is used to guide him/her towards the appropriate documents (Carro, Moriyon, Pulido, & Rodriguez, 1999). Other approach is adaptive feedback which is designed on the basis of hypotheses and activities made during the learning process by each learner. This is different from pre-defined feedback which has the same answer for each student (Veerman, Andriessen, & Kanselaar, 2000). In short, the adaptive learning system takes features of the user as the sources of the adaptation, and further provides different feedback and/or learning modules based on the user model. Adaptive learning technology enables the system to offer flexible solutions that dynamically adapt content to fit individual real-time learning needs. The adaptive learning technologies have been implemented in the field of education, such as distance education (Brusilovsky, 1995; Saba, 2000), adaptive tutoring (Sessink, Beeftink, & Tramper, 2007), and online discussion (Du, Havard, & Li, 2005). Most of the studies focus on developing and using different types of adaptive techniques in the design of adaptive learning in education, and only a limited study reports the impact of adaptive learning in education. One of the studies reports that dynamic online discussion environments in which students learn beyond the course goal paves the way for surface to deep learning (Du et al., 2005). The other study reports that the experimental group students who received the adaptive feedback learning design improved significantly more in students' understanding of the processes and in applying the knowledge to new situations compared to the group who received pre-defined feedback (Veerman et al., 2000).

The DSLML has been implemented in the classroom for several topics and has evidenced success in fostering students' conceptual change within the classroom setting. But one previous limitation of implementing the DSLML in classroom teaching is that it cannot provide students with different learning feedback or contents on the basis of different alternative conceptions and reasoning patterns. In addition, many scientific concepts are invisible and abstract in nature, so that the use of models and analogies or simulation would make it more possible to foster students' constructions or reconstructions of more scientific view of the concepts. Therefore, this study moves one step beyond classroom instruction to an adaptive

multimedia web-learning approach. It seems to be a very promising direction, which may maximize the efficiency and effectiveness of conceptual change and scientific reasoning.

Purpose

This study explores the potential of maximizing students' success with both conceptual change and scientific reasoning ability by incorporating both scientific reasoning and the DSLM into the design of an adaptive digital learning program. A one-group pre-, post-, and retention quasi-experimental design was used in the study. It examines the effects on students' performance on the Atomic Achievement Test (AAT), Scientific Reasoning Test (SRT), and Atomic Dependent Reasoning Test (ADRT). In addition to quantitative data, a flow map is used to provide a sequential representation of the flow of students' conceptual frameworks as elicited in interviews. This framework is further analyzed from two major parts: complexity of scientific reasoning and quantity of conceptual change. Moreover, the relationships among students' scientific reasoning, atomic concepts, and atomic dependent reasoning are also examined.

Methods

Participants

A total of 108 eighth graders recruited from three classes of a middle school participated in this study. There were 60 boys and 48 girls. These three classes' students were taught by the same physical science teacher. The physical science teacher is willing to try new way of instruction and involved in the study. There were 25 classes of students for each grade level (7th, 8th, and 9th grade levels), and total of about 75 classes overall in the school. All of the classes are heterogeneous. Students were mixed with different achievement levels when they first entered school at the 7th grade level. The physical science achievement of these three classes of students was about average for the 8th grade level of their school.

Learning Materials

Design of SCCR Content: Unit on Atoms. An eight-person panel was involved in the development of the atom unit: two science educators, four middle school physical science teachers, and two science education graduates.

The design of the unit on atomic structure was based upon the six stages of the DSLM described earlier. Four topics were covered in developing a series of dual situated learning events: (1) Elements and compounds: identify compounds and elements, where compounds can be separated into elements through chemical means. (2) Atomic structure: the components of atoms and their properties as well as the motion of electrons. (3) Arrangement of electrons and chemical reactivity of elements: the arrangement of electrons in a noble gas is stable because there are eight electrons in the outer shell; alkali metals (e.g., Sodium and Potassium) have greater chemical reactivity because there is only one electron in the outer shell of the atom. (4) Atomic and chemical reactions: the nature and number of electron transfers occurring while two different atoms react with each other to form a compound; the relationship between the electrons donor/receipt and the electron arrangement of atoms during a chemical reaction.

It is clear that students' alternative conceptions of atoms are due to the invisibility of molecules and their dynamic nature, making it more difficult to construct concepts related to atoms. Therefore, the design of each web-based dual situated learning event in this unit emphasizes providing students with visualizations for the 2D- and 3D-models to help them build more scientific views of atomic structure. For example, one of the 2D atomic models lets students interacting with it to understand the number of electrons distributed at each shell, and the number of protons and neutrons in the atomic nucleus (Figure 1). The other 3D atomic model provides students with more clear ideas about the dynamic movement of electrons around the nucleus.

Each dual situated learning event requires students to provide an answer and their reasons to the driving question before proceeding with various activities. The same driving question is asked again after the event to examine the students' conceptual change as well as their reasoning changes. In addition to writing down their reasons, students also are required to choose the best reasons for what they had written down. This is because the system needs to have each individual student's choices of answers and reasons made before and after events in order to quickly generate an appropriate HTML page for each individual student. In order to activate

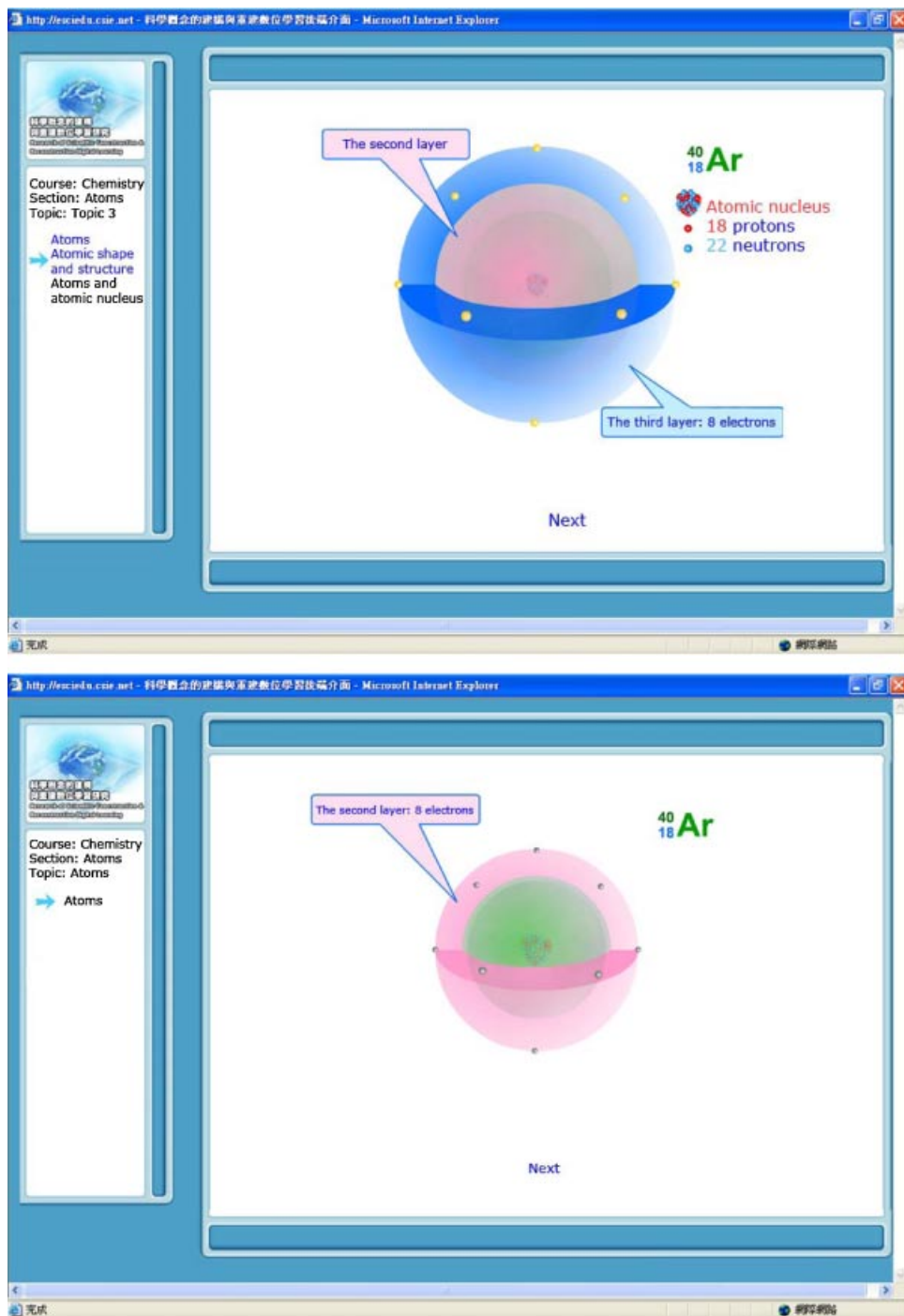


Figure 1. The 2D-atomic structure model.

Course: Chemistry
Section: Atoms
Topic: Topic 2

Elements and atoms
Elements and compounds
Living examples
Atoms

Question

Where do the atoms exist?

1. Living beings
2. Nonliving beings
3. All materials
4. Cells

Reason

Which one of the following is most close to your reason?

1. The atoms must exist in the living objects.
2. Atoms themselves have no life, so they exist on nonliving objects (the object without life).
3. Everything consists of atoms, so every object contains atoms.
4. The cells are all made up of atoms, and the cells only exist on living beings, so the atoms only exist in the cells.

	Before	After	Correct answer
[Answer]	2	3	3
[Reason]	Atoms themselves have no life.	According to Dalton's atomic hypothesis, everything consists of atoms.	-
[Answer]	2	3	3

Your later answer is **not the same** as the original.
Your explanation is: It was mentioned in the multimedia, according to Dalton's atomic hypothesis, everything consists of atoms. Therefore, every object contains atoms.

Send

Figure 2. Students answers and reasoning before and after the web-based dual situated learning events.

students' use of scientific reasoning, therefore, we specifically restructure the process to let students view both of their answers and written reasons before and after events, as well as the correct answers; and then to request that students justify why they changed or stayed with their original thoughts after the learning events. This draws students into the process of scientific reasoning as well as conceptual change (Figure 2).

Throughout the unit on atoms, students need to use both deductive and inductive scientific reasoning for tasks such as: formulating plans, analyzing elements, evaluating alternative ideas, determining the consequence and hypothesis, identifying variables, making inferences, making clarifications, making justifications, making conclusions based upon observations, experimenting, processing rules and general principles, judging the credibility of a source; distinguishing between fact, opinion and reasoned judgment, weighing evidence and assessing data, deciding between competing theories, developing concepts/rules/principles from observation and knowledge of specific examples, extracting similarities and differences among specific objects and events, arriving at generations and conclusions, testing generations by applying them to new experiences or using them to predict future specific instances.

Learning of Atomic Activities. Two examples of atomic activities are provided to show how dual situated learning events can help students to construct and reconstruct their understanding of atomic concepts.

The first example was purposely designed to help students construct how different compounds are composed of different atoms and how different atoms have different properties. Several driving questions were initiated: Are different compounds composed of the same kind of atom? Do all atoms have the same mass, size, and properties? Students need to provide their answers and their reasons before the events. Following the driving questions, a series of dual situated learning events were provided: (1) Different compounds are composed of different atoms: demonstrations of how the electroanalysis of water produces oxygen and hydrogen, the reaction of magnesium and hydrochloride, etc. (2) Different atoms have different properties: demonstrations of how hydrogen can create explosions, how oxygen can light a stick of incense, gold and silver, etc. (3). Historical views about atoms and their properties: videos of theories and experiments proposed by Pythagoras, Democritus, Dalton, etc. Then similar major driving questions were asked again

right after the events and students provided their answers and reasons again. Students would view their answers and reasons from before and after the events, as well as the correct answers, and they were further requested to justify why they had changed or retained their original thoughts after learning the events.

The second examples were designed to help students construct why some element are more stable than others. Several driving questions were initiated: Why are sodium and potassium unstable in air and why do they react more easily with other substances? Why are helium, argon, and neon stable? Why is chloride unstable in comparison with a noble gas? Following driving questions, a series of dual situated learning events were provided. (1). Macroscopic representations: demonstrations of how sodium burns easily with a yellow flame, potassium reacts easily with air and loses its shine, etc. (2). Microscopic representations: a series of animation of 2D argon, neon, potassium, and sodium atomic structure were presented individually to show students the number, arrangement, and movement of electrons at each shell, and the number of protons and neutrons in the nucleus of each atom. (3) Microscopic representations: a series of animations of 2D argon, neon, and sodium (or chloride or potassium) atomic structures were presented simultaneously. Students can understand the similarities and differences among those different atoms, specifically the number and arrangement of electrons in each shell, and the number of protons and neutrons in the nucleus of each atom. (4). The periodic table was presented for making comparison among different atoms. Then similar major driving questions were asked again right after and students provided their answers and reasons again. Students again viewed their answers and reasoning from before and after the events, as well as the correct answers, and they further provided the reasons why they changed or retained their original thoughts after learning the events.

Dynamic Generation of HTML Pages. Our study describes a dynamic generation of web-based learning content based on the DSLM and reasoning. These contents are defined by means of learning tasks that correspond to basic conceptual units, and rules which described how learning tasks are divided into subtasks. Adaptation is implemented by presenting students with different HTML pages depending on their prior alternative conceptions and their previous reasoning results. In addition, the adaptive feedback of comparison HTML page of student's previous concept and scientific reasoning, changed concept and scientific reasoning, and correct concepts also are dynamically generated for each individual student. The SCCR platform was the FreeBSD running on an Apache WWW server. The core of the SCCR system was programmed in PHP, Perl, Java Applet, Java script, and works with MySQL to efficiently handle extremely large data sets and analytical programs.

Instruments

Atomic Achievement Test (AAT). The AAT is a multiple choice diagnostic instrument that was developed to measure students' atom-related conceptions before, directly after, and 3-month after receiving the atom unit of the SCCR digital learning program (Appendix 2). The content validity was established by the same panel of eight evaluators, ensuring that the items were properly constructed and relevant to the atom unit web-learning materials we developed. The questions requiring students to use deeper information processing ability are mainly concerned with analysis and synthesis. There are nine items for topic 1, and the other three topics all have eight items, for a total of 33 items. Students receive one point for each question they answer correctly, so the possible score is 33. The Cronbach's α of the AAT was 0.74 for the pretest, 0.90 for the posttest, and 0.93 for the retention-test.

Scientific Reasoning Test (SRT). The SRT is a two-tier multiple-choice diagnostic instrument developed to measure students' scientific reasoning before, directly after, and 2 months after receiving the atom unit of the SCCR digital learning program (Appendix 3). The SRT was originally developed by Lawson (1978) and modified in 2000. It measures students' deductive reasoning for aspects of conservation, proportional thinking, identification and control of variables, probabilistic thinking, correlative thinking and hypothetic-deductive ability. There are 12 items, and each item contains two tiers. In the first tier students choose the answer, and in the second tier they use the scientific reasoning abilities mentioned above. Students need to answer both tiers correctly in order to receive one point, so the highest possible score is 12. Cronbach α of the SRT was 0.78 for the pretest, 0.76 for the posttest, and 0.78 for the retention-test which is close to the Lawson's result of Cronbach α .

Atomic Dependent Reasoning Test (ADRT). The ADRT is a two-tier multiple choice diagnostic instrument that was developed to measure the degree of students’ conceptual change involving atom-related concepts before, directly after, and 2 months after receiving the atom unit of the SCCR digital learning program (Appendix 4). The content validity was established by the same panel of eight evaluators, ensuring that the items were properly constructed and relevant to the atom unit Web-learning materials we developed. There are eight items for each topic, and each item contains two-tiers, with the first tier to check students’ scientific conceptions/alternative conceptions, and the second tier to justify their response by telling why they selected that response. Students use scientific reasoning while answering the second-tier of the ADRT. There are 32 items and each item has two tiers. Students need to answer both tiers correctly in order to receive one point, so the highest possible score is 32. The Cronbach α of ADRT was 0.88 for the pretest, 0.95 for the posttest, and 0.95 for the retention-test.

Interview Analysis. Students’ interview results were transcribed and then analyzed by a flow map method (Anderson & Demetrius, 1993). A flow map is constructed by diagramming the interviewee’s verbalization of thought as it unfolds. The map also displays the sequence of complex thought patterns expressed by the interviewee. This method of analyzing cognitive structure based on respondents’ narrative, has been employed in several studies and it has been suggested that flow map analyses are a useful and valid method of representing students’ conceptual frameworks in science (Anderson, Randle, & Covotos, 2001).

By using the flow map method, this study evaluated the complexity of students’ scientific reasoning and quantity of conceptual change in two major parts.

Concerning the complexity of scientific reasoning, four levels of scientific reasoning modified from Hogan, Nastasi, and Pressley’s study (2000) were used in this study: Generativity (G), Elaboration (EL), Justification (J), and Explanation (Ex) (see Figure 3 for an example). About one fifth of the interviewee’s

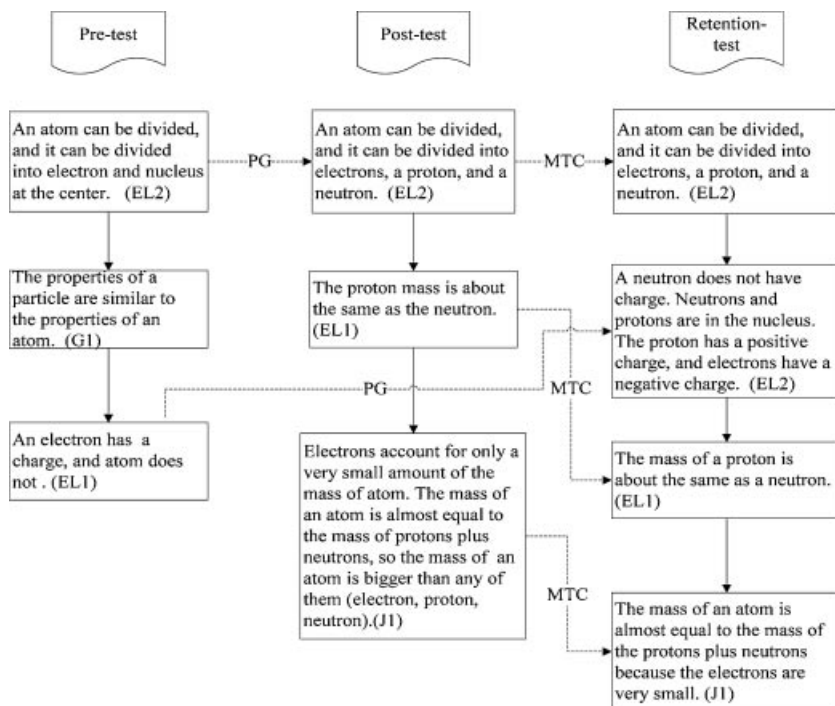


Figure 3. Flow Map of Atomic Composition. Note 1: Scientific reasoning: Generativity (G), Elaboration (EL), Justification (J), Explanation (EX). Note 2: Conceptual change: Progress (PG), Maintain-Correct (MTC), Maintain-Partial Correct (MTPC), Maintain-incorrect(MTIC), Retrogress (RTG).

results were checked by the second coder and the inter-rater reliability is 0.89. These levels can be described as follows.

- (1) Generativity (G): the number of students' own observation, ideas, or conjectures. For instance, "I do not know" was coded as G0 because students did not answer anything relevant; and "electrons move randomly" was coded as G1 since there was one idea presented by the student. G0 and G1 represent students receive 0 and 1 score for G level, respectively.
- (2) Elaboration (EL): the number of scientific concepts used to describe and explain the concepts. For instance, "electrons have a charge and atoms do not" was coded as EL1 since only one scientific conception was used to describe the idea of electrons with a charge; "An atom can be divided, and it can be divided into electrons with a nucleus at the center of the atom." was coded as EL2 since two scientific concepts were presented to describe two components of the atom.
- (3) Justification (J): the number of aspects based on evidence, inference or experiments used to support the ideas or assertions. For instance, "the mass of an atom is almost equal to the neutron plus proton because the mass of electrons is very small;" was coded as J1 since one inference was used to explain the mass of the atom. "The mass of an atom is almost equal to the neutron plus proton because the mass of electron is very small, and if an atom loses one electron that would not change the mass of the atom;" was coded as J2 since two different inferences were used to explain why the mass of an atom is equal to the neutron plus proton.
- (4) Explanation (Ex): the number of proposed rules or mechanisms used to explain the concepts or assertions. For instance, "chlorine and bromine can react easily with sodium, because the most stable arrangement of electrons is 8." was coded as Ex 1 since the proposed rule of "the most stable arrangement of electrons is 8" was used to explain why chlorine can react easily with sodium. "Chlorine and bromine can react easily with sodium because the most stable arrangement of electrons is 8. Both chlorine and bromine still need one electron, and both of them lack one electron on their outer shell, so their outer shell electron arrangement is either 7 or 17. Therefore, sodium would give chlorine or bromine 1 electron, and thus they easily react with sodium;" was coded as Ex2 since two proposed rules of "the most stable arrangement of electrons is 8" and "the outer shell lacks one electron" are used to explain why chlorine and bromine can react with sodium easily.

To quantify conceptual change, several categories were measured as follows:

- (1) Correct concept: whether students' alternative conceptions decrease or increase throughout the learning.
- (2) Nature and quantity of conceptual changes: the nature and quantity of conceptual change are shown by the number of linkages between pre- and post-flow map, or between post- and retention-flow map, or between pre- and retention-flow map (see Figure 3 for an example).
 - (2a) Progress (PG): the number of linkages shows to what extent the student's concepts improved (Figure 5).
 - (2b) Maintain-correct (MTC): the number of linkages shows to what extent the student's concepts were maintained correctly.
 - (2c) Maintain-partial correct (MTPC): the number of linkages shows to what extent the student's concepts were maintained as partially correct.
 - (2d) Maintain-incorrect (MTIC): the number of linkages shows to what extent the student's concepts were maintained as partially incorrect.
 - (2e) Retrogression (RTG): the number of linkage shows to what extent the student's concepts retrogressed.

Procedure. All of the students received the Web-based DSLM learning program for ten class periods. A pretest of ADRT, the SRT, and the AAT were administered to all students before the instruction in their regular classroom. These instruments were piloted by the other three classes of students. One and eight weeks respectively after the instruction, a posttest and a retention test of the ADRT, SRT, and AAT were administered in their regular classroom. In addition, 18 students from three classes (six students from each class) were interviewed and fully recorded by audio tape before, directly after, and 2 months after learning. Ten questions (Appendix 1) were used to interview students' understanding about atomic conceptions each time of an hour. Students were selected for interviews based on the following basis: two high achievers

(one male and one female), two middle achievers (one male and one female), and two low achievers (one male and one female).

Results

Atomic Achievement Test (AAT)

Table 2 presents the descriptive statistics of the pre-, post-, and retention test results for the AATs. It can be seen that students made great progress from pre-test to post-test (from 12.71 to 20.02). They also made slight gains from post- to retention test (from 20.02 to 21.04).

Repeated measures of ANOVA were used to examine any increases in mean scores for the pre-test, post-test and retention test. The table shows an increase in pre-, post-, and retention-test mean scores that also reached statistical significance ($F = 91.25, p = 0.000$). The Mauchly's test of sphericity was not significant, so the sphericity assumption of F was used. The Sidak test used to perform post-hoc analysis suggests that the post-test score is significantly higher than pre-test score ($p_{(\text{post} > \text{pre})} = 0.000$), and the retention-test score was significantly higher than pre-test ($p_{(\text{retention} > \text{pre})} = 0.000$).

Atomic Dependent Reasoning Test (ADRT)

Table 2 presents descriptive statistics for the pre-, post-, and retention test of the ADRT. It shows that students made great progress from pre- to post-test of the ADRT (from 9.39 to 18.61). However, students were not able to retain the same level of performance for the retention of the ADRT (from 18.61 to 16.89).

Repeated measures of ANOVA were used to examine any increase in pre-, post-, and retention test of ADRT mean scores. This indicates that the increases in pre-, post- and retention-test mean scores also reached statistical significance ($F = 119.24, p = 0.000$). The Mauchly's test of sphericity was not significant, so the sphericity assumption of F was used. The Sidak test suggests that the post test score is significantly higher than pre-test score ($p_{(\text{post} > \text{pre})} = 0.000$), post-test is significantly higher than retention-test score ($p_{(\text{post} > \text{retention})} = 0.009$), and the retention test score was significantly higher than pre-test ($p_{(\text{retention} > \text{pre})} = 0.000$).

Scientific Reasoning Test (SRT)

Table 2 presents the descriptive statistics of the pre-, post-, and retention of the SRT. This shows that students made great progress from pre- to post-test of the SRT (from 4.09 to 4.17). This shows that students made progress from pre- to post-test and from post- to retention test of the SRT (from 4.17 to 4.96).

Table 2

Repeated measures ANOVA of pre-, post-, and retention of Atomic Achievement Test (AAT), Atomic Dependent Reasoning Test (ADRT), and Scientific Reasoning Test (SRT)

	Mean	SD	F-Value of Repeated Measures ANOVA	Post-Hoc Comparisons
Atomic Achievement Test (AAT)			91.25***	
Pre-test	12.71	4.01		
Post-test	20.05	8.53		Post-test > Pre-test
Retention-test	21.04	7.54		Retention > Pre-test
Atomic Dependent Reasoning Test (ADRT)			119.24***	
Pretest	9.39	4.46		Post-test > Pre-test
Post-test	18.61	7.44		Post-test > Retention
Retention-test	16.89	8.65		Retention > Pretest
Scientific Reasoning Test (SRT)			9.70***	
Pre-test	4.09	1.98		
Post-test	4.17	2.35		Retention > Pretest
Retention-test	4.96	2.73		Retention > Posttest

*** $p \leq 0.000$.

Repeated measures of ANOVA were used to examine any increase in pre-, post-, and retention test of the SRT mean scores. This indicates that the increases in pre-, post-, and retention-test mean scores reached statistical significance ($F = 9.70, p = 0.000$). The Mauchly's test of sphericity was significant at 0.05, so the Huynh-Feldt of F was used. The Sidak test suggests that the retention-test score is significantly higher than pre-test ($p_{(\text{retention} > \text{pre})} = 0.000$), and retention-test score was significantly higher than post-test ($p_{(\text{retention} > \text{post})} = 0.009$).

Multiple Regression Analysis

This section examines whether students' degree of conceptual change would increase as their scientific reasoning ability increased. Therefore, the stepwise regression method was used to explore whether the post-SRT or post-AAT test would be most important for predicting the post-ADRT scores, and whether retention-SRT or retention-AAT would be the most important for predicting the retention-ADRT scores. Results indicated that the best single predictor for post-ADRT scores was the post-SRT followed by post-AAT scores. The standardized regression coefficient for post-SRT, and post-AAT were 0.36 and 0.33. Together post-SRT and post-AAT accounted for 33.7% of the variance in post-ADRT scores (Table 3).

Results indicated that the best single predictor for retention-ADRT scores was retention-AAT scores followed by retention-SRT. The standardized regression coefficient for retention-AAT and retention-SRT were 0.64 and 0.30. Together, retention-AAT and retention-SRT accounted for 67.1% of the variance in retention-ADRT scores.

Interview Results

Students were interviewed with 10 questions before, immediately after and 2 months after instruction, with the results transcribed and analyzed by a flow map method. Therefore, ten flow maps were generated after each interview for each individual and each flow map contains students' pre-, post-, and retention-interview together. Flow map data were analyzed in two parts: complexity of scientific reasoning and degree of conceptual change.

Complexity of Scientific Reasoning

For analyzing the complexity of scientific reasoning, four levels of scientific reasoning, Generativity (G), Elaboration (EL), Justification (J), and Explanation (Ex) were used in this study. Each flow map generated separate scores on G, EL, J, Ex for the pre-, post-, and retention-interview three parts.

Table 4 summarizes the means of students' complexity of scientific reasoning, and repeated measures of ANOVA of flow map from pre-interview, post-interview and retention-interview stages. The Mauchly's test of sphericity was not significant for most of the level of scientific reasoning across questions, thus the sphericity assumption of F was used. With exceptions, Mauchly's test of sphericity was significant for questions 4, 5, and 6 Generativity (G), questions 7 Justification (J), and questions 8–10 Explanation (Ex); thus the Huynh-Feldt of F was used. Moreover, the Sidak test was further performed for post-hoc analysis, when repeated measures F value is statistically significant, for comparing pre-, post-, and retention-interview

Table 3

Stepwise multiple regression summary for relationships among Atomic Dependent Reasoning Test (ADRT), Atomic Achievement Test (AAT), and Scientific Reasoning Test (SRT)

Significant Predictor Variable	Standardized Regression Coefficients	Multiple R	R^2	Cumulative % of Variance Explained
Post-test of Atomic Dependent Reasoning Test (ADRT)				
Post-test of Scientific Reasoning Test (SRT)	0.36			26.2%
Post-test of Atomic Achievement Test (AAT)	0.33	0.60	0.35	33.7%
Retention test of Atomic Dependent Reasoning Test (ADRT)				
Retention test of Atomic Achievement Test (AAT)	0.64			63.9%
Retention test of Scientific Reasoning Test (SRT)	0.30	0.82	0.68	67.1%

Table 4

Repeated measures ANOVA of students' use of scientific reasoning in the pre-, post-, and retention-flow map for 10 interview questions

Levels of Scientific Reasoning Involving Concept Understanding	Pre-Flow Map		Post-Flow Map		Retention Flow Map		F-Value of Repeated Measures ANOVA	Post-Hoc Comparisons
	Mean	SD	Mean	SD	Mean	SD		
(1) Chemical compound and elements								
Generativity (G)	9.67	3.90	3.61	2.66	1.61	2.75	62.37 ^{***}	Pre > post, pre > retention, post > retention
Elaboration (EL)	3.72	3.20	3.89	2.70	7.22	4.65	13.43 ^{***}	Retention > pre, retention > post
Justifications (J)	—	—	—	—	0.22	0.94	1.00	—
Explanations (EX)	—	—	—	—	—	—	—	—
(2) Shape and structure of atoms								
Generativity (G)	1.83	0.99	1.39	0.61	0.94	0.87	4.00 [*]	—
Elaboration (EL)	0.67	0.97	0.39	0.70	1.78	1.00	11.85 ^{***}	Retention > pre, retention > post
Justifications (J)	—	—	—	—	0.06	0.24	1.00	—
Explanations (EX)	—	—	—	—	—	—	—	—
(3) Movement of electrons								
Generativity (G)	0.72	0.58	0.22	0.55	0.00	0.00	11.84 ^{***}	Pre > post, pre > retention
Elaboration (EL)	0.39	0.61	0.94	0.54	1.28	0.46	14.12 ^{***}	Post > pre, retention > pre
Justifications (J)	—	—	—	—	—	—	—	—
Explanations (EX)	—	—	—	—	—	—	—	—
(4) Arrangement of electrons within atom								
Generativity (G)	1.33	0.49	0.89	0.32	1.39	0.98	3.29	Pre > post
Elaboration (EL)	0.78	0.73	2.22	0.88	2.33	1.28	17.58 ^{***}	Post > pre, retention > pre
Justifications (J)	0.00	0.00	0.11	0.32	0.06	0.24	1.55	—
Explanations (EX)	—	—	—	—	—	—	—	—
(5) Composition of gold atom and iron atom								
Generativity (G)	2.33	1.57	1.67	1.03	1.17	0.62	6.62 [*]	Pre > retention
Elaboration (EL)	1.22	1.73	2.22	1.44	1.33	1.19	3.18	—
Justifications (J)	0.00	0.00	0.28	0.58	0.17	0.51	2.26	—
Explanations (EX)	—	—	—	—	—	—	—	—
(6) Composition of atom								
Generativity (G)	1.28	0.96	0.17	0.38	0.22	0.43	15.10 ^{***}	Pre > post, pre > retention
Elaboration (EL)	1.50	1.82	4.50	1.20	5.39	2.33	32.36 ^{***}	Post > pre, retention > pre
Justifications (J)	0.17	0.51	0.22	0.43	0.17	0.38	0.14	—
Explanations (EX)	—	—	—	—	—	—	—	—
(7) Stability of noble gas								
Generativity (G)	0.94	0.54	0.33	0.49	0.39	0.50	13.38 ^{***}	Pre > post, pre > retention
Elaboration (EL)	0.17	0.38	0.33	0.69	0.28	0.58	00.38	—
Justifications (J)	0.00	0.00	0.78	0.55	0.83	0.99	10.34 ^{**}	Post > pre, retention > pre
Explanations (EX)	—	—	—	—	—	—	—	—
(8) Stability among sodium, potassium, and noble gas								
Generativity (G)	0.22	0.43	0.11	0.32	0.33	0.49	1.36	—
Elaboration (EL)	1.00	0.77	0.33	0.49	0.33	0.69	6.48 [*]	Pre > post, pre > retention
Justifications (J)	0.11	0.32	0.33	0.59	0.28	0.46	1.48	—
Explanations (EX)	0.00	0.00	0.33	0.59	0.11	0.32	4.86 [*]	—

(Continued)

Table 4
(Continued)

Levels of Scientific Reasoning Involving Concept Understanding	Pre-Flow Map		Post-Flow Map		Retention Flow Map		F-Value of Repeated Measures ANOVA	Post-Hoc Comparisons
	Mean	SD	Mean	SD	Mean	SD		
(9) Reactions of chlorine and bromine, with sodium								
Generativity (G)	0.33	0.60	0.06	0.24	0.28	0.46	2.53	
Elaboration (EL)	0.78	1.00	0.33	0.59	0.39	0.78	1.69	
Justifications (J)	0.39	0.78	0.61	0.92	0.44	0.78	0.36	—
Explanations (EX)	0.00	0.00	0.67	0.97	0.17	0.38	6.70*	Post > pre
(10) Stability between hydrogen atom and hydrogen molecule								
Generativity (G)	0.39	0.50	0.06	0.24	0.06	0.24	8.50*	Pre > post, pre > retention
Elaboration (EL)	0.56	0.51	0.50	0.62	0.44	0.62	0.24	—
Justifications (J)	0.00	0.00	0.50	0.51	0.50	0.62	7.29*	Post > pre, retention > pre
Explanations (EX)	0.11	0.47	0.00	0.00	0.06	0.24	0.59	—

$N = 18$.

* $p \leq 0.05$.

** $p \leq 0.01$.

*** $p \leq 0.000$.

results. It indicates that there was a decrease in pre-, post-, and retention- flow map of Generativity (G) mean scores that reached a statistically significant difference level for questions 1, 2, 3, 5, 6, 7, and 10. In addition, their post-hoc results suggest that either (1) pre- or post-Generativity (G) mean scores are significantly greater than the retention-of Generativity (G); or (2) the pre-Generativity (G) mean score is significantly greater than the post-Generativity (G) mean score. On the other hand, it indicates that there is an increase in pre-, post-, and retention-flow map of Elaboration (EL) mean scores that reached a statistically significant difference level for questions 1, 2, 3, 4, 6, and 8. In addition, their post-hoc results suggests that either: (1) most of their retention- or post-Elaboration (EL) mean scores are significantly greater than the pre- Elaboration (EL) mean score; or (2) that their post-Elaboration (EL) mean score is significantly greater than the pre-Elaboration (EL) mean score. It also shows that there is an increase in pre-, post-, and retention-flow map of Justification (J) mean scores that reached a statistically significant difference level for questions 7 and 10; and their post hoc results suggest that either their retention- or post-Justification (J) mean scores are significantly higher than the pre-Justification (J) mean scores; or that their post-Justification (J) mean score is significantly higher than the pre-Justification (J) mean score. Some of the mean scores of justification and explanation are very small which need to be noted. It also shows that there is an increase in their pre-, post-, and retention-test of Explanation (EX) mean scores that reached a statistically significant difference level for questions 8 and 9; and the Sidak test results indicate that their post-Explanation (EX) mean scores are significantly higher than the pre-Explanation (EX) mean score.

Figures 4 and 5 clarify the distribution of mean score of students' level of scientific reasoning at pre- and post-test. Before instruction, it shows students' levels of scientific reasoning primary are at Generativity (G) and Elaboration (EL), with almost no Explanation (EX) level appearing (Figure 5). After instruction, Elaboration (EL) becomes the major level of reasoning used by students; Justifications (J) and Explanations (EX) increase substantially, although Generativity (G) decreased substantially (Figure 6). Two months after learning, the level of Elaboration (EL) increased for several topics. In short, students' use of levels of scientific reasoning progressed from Generativity (G) to Elaboration (EL) and then Justification (J) and explanation (EX) after they received the learning program.

Quantity (Measure) of Conceptual Change

Quantity of Correct Concept. Table 5 presents the descriptive statistics for the mean scores of correct concept and repeated measures of ANOVA. The Mauchly's test of sphericity was not significant then the

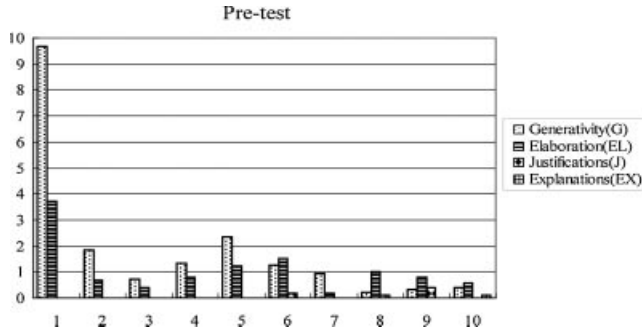


Figure 4. Distribution of means of students' level of scientific reasoning across 10 interview results before instruction.

sphericity assumption of F was used for most of the question. With only one exception in question 8, Mauchly's test of sphericity was significant thus the Huynh-Feldt of F was used. It indicates that there is an increase in the mean scores of correct concepts from pre-, post-, and retention-flow maps, and all reached statistically significant effect across different topics. It is because all of the repeated measures of ANOVA across 10 interview question all reached statistically significant difference levels; therefore, the Sidak tests were further performed. In general, the post-hoc analysis suggests that either post-test score is significantly higher than pre-test score or the retention-test score is significantly higher than pre- or post-test across different topics.

Quantity of Conceptual Change. For analyzing the quantity of conceptual change, five categories: PG, MTC, MTPC, MTIC, and RTG were used in this study. Each flow map would generate separate scores for PG, MTC, MTPC, MTIC, and RTG from pre- to post-interview, and then post- to retention-interview.

The mean scores of the quantity of conceptual change from pre- to post-, post- to retention, and pre- to retention are presented in the following. For pre- to post-interview, the mean scores of the progress (PG) category was higher than any other category across most of the ten topics, except for one topic, where maintain-partial correct (MTPC) was the highest. The mean scores for Progress (PG) ranged from 3.22 to 0.39, maintain-correct category (MC) ranged from 0.00 to 0.86, maintain-partial correct (MTPC) ranged from 0.00 to 1.06, maintain-incorrect (MTIC) ranged from 0.00 to 1.17, and Retrogress (RTG) ranged from 0.00 to 0.94 (Figure 6).

For post- to retention interview results, the mean scores of the progress (PG) category were higher than other categories for about five topics, the mean scores of the maintain-correct category (MTC) were higher than any other category for four topics, and maintain-partial correct (MTPC) was the highest for one topic. The mean scores for PG ranged from 2.28 to 0.11, MC ranged from 1.39 to 0.17, MTPC ranged from 0.06 to

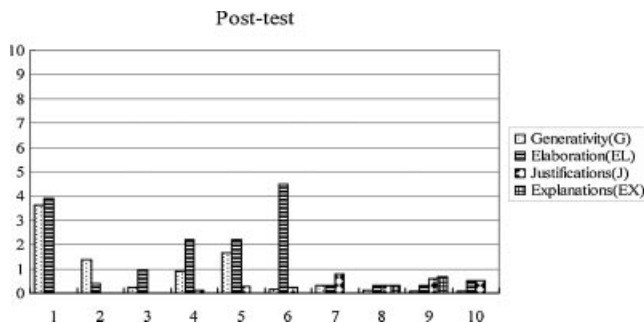


Figure 5. Distribution of means of students' level of scientific reasoning across 10 interview results after instruction.

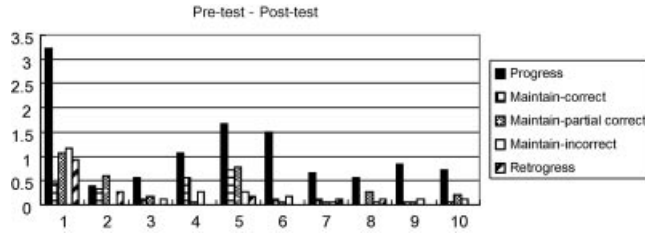


Figure 6. Distribution of conceptual change across 10 interview results from pre- to post-test.

0.56, MTIC ranged from 0.00 to 0.28, and RTG ranged from 0.06 to 0.78 for post- to retention-interview (Figure 7).

From the pre- to retention-interview, it was found that the means scores of progress (PG) category remained highest for about eight topics, and the mean scores of maintain-correct (MTC) category remained highest for about two topics. The mean scores for PG ranged from 2.50 to 0.44, MC ranged from 0.00 to 1.17, MTPC ranged from 0.00 to 0.50, MTIC ranged from 0.00 to 0.50, and retrogress ranged from 0.00 to 0.61 for pre- to post-interview.

Discussion and Conclusions

This study reports an adaptive web learning project that was developed based on the Dual Situated Learning Model (DSL) and scientific reasoning in order to promote middle students' conceptual change as

Table 5

Repeated measures ANOVA of students' correct concepts in the pre-, post-, and retention-flow map for 10 interview questions

Correct Concepts	Pre-Test		Post-Test		Retention-Test		F Value of Repeated Measures ANOVA	Post-Hoc Comparisons
	Mean	SD	Mean	SD	Mean	SD		
(1) Chemical compound and elements	6.11	2.27	8.11	2.30	7.22	2.88	6.55*	Post > pre
(2) Shape and structure of atoms	2.89	1.37	2.17	1.25	5.39	2.36	21.06***	Retention > pre, retention > post
(3) Movement of electrons	1.56	0.62	1.94	0.64	2.06	0.42	7.64*	Retention > pre
(4) Arrangement of electrons within atom	0.72	0.58	2.00	1.28	2.33	1.28	14.14***	Post > pre, retention > pre
(5) Composition of gold atom and iron atom	2.44	1.25	5.17	2.33	0.322	1.87	18.26***	Post > pre, post > retention
(6) Composition of atom	2.00	2.43	6.00	2.06	6.78	2.94	34.45***	Post > pre, retention > pre
(7) Stability of noble gas	0.72	0.58	3.11	2.37	2.94	2.04	13.28***	Post > pre, retention > pre
(8) Stability among sodium, potassium, and noble gas	2.11	1.37	3.39	2.17	2.28	1.71	3.77*	Post > retention
(9) Reactions chlorine and bromine, with sodium	1.33	1.28	3.89	2.65	3.06	2.71	9.38**	Post > pre, retention > pre
(10) Stability between hydrogen atom and hydrogen molecule	1.11	0.68	2.28	1.27	2.89	1.13	19.74***	Post > pre, retention > pre

* $p \leq 0.05$.

** $p \leq 0.01$.

*** $p \leq 0.000$.

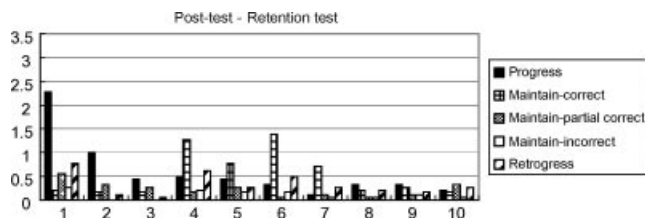


Figure 7. Distribution of conceptual change across 10 interview results from post- to retention-test.

well as scientific reasoning ability. The study examines the effectiveness of students' conceptual change involving atomic related concepts as well as their scientific reasoning through both qualitative and quantitative methods. For quantitative results, it shows an increase in pre-, post-, and retention-test mean scores that reached statistically significant effect for AAT, SRT, and ADRT. This demonstrates that students' concepts of atoms, scientific reasoning, and conceptual change all made progress throughout the learning of the SCCR atom unit.

One possible explanation for why students made progress from pre- to post-SRT and then to retention-SRT, but did not reach statistically significant levels from pre- to post-SRT is that SRT specifically focuses on measuring students' conservation, proportional thinking, identification and control of variables, probabilistic thinking, correlative thinking and hypothetic-deductive ability. Our design of the SCCR atom unit purposely focused on the broader ability of scientific reasoning, which includes the use of inductive and deductive reasoning abilities in the construction of atomic-related conceptions: analyzing elements; evaluating alternative ideas; determining consequences; making inferences, clarifications, and justifications; making conclusion based upon observation, experiment, and previous inference; processing rules and general principles; judging the credibility of a source; distinguishing between fact, opinion and reason judgment; weighing evidence; extracting similarities and differences among specific objects and events; and deciding between competing theories. Therefore, the effect on the immediate SRT may not be large enough to reach a statistically significant difference.

The students' use of scientific reasoning results moved from Generativity (G) to Elaboration (EL) after learning from the program, and the use of Justification (J) and Explanation (EX) also appeared more often after learning. This demonstrates the effectiveness of specifically designing each dual situated learning event with scientific reasoning. It also supports the idea that students' scientific reasoning ability can be developed within a short period if the design of learning events carefully addresses this ability. Our result is inconsistent with the Duncan and Reiser (2007) study, which found that there was no substantial improvement in students' reasoning after 5 weeks of instruction regarding molecular genetics. They attributed the absence of substantial improvement in students' reasoning to the lack of a cognitive model of reasoning in the design of learning content. This supports our study that scientific reasoning ability would be improved if with a well-designed model as the basis for the development of learning materials.

The quantity of correct concepts indicates that there is an increase in pre-, post-, and retention-mean scores of the correct concepts that reached statistically significantly effect across 10 topics. It supports the conclusion that the results of students' scores of AAT made statistically significant progress from pre-, post- to retention-test. Our finding supports two studies that the use of Web-based learning programs can improve students' scientific achievement (Cepni et al., 2006; Marbach-Ad et al., 2008).

The quantity of conceptual change shows that the mean scores of the progress (PG) category are higher than any other category across most of the topics from pre- to post-interview. This supports the conclusion that the results of students' scores of ADRT made significant progress from pre- and post-test. However, the mean scores of the progress (PG) category are higher than other categories for about half of the topics, and the mean scores of the maintain-correct category (MTC) were higher than other category for four topics, and the mean scores of the maintain-partial correct (MTPC) was the highest for only one topic from post- to retention-interview. This might explain why students' scores of the ADRT decreased

slightly from post-test to retention-test. Our result is inconsistent with Cepni et al. (2006) study, which found that their computer assisted materials did not change students' alternative conceptions related to photosynthesis. It is possible to ascribe this result to the fact that their instructional materials were not specifically developed based on an effective conceptual change model.

Our study adds empirical evidence that takes specific pedagogical considerations, the DSLM and scientific reasoning, in the design of the Web-learning program which successfully promotes students' concepts of atoms, scientific reasoning, and conceptual change. Our finding is different from one of the Web-based learning studies (Tsui & Treagust, 2007) which reported that multiple representations may not sufficiently develop all students' genetic reasoning and reconstruction of genetics conceptions. This may result from their development of Web-based learning materials which lack an effective conceptual change and scientific reasoning model. On the other hand, one of the major reasons making SCCR successful is the use of an adaptive Web-based learning environment. SCCR provides students with adaptive feedback of comparison HTML pages which activate students' use of scientific reasoning to justify why they change their original scientific conceptions, which turn out to be quite effective in improving their scientific concept, conceptual change, and the level of scientific reasoning. It supports Veerman et al. (2000) study, that the experimental group students who received adaptive feedback learning design improved significantly more in students' understanding the processes and applying the knowledge in new situations than the pre-defined feedback group.

Regression indicated that the best predictor for post-ADRT was post-SRT, followed by post-AAT scores. This implies that students' post-ADRT would increase as their post-SRT increased. It can be interpreted that students' conceptual change could be increased as their scientific reasoning was increased after learning. Immediately after learning, students' scientific reasoning contributes more to their conceptual change than with the concepts students hold. This supports previous researchers' suggestions that conceptual change involves deep restructuring, not only in the concepts, but also in the way of reasoning (Furio et al., 2000; Gil & Carrascosa, 1994); that conceptual change must not be considered merely as a change in content (Hewson & Thorley, 1989); and that a relationship exists between students' alternative conceptions and reasoning ability (Lawson, 2003). Moreover, our study provides much more relevant results for supporting the contention that students' conceptual change would be enhanced as their scientific reasoning ability increased immediately after learning.

Differing from previous research, we found that the best predictor for retention-ADRT scores was retention-AAT, followed by retention-SRT scores. This implies that students' retention-ADRT would increase as their retention-AAT increased. Two months after learning, students' grasp of correct concepts contributes more to their conceptual change than scientific reasoning after 3-month of learning. It is very interesting that students' conceptual change would be enhanced more as their grasp of correct concepts increased instead of their scientific reasoning 2 months after learning.

Why would the patterns differ between immediately after learning and 2 months after learning? One possible explanation is that students' use of scientific reasoning is critical for conceptual change to occur during the process of conceptual change. Scientific reasoning helps them to reason and justify why concepts are reasonable for them to believe and further helps the concepts to become their own concepts. Their brains are working on making connections among many conceptions and already-existed conceptions while they are using reasoning to attain the conceptions. If students change their conceptions successfully 2 months after learning, this means the process of consolidation has finished and they have made changes in an already established network so that a modified set of hierarchical organizations is established and stabilized.

According to research on the brain, the first stage of consolidation involves interactions between hippocampus and the parahippocampal region, while the second stage of consolidation involves a similar interplay between the cortical association areas and the parahippocampal region (Eichenbaum & Cohen, 2001). Parahippocampal neurons receive direct inputs from many cortical areas. Parahippocampal neurons have an unusual capacity for prolonged firings following discrete events (Suzuki, Miller, & Desimone, 1997; Young, Otto, Fox, & Eichenbaum, 1997), and cells in this region may rapidly support the coding of event sequences through the interactions with the hippocampus. Initially cortical association is believed to depend on the parahippocampal regions to supply linkages between their representations. In addition, by simultaneously driving cells in cortical areas and activating their intracortical connections, these linkages

would be expected to mediate the ultimate development of context and nodal properties in the cortical association areas (Eichenbaum & Cohen, 2001). This indicates that scientific reasoning is a strategy that acts to trigger the hippocampus, parahippocampal region and cortical areas to make association among the new representations/conceptions with existing representations/conceptions that we already have. Once the consolidation is accomplished, the entire hippocampal circuit would no longer be necessary for the existence of events, sequence, and nodal representations (Eichenbaum & Cohen, 2001). This implies that scientific reasoning may not be needed to recall the already existing scientific conceptions once consolidation has been completed.

On the other hand, McClelland, McNaughton, and O'Reilly (1995) proposed that cortical representations involve systematic organizations of related items in parallel, multidimensional hierarchies. Once a set of hierarchical organizations is established and stabilized, it is difficult to smoothly add new items, which can explain why alternative scientific conceptions are more difficult to change. This is because such novel training causes changes in an already established network, resulting in catastrophic interference among the already-existing items (McCloskey & Cohen, 1989). New training alters a network to identify the new item, but such learning results in network modifications that interfere with the previously developed ability to correctly identify the old information. This can explain why conceptual change is difficult. In contrast, if students successfully change their alternative conceptions, that means they may have acquired the correct scientific conceptions through the use of scientific reasoning for making associations with existing hierarchically organized conceptions, which results in changes to already-existing networks as the consolidation process finishes. All these aspects together become part of their long-term memory. Squire and Kandel (1999, p. 21) indicated that long-term memory involves changes in the structure of nerve cells. Depending upon the type of learning, the nerve cells involved can make more/fewer and stronger/weaker connections. They further suggested that the switch from short-term memory to long-term memory facilitation is a switch from a process-based memory to a structure-based memory (p. 146). This can explain our observation that students change their scientific conceptions successfully 2 months after learning, meaning they already formed long-term memory that had become structure-based memory. Therefore, they would not necessarily depend reasoning to recall specific scientific conceptions 2 months after learning since they already had become part of their structure-based memory (semantic memory). The AAT assesses students' memorization of conceptions of atom-related concepts, and the ADRT measures the degree of students' conceptual change involving atom-related concepts. Once students' conceptual change is successful, it would become their long-term structure-based memory, so students ADRT would be more closely related with their AAT scores. This indicates that AAT and ADRT are both testing students' long-term memory 2 months after learning.

Implications

Several implications derive from the findings of the study. Results indicate that the best predictor of post-ADRT is post-SRT, and the best predictor of retention-ADRT is retention-AAT. This may be interpreted to indicate that students' scientific reasoning contributes more to their conceptual change than to the concepts students hold right after learning. On the contrary, students' conceptual change would be further enhanced as their grasp of correct concepts increased instead of their scientific reasoning improving 2 months after learning. Brain research provides important concepts and convincing explanations for our interesting regression results. The following are the two main insights of the study: (1) Scientific reasoning is critical for conceptual change to happen during learning. It is a very important strategy for students to make associations among new mental sets with already-existed hierarchical structure-based memory. This provides the science teacher and science educator directions for helping students reconstruct scientific conceptions more efficiently. (2). Once students' conceptual change is successful and it has become structure-based memory (semantic memory), then the scientific reasoning may not necessary be required to recall the already-established correct scientific conceptions. This implies that students can more quickly and efficiently recall correct scientific conceptions once their conceptual change is successful. It would be worth to bring neuroimaging study (EEG and fMRI) to investigate how the brain works during conceptual change and scientific reasoning process.

Our results confirm that the DSLM is efficient for facilitating students' conceptual changes, especially, as we integrated it here with scientific reasoning and deployed it in an adaptive digital learning environment. This further demonstrates that the DSLM can be effective in fostering students' conceptual change in a web-learning environment as well as in the classroom. The study provides evidence that conceptual change can be possible if the instruction approach is supported by well-developed educational models or theories.

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Appendix 1: Interview Questions

- (1) Please describe your understanding about chemical compounds and chemical elements. In addition, provide examples for each of them and further make explanations to differentiate them.
- (2) Please describe the shape and structure of atoms.
- (3) Can electrons move? Please describe the movement of electrons.
- (4) Please describe the arrangement of electrons. How many electron shells exist in an atom?
- (5) Are all atoms the same? Are gold and iron made of the same kind of atom?
 - (5a) If so, why do the properties of gold differ from properties of iron?
 - (5b) If not, what are the reasons making them different?
- (6) Can atoms be divided into any other substances? If yes, please describe the properties of substances and further compare their similarities and differences.

- (7) Do you think a noble gas is stable? Provide your explanations.
- (8) Compare the stability among sodium, potassium and noble gas, and further provide explanations.
- (9) Please describe which one of two compounds (chlorine or bromine) react with sodium much more easily? Further provide explanations.
- (10) Compare the stability of hydrogen atom and hydrogen molecule. Further provide your explanations.

Appendix 2: Atomic Achievement Test (AAT) Example Question

Which one is correct about the properties of particles?

- (1) Atomic mass and size for all elements are the same.
- (2) All chemical compounds are composed of the same kinds of atoms.
- (3) Atoms consist of a nucleus and electrons.
- (4) Electrons are charge-free.

Appendix 3. Scientific Reasoning Test (SRT) Example Question (Lawson, 1978)

Farmer Brown was observing the mice that live in his field. He discovered that all of them were either fat or thin. Also, all of them had either black tails or white tails. This made him wonder if there might be a link between the size of the mice and the color of their tails. So he captured all of the mice in one part of his field and observed them. Below are the mice that he captured.



Do you think there is a link between the size of mice and the color of their tails?

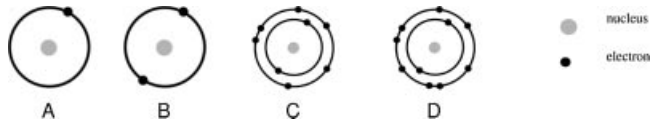
- (1) Appears to be a link.
- (2) Appears not to be a link.
- (3) Cannot make a reasonable guess.

Because

- (1) There are some of each kind of mouse.
- (2) There may be a genetic link between mouse size and tail color.
- (3) There were not enough mice captured.
- (4) Most of the fat mice have black tails while most of the thin mice have white tails.
- (5) As the mice grew fatter, their tails became darker.

Appendix 4: Atomic Dependent Reasoning Test (ADRT) Example Question

The following diagrams A–D show the number of electrons and their arrangement for four different kinds of atoms. Which one of the atoms is very stable and does not easily react with other substances?



- (1) B and D
- (2) B, C, and D
- (3) A and B
- (4) C and D

Because

- (1) It is more stable if there are fewer electron shells.
- (2) It is more stable if there are more electron shells.
- (3) It is more stable if the outermost shell either has two electrons for one-shell atom or eight electrons for a multi-shell atom.
- (4) It is more stable as long as the shell has two electrons.