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SCCR digital learning system for scientific conceptual change and scientific reasoning

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Abstract

This study reports an adaptive digital learning project, scientific concept construction and reconstruction (SCCR), that was developed based on the theories of Dual Situated Learning Model (DSLM) and scientific reasoning. In addition, the authors investigated the effects of an SCCR related to a "combustion" topic for sixth grade students conceptual change and scientific reasoning. An experimental research design including the Combustion Achievement Test (CAT), Scientific Reasoning Test (SRT) and Combustion Dependent Reasoning Test (CDRT) was applied for both experimental and conventional group students before, directly after, and after the sixth week of the research as pre-, post- and retention-test. Results indicated that the experimental group students significantly outperformed the conventional group students on both post- and retention- of CAT and CDRT scores. In addition, experimental group students performed better than conventional group students on the post-SRT scores. The success rate of conceptual change ranged from 70% to 100% for experimental group students for most web-based dual situated learning events. The nature of the scientific reasoning used by experimental group students mainly either made progression (PG) or maintain-correct (MTC) across most events from before to after web-based dual situated learning events. All of these results support the claim that students' conceptual change their scientific reasoning ability can be promoted through an SCCR digital learning program.
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Keywords: SCCR digital learning system; Dual situated learning model; Conceptual change; Scientific reasoning

1. Introduction

Lawson (2003) indicated that the view of development of advanced reasoning and its emphasis on alternative conceptions or misconceptions leads quite naturally to a theory of science instruction that has the potential to unite two previously competing research traditions in science education. From this viewpoint he provided an initial discussion of the relationship between students' misconceptions and reasoning ability. For students to modify prior conceptions they must become aware of both the scientific conceptions and their own alternative conceptions, and they must also become aware of the evidence and reasoning which bears on

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the validity of their alternative conceptions. In other words, they must be able logically to see how the evidence supports the scientific conceptions and how it contradicts the prior alternatives. In Lawson and Thompson (1988) study, a test following instruction on concepts of evolution and genetics administered to a sample of empirico-inductive seventh grade students revealed an average of 1.67 misconceptions per student, whereas their hypothetico-deductive classmates held only 0.43 misconceptions per student. This indicates that students who have internalized the hypothetico-deductive reasoning pattern hold fewer misconceptions. However, none of these previous studies have examined whether relationships exists between students' scientific reasoning and conceptual change.

Conceptual change has been a major research area of science education in the past two decades (Duit & Treagust, 2003). Research on conceptual change has been spurred by many findings on students' alternative conceptions, misconceptions or pre-instructional conceptions about scientific concepts accumulated from studies over the past 30 years. Over the past 30 years, the perspectives on conceptual change of science education researchers (Brown, 1993; Clement, 1991, 1993; Posner, Strike, Hewson, & Gertzog, 1982; Steinberg & Clement, 1997) have differed greatly from those of the cognitive psychologists (Carey, 1985; Chi, Slotta, & deLeeuw, 1994; Thagard, 1992; Vosniadou & Brewer, 1987). To reconcile these differences, She (2002, 2003, 2004a, 2004b) has integrated the strengths from both sides into a theoretical construct to develop the Dual Situated Learning Model (DSLM). According to She (2004a, 2004b), situated learning means that learning process of conceptual change should be situated on the nature of science concepts and students' beliefs of the science concepts in order to determine what essential mental sets are needed for constructing a more scientific view of the concepts. Dual means two essential components are important for conceptual change to be happened and they are interacting with each other. There are three duals and each dual situated learning events need to be constructed based upon these three duals: first dual, considering both the nature of science concepts and students' beliefs of science concepts; second dual, creating dissonance with students' pre-existing knowledge and providing a new mental set for them to achieve a more scientific view of the concept; and third dual, arousing students' motivation and challenging their beliefs of the concepts and challenging students' ontological and epistemological beliefs of science concepts. To implement this theory, DSLM was transformed into a six stage instructional model (Fig. 1). Application of the DSLM instructional approach has demonstrated effective conceptual change in middle school students in 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, She, & Lee, 2005). The author feels that there is a great potential to unite both scientific reasoning and conceptual change in order to maximize the success of conceptual change as well as scientific reasoning ability.

Using a taxonomy modified from that of Mioduser, Nachmias, Oren, and Lahav (2000), Tuvi and Nachmias (2001) reviewed 93 websites that focused on introducing atomic structures and obtained similar findings: text was clearly the major means to present informations, with automatic/human and technical/content- based help accounting for less than 18%; less than 6% of the sites had interactive images, animation or sound; none of those websites was inquiry-based; and memorizing was the main cognitive process. This pointed out the following critical problems of the most of the web learning program designed for science education purpose. First, it is clear that science teaching and learning theories are not the basis for most science web-learning programs. Second, pedagogical aspects are insufficiently considered in the design of the web-learning programs. Third, the capacities of the web and multimedia not fully used to enhance students' science learning.

Many studies suggest there is no difference in test scores between web-based and traditional format courses, although students gain more confidence with computers in a web-based course (Leasure, Davis, & Thievon, 2000), others find that students enrolled in a web-based course perform worse than conventional students in the final exam (Wang & Newlin, 2000). Cepni, Tas, and Kose (2006) showed that computer assisted instructional materials are effective for reaching comprehension and application levels of cognitive domain, although they are not effective for changing students misconceptions of photosynthesis for an experimental group of students compared to a conventional group. The author suggests the reason why disagreement remains on whether computer-assisted instruction is more effective on student achievement and attitudes than traditional teaching is that most of the web-based science learning programs contain the problems mentioned by Tuvi and Nachmias above. It is clearly that most computer-assisted instructional

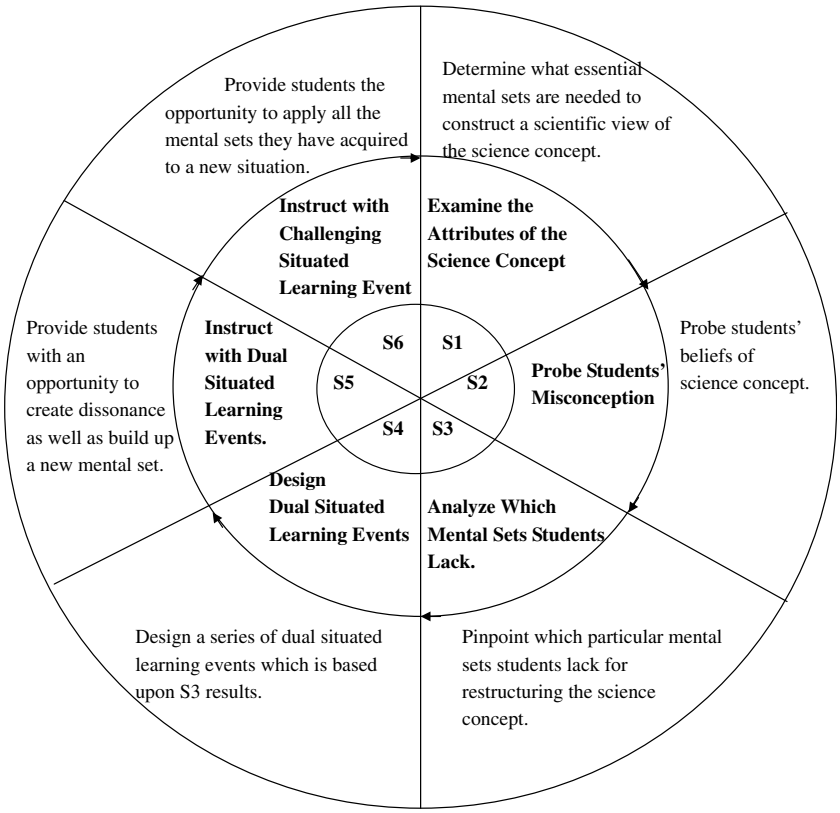


Fig. 1. Dual situated learning model.

materials do not use solid and specific conceptual change theories and models as the basis for its web-design theories, so it is very difficult to have any significant progress in changing students' alternative conceptions. Thus this study attempts to employ the Dual Situated Learning Model (DSLM) and scientific reasoning for the development of a Web-based science learning program in order to facilitate students' conceptual change and scientific reasoning.

Veerman, Andriessen, and Kanselaar (2000) studied the effect of adaptive feedback compared to pre-defined feedback. Adaptive feedback is designed on the basis of hypotheses and activities made during the inquiry process by each learner, whereas pre-defined feedback has the same answer for each student. Their results showed that although there were no differences in defining the concepts of physics and recalling equations, the experimental group improved significantly more in understanding the processes and applying the knowledge in new situations.

An internet-based learning system will be effective if it not only allows students to navigate between different pages but also helps students to better achieve their learning goals. It is also necessary for sites to have more sophisticated mechanisms that modify the navigation alternatives by some sort of adaptation procedure. Moreover, there are important differences among students. Some of these differences are related to personal features such as age, interests, preferences, etc., or to their previous knowledge about the subject (Eklund & Brusilovsky, 1998). There are also factors that have to do with their preferences for a specific learning strategy. One of the desirable features of any web-based educational system is adaptivity, i.e. the ability to take into account all the above mentioned features of an individual learner in order to customize the course contents, as well as the presentation format (Brusilovsky et al., 1998). Different approaches have been proposed to incorporate adaptivity into hypermedia courses. One of them is the technique of sensitive links that are used to establish links between hyper-documents whose availability and contents change depending on the state of teaching (Brusilovsky & Anderson, 1998). The student's knowledge of each concept is used for guidance towards the appropriate documents (Carro, Roberto, Estrella, & Pilar, 1999).

The DSLM has been applied in the classroom for several topics and demonstrated successful fostering of students' conceptual change within the classroom setting. However, the main limitation of employing DSLM in a classroom is the inability to provide different students with adaptive learning according to their individual misconceptions. The author believes that if students can be involved with an adaptive individualized learning environment, it would help to overcome this limitation and increase the effectiveness of both conceptual change and scientific reasoning. Therefore, it is necessary to move beyond the classroom instruction to the adaptive web-learning approach. This is a very promising direction that would enable teachers to maximize the efficiency and effectiveness of conceptual change and scientific reasoning.

Many students have problems understanding the requirements for combustion and the process of combustion. Many studies have reported that students describe combustible materials as being reduced to ashes with much of the combustible material simply disappearing (Anderson, 1990; BouJaoude, 1991), and that ashes get lighter when they are burnt (Driver, 1985). Students are not clear that oxygen (gas) is needed for burning or about its function for the burning (Anderson, 1990; Driver, 1985; Watson, Prieto, & Dillon, 1995). Some consider that flames contain only the combustible substance or oxygen and air, or possibly both but with no interaction. The flame or fire is seen as a source of heat to make the modification occur (Watson et al., 1995). Prieto (1992) noticed that students concentrated on the perceptually obvious features of changes such as candle wax melting and did not see the wax as being used up or interacting with the air. They also reported that students see the wood changing to ash, but did not mention oxygen or air being involved in the burning process, ignoring any gases produced. Students also think that a change in form of a substance can cause a change in mass, and in particularly that gases have zero or negative weight. BouJaoude (1991) reported that students' understanding about burning are: wax, alcohol, and oxygen are not actively involved in burning; substances undergo no chemical change during burning; terms such as evaporation and burning can be used interchangeably when describing burning alcohol; phrases such as physical change and chemical change can be used interchangeably when describing burning things; burning wax was melting and its mass would not change; the loss in weight of a candle would be minimal due to the consumption of the wick or evaporation of wax. Schollum (1982) reported that students alternative conceptions of combustion and rustiness are: air is not involved with burning; burning does not produce new substances; the evaporation of a substance is the process of burning; the flame of burning does not contain any molecules; rust is a protective layer for metal and does not destroy it; rustiness exists in the air and can attach to metal nails through some process; water and some other materials would produce rustiness; rustiness is due to water destroying a metal nail.

The design of the combustion-related adaptive web-based program in this study uses these students' misconceptions from the previous studies describing above as one of the major sources to the design of adaptive web-based dual situated learning events to facilitate students' scientific reasoning and conceptual change in the combustion unit.

2. Development of SCCR digital learning project

The SCCR project was developed based on the theories of DSLM and scientific reasoning as the major basis for developing the web-learning content. The current SCCR digital learning project includes several units: the electricity unit and buoyancy unit in physics, the atom unit and combustion unit in chemistry, and the genetics unit in biology. This paper reports the impact of students' learning from the combustion unit.

2.1. SCCR digital learning system software and operating requirement

The SCCR platform was the FreeBSD running with an Apache WWW server. The core of the SCCR system is programmed in PHP and Java Applet and JavaScript and works with MySQL to efficiently handle extremely large data sets and analytical programs.

By using PHP, we can receive user input and process it on the server side, then dynamically generating the next new pages.

We also use the free software Simple Machine Forum (SMF) which is programmed in PHP to build up a discussion forum. To synchronize the data between SCCR and SMF, we rewrote some codes in SMF.

2.2. Functions of the SCCR digital learning system

2.2.1. Teacher authoring module

The teacher authoring module provides teachers with a convenient user interface that allows them to develop learning content. In order to provide students' with different ways of learning based upon their prior misconception and scientific reasoning, the authoring modules contain the following functions: (1) conducting driving questions; (2) intervention based upon the results of the students' driving questions; (3) generate feedback page that provides correct answers and generates a comparison of students' answers and reasons before and after instruction for each driving question.

For the authoring interface, we can make all kinds of web pages simply by choosing some options and keying in the data. There are three major kinds of pages and ten kinds of pages in all that we can make, depending on the nature of the science concept and students' learning progress (see Fig. 2) as described below:

(1) Normal
1. Text – display explanations or answers.
2. Multimedia – play video or flash.
3. Questions – e.g.: multiple choice, essay questions.
4. Discussion – a special question is provided for students to have a group discussion.

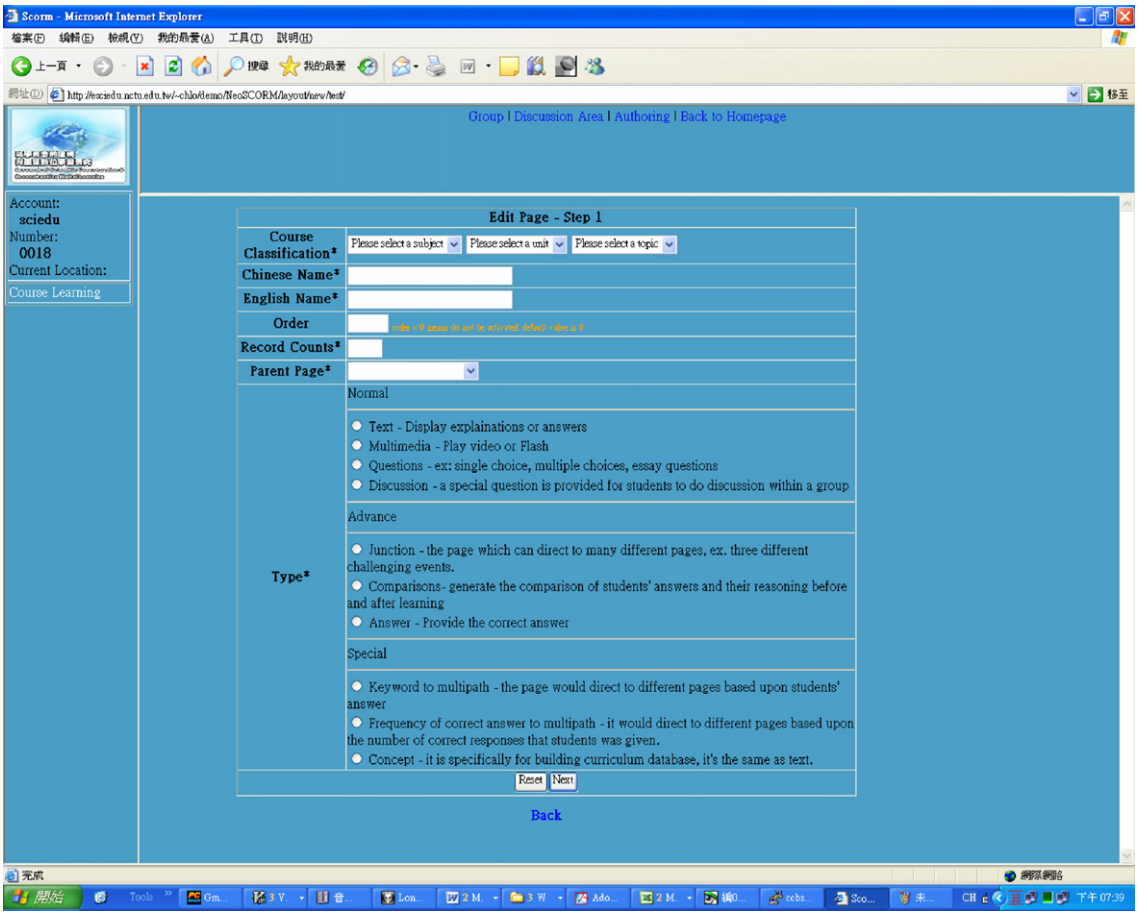


Fig. 2. Web page of teacher authoring module.

(2) Advance
1. Junction – a page which can direct a user to many other pages, e.g. three different challenging events.
2. Comparisons – generate a comparison of students' answers and their reasoning before and after learning.
3. Answer – provide the correct answer.

(3) Special
1. Keyword to multipath – the page would direct to different pages based upon students' answers.
2. Frequency of correct answers to multipath – it would direct to different pages based on the number of correct responses a student gives.
3. Concept – specifically for building a curriculum database, the same as text.

2.2.2. Teacher management module

This module provides teachers with a user-friendly interface that allows them to execute various online management functions, such as setting up accounts, setting up class parameters, queries as to students' performance of the questions, and various learning processes. In addition, teachers would need to arrange students into groups. Teachers also can see students' learning progress, learning performance, class ranking, school ranking, etc. Teachers can also view the frequency and nature of student discussions.

Group Management: SCCR can generate many groups in each unit and then assign the members to these groups. The members in one group can discuss their ideas with each other on the discussion page.

Account Management: There are three types of members: student, teacher and administrator. Students can join in SCCR, teachers can do the authoring and assign members to groups, while the administrator can do all of these things as well as assign permissions to members.

2.3. Characteristics of the SCCR

2.3.1. Facilitate students' conceptual change and scientific reasoning

To facilitate students' conceptual change and scientific reasoning, therefore, the design of each web-based dual situated learning event would require students to provide an answer to the driving question and their reasoning for that answer before each learning event. The same driving question is asked again after the event to examine the students' conceptual change and their reasoning changes. Therefore, in order to activate students use of scientific reasoning, we specifically restructure the process to let students view both their answers and reasoning before and after events, as well as the correct answers, and further request students to reason why they change or stay with their original thoughts after learning the events. This is intended to encourage students' minds spontaneously to become involved with the process of scientific reasoning as well as conceptual change (Fig. 3). Throughout the unit of combustion, students need to use scientific reasoning for tasks such as: formulate plans; analyze elements; evaluate alternative ideas; determine consequences and hypotheses; identify variables; make inferences; make clarifications; make justifications; make conclusions based upon observations, experiments and previous inferences; process rules and general principles; judge the credibility of a source; distinguish between fact, opinion and reasoned judgment; weigh evidence and assess data; decide between competing theories.

2.3.2. Dynamic generation of adaptive web-learning content

In order to provide students with different learning tasks depending their different misconceptions and different reasoning patterns, the adaptive learning approach was used for SCCR. More specifically, some of the units of SCCR would provide different learning events according to the responses the students made regarding either accuracy of concepts or reasoning and further determine which learning pathway they need to work on.

These contents are defined by means of learning tasks that correspond to basic concepts units, and rules which describe how learning tasks are divided into subtasks. Both tasks and rules are used at the time of exe-

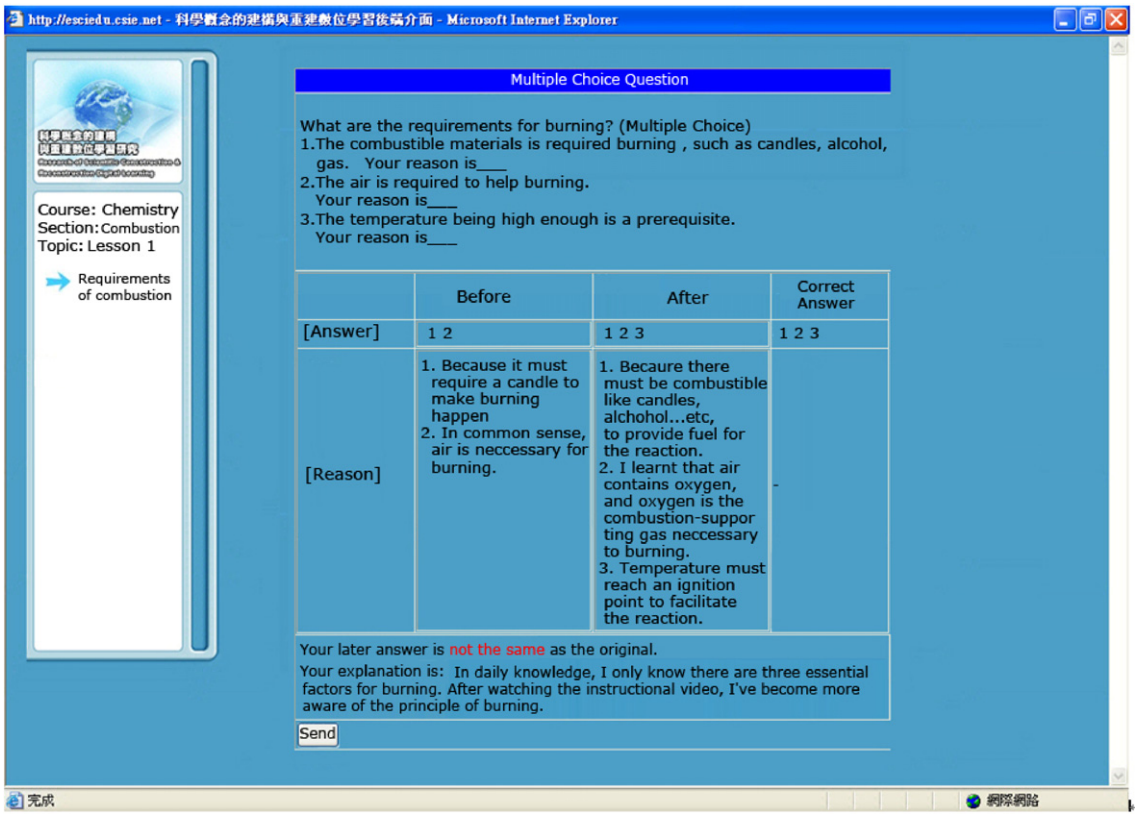


Fig. 3. Students' answer and reasoning before and after the web-based dual situated learning events.

cution to guide the students during their learning process by determining the set of achievable tasks to be presented to the students at every step. Adaptivity is implemented by presenting students with different HTML pages, depending on their prior misconceptions and their previous reasoning results. The adaptive linking is used to modify the link structure depending on the individual student's knowledge state. This leads to the development of a new course text, with a dynamically changing link structure, depending on each individual student's progress (Fig. 4 flow chart).

2.3.3. Student–student knowledge construction within a small group

This web site also provides students with the opportunity for interaction with their peers to discuss the content and questions throughout the learning, some of the topics are very good for student discussion. Therefore, this feature is also provided for students to construct their knowledge in an environment of social interaction.

2.4. The design of SCCR content: unit of combustion

The design of the combustion-related web-based program in this study uses the student misconceptions found by previous studies (Anderson, 1990; BouJaoude, 1991; Prieto, 1992; Schollum, 1982; Watson et al., 1995) described above as one of the major sources for the design of learning events to facilitate students' conceptual change. It is clear that student misconceptions of burning originate from their personal observations since they can not visualize many substances and are not able to use conservation ideas to explain the products of burning. Therefore, the design of this combustion unit emphasizes providing students with many experiments and multimedia representation to visualize the real events in order to help them build a more scientific understanding of combustion and corrosion.

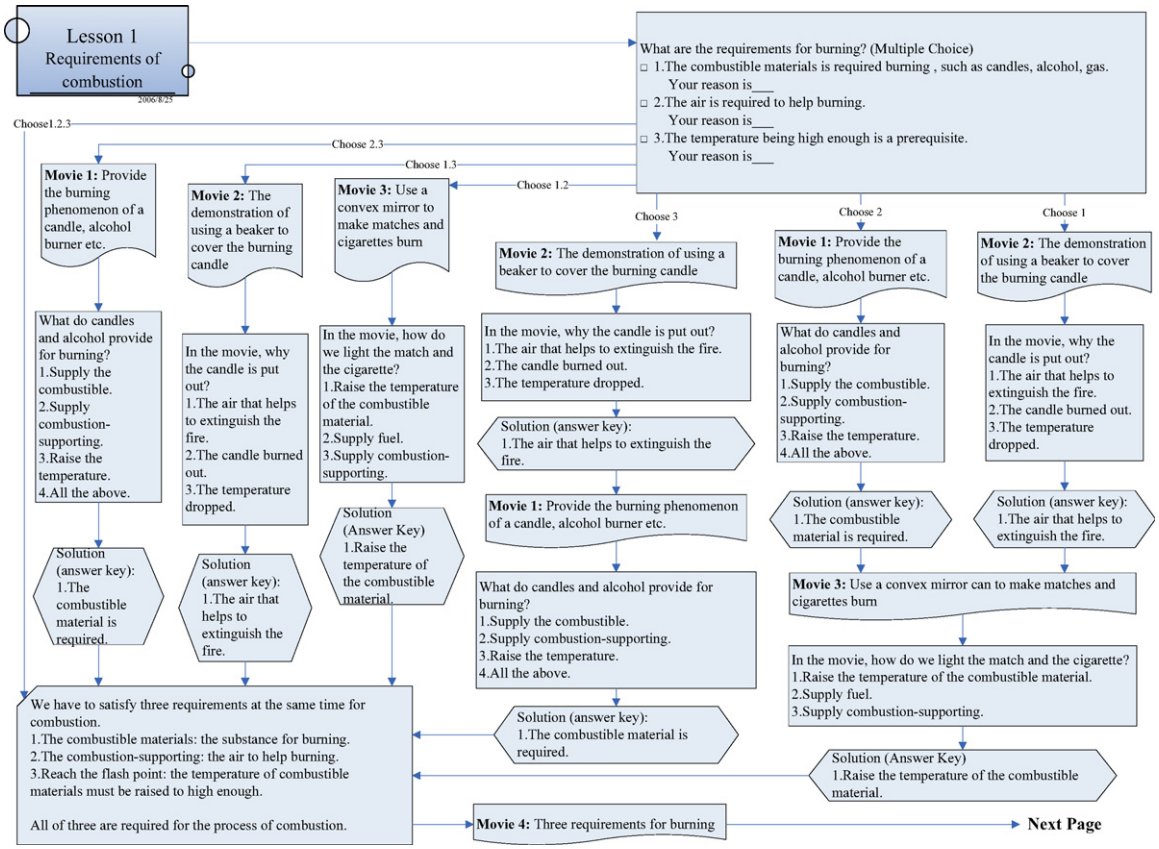


Fig. 4. Flow chart of *dynamic generation of adaptive web-learning content*.

The design of the combustion content is basically based upon the six stages of DSLM described above. The mental sets students lack were categorized into five topics and further developed into a series of web-based dual situated learning events: (1) requirements for combustion: combustible materials, flammable gas, and raising the temperature to reach the flash point. (2) oxygen: production of oxygen, oxygen is a flammable gas, oxygen is needed for burning and its function for the burning, and the characteristics of oxygen such as its density and solubility. (3) carbon dioxide: production of carbon dioxide, verifying the existence of carbon dioxide, carbon dioxide is produced from burning, the characteristics of carbon dioxide such as its density and solubility. (4) fire extinguishing: the methods and reasons to extinguish fire. (5) corrosion: the nature of rusting substances, reasons for rustiness, requirements for protection from rusting.

3. Purpose

This study reports an adaptive digital learning project, scientific concept construction and reconstruction (SCCR), that was developed based on the theories of Dual Situated Learning Model (DSLM) and scientific reasoning. In addition, this study investigated the effects of an SCCR related to the "combustion" topic for sixth grade students' conceptual change and scientific reasoning. Three instruments: Combustion Achievement Test (CAT), Scientific Reasoning Test (SRT) and Combustion Dependent Reasoning Test (CDRT) were developed to examine students' scientific concepts, scientific reasoning ability, and conceptual change. Three instruments were administered to both experimental (received SCCR web-based instruction) and conventional groups' (received conventional instruction) students before, directly after, and six weeks after the research as pre-, post- and retention-test. Moreover, experimental group students' learning of the web-based dual situated learning events (DSLE) was analyzed and yielded the level of scientific reasoning and success rate of conceptual change to examine the effects of SCCR.

4. Subjects and procedures

A total of 62 sixth graders recruited from two average-achievement classes of an elementary school participated in this study. One class of students received the SCCR digital learning Program "combustion" unit (experimental group), and the other class of students received conventional instruction for the "combustion" unit (conventional group). Pretests for Combustion Dependent Reasoning Test (CDRT), Scientific Reasoning Test (SRT), and Combustion Achievement Test (CAT) were administered to all students before the instruction. One week and sixth weeks respectively after the instruction, a post-test and a retention-test of the CDRT, SRT, and CAT were administered to both groups. In addition, the experimental group students learning form a series of web-based dual situated learning events in the "combustion" unit were further analyzed and yielded information on both the scientific conceptual change and the scientific reasoning results.

5. Instrument

5.1. Combustion Achievement Test (CAT)

The CAT is a multiple choice diagnostic instrument that was developed to measure students' concepts of combustion related concepts before, directly after, and 6 weeks after receiving the combustion unit of the SCCR digital learning program. The content validity was established by a panel of three evaluators (two elementary science teachers and one university science educator), ensuring that the items were properly constructed and relevant to the combustion 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 a total of 96 items. Students would receive one point if they answer one question right, so the highest score can be 96. The Cronbach's α for the CAT was 0.90 for the pre-test, 0.93 for the post-test, and 0.94 for the retention-test.

5.2. Scientific Reasoning Test (SRT)

The SRT is a two-tier multiple choice diagnostic instrument that was developed to measure students' scientific reasoning before, directly after, and 6 weeks after receiving the combustion unit of the SCCR digital learning program. Lawson's Scientific Reasoning Test was first developed at 1978 and then revised at 2000. The SRT was modified from Lawson's Scientific Reasoning Test (Lawson, 1978, 2000). It measures students' conservation, proportional thinking, identification and control of variables, probabilistic thinking, correlative thinking and hypothetic–deductive ability. There is a total of 12 items, each of which contains two tiers; the first tier is to choose the answer, and second tier is to use the thinking ability mentioned above. Students need to answer both tiers correctly in order to receive one point (example question see Appendix A). The highest score can be 12. The Cronbach's α of the SRT was 0.71 for the pre-test, 0.61 for the post-test, and 0.76 for the retention-test which is close to the Lawson's results for Cronbach's α.

5.3. Combustion Dependent Reasoning Test (CDRT)

The CDRT is a two-tier multiple choice diagnostic instrument that was developed to measure the degree of students' conceptual change involving combustion related concepts before, directly after, and 6 weeks after receiving the combustion unit of the SCCR digital learning program. The questions of CDRT require students to use a more scientific view of combustion-related concepts and their scientific reasoning for the combustion-related concepts (example question see Appendix B). The content validity was established by the same panel of three evaluators, ensuring that the items were properly constructed and relevant to the combustion unit web-learning materials we developed. There are 41 items, and each item contains two tiers, first tier is to check students scientific concepts/misconceptions, while the second tier requires students to use scientific reasoning to consider combustion-related concepts, so students need to answer both tier correctly in order to receive one point. The highest score can be 41. Cronbach's α of the CDRT was 0.89 for the pre-test, 0.92 for the post-test, and 0.94 for the retention-test.

5.4. Web-based learning process results analyses

Students web-learning results were analyzed for two aspects: students' level of scientific reasoning and the degree of conceptual change.

The design of each web-based dual situated learning event requires students to provide an answer and their reasoning for the driving question before each learning event. The same driving question is asked again after the event to examine the students' conceptual change and their reasoning changes. In order to measure the level of scientific reasoning of students reasoning provided to the driving question before and after of the web-based dual situated learning events, we used the four categories of scientific reasoning, as modified from Hogan, Nastasi, and Pressley, 2000: Generativity (G), Elaboration (EL), Justification (J), and Explanation (Ex).

1. Generativity (G): the number of a students own observations, ideas, or conjectures. For instance, "I do not know" was coded as G0 because it did not answer anything relevant; "water can be used to extinguish the fire" was coded as G1.
2. Elaboration (EL): the number of scientific concepts used to describe and explain the concepts. For instance, "oxygen can help with burning." was coded as EL1; "air is composed many different gases, oxygen is one of them, and carbon dioxide is one of them." was coded as EL2.
3. Justification (J): the number of evidence-based or inference-based conclusions or experiments that were used to support the ideas or assertions. For instance, "the solubility of carbon dioxide is higher than oxygen because we did the experiment and it shows that water level of carbon dioxide test tube is higher than oxygen." was coded as J1; "A balloon would float in the air if we filled it with oxygen, because the density of oxygen is lower than air. Air is composed of many different gases and their density is different, some of them are denser than oxygen, and some of them are lighter than oxygen; when mixed together, the density of air is greater than oxygen." was coded as J2.
4. Explanation (Ex): the number of rules or mechanisms proposed to explain the concepts or assertions. For instance, "The reason for putting the cap on the alcohol burner is to extinguish the fire; it is done to stop providing one of the requirements for burning, which is oxygen." was coded as Ex 1; "In order to prove that the mechanism for a metal nail to rust is related to oxygen, the experimental design used paraffin to seal one metal nail with oxygen inside and another nail without oxygen inside. It was intended to determine whether oxygen or air is the major component causing serious rusting. If the sample with oxygen has more serious rusting than the other one, then it proves the idea that oxygen fosters a metal nail rusting more than air." was coded as Ex 2.

After the web-based dual-situated learning events were coded according to the four categories of scientific reasoning provided above, the following step is used to compare the changes between students' use of scientific reasoning before and after each events. Three categories: progress (PG), maintain-correct (MTC), and retrogress (RTG) were used to classify the degree of change in scientific reasoning from before to after learning. For example, if a student's scientific reasoning was categorized as G0 before the dual situated learning event 1, and after the event was categorized as EL1, then this would be classified as progress (PG).

The degree and nature of conceptual change was judged and classified into four categories according to their before and after answers to the driving questions: correct–correct, incorrect–correct, correct–incorrect, incorrect–incorrect. Adding both the correct–correct and incorrect–correct categories together yields the success rate of conceptual change.

6. Results

6.1. Combustion Achievement Test (CAT)

Table 1 presents the descriptive statistics of the pre-, post-, and retention-test of the CAT. Although the experimental group has a lower pre-CAT mean score than the control group, the experimental group outperformed the control group in the CAT scores for post- and retention-tests. The experimental group students

Table 1
Descriptive statistics and T-test of the pre-, post-, and retention- of CAT, SRT, and CDRT

	N	Pre-test		Post-test		Retention-test		$T_{(\text{Post–Pre})}$	$T_{(\text{Retention–Post})}$
		M	SD	M	SD	M	SD		
Combustion Achievement Test									
Experimental Group	31	44.71	14.23	64.87	14.81	63.68	17.45	11.24^{***}	−0.97
Conventional Group	30	45.93	12.47	40.93	18.47	56.67	15.81	−1.48	4.97^{***}
Scientific Reasoning Test									
Experimental Group	31	2.48	2.00	3.10	2.02	3.65	2.56	2.18^{*}	1.68
Conventional Group	30	2.16	2.13	2.13	1.96	3.32	2.64	−0.07	2
Combustion Concepts Dependent Reasoning Test									
Experimental Group	31	13.48	7.41	20.71	8.38	22.45	10.17	7.39^{***}	1.62
Conventional Group	30	11.37	7.61	10.33	9.37	14.30	9.05	−0.52	2.07^{*}

Note. $N = 61$; $^{***}p < 0.0001$, $^{**}p < 0.001$, $^{*}p < 0.01$.

made significant progress from pre- to post-CAT ($T_{(\text{post–pre})} = 11.24$, $P = 0.000$), in contrast, the conventional group made significant progress from post to retention-CAT ($T_{(\text{retention–post})} = 4.97$, $P = 0.000$).

One-factor MANCOVA was conducted to examine the effects of instructional approaches and using post- and retention-CAT scores as the dependent measures, and pre-test scores as the covariate. Table 2 summarizes the results of the one-factor MANCOVA, indicating that instructional approaches (Wilk's $\Lambda = 0.54$, $p = 0.000$) reach a statistically significant effect on the performance of post- and retention-CAT. Therefore, the following main effect for instructional approach was performed.

The univariate F (one-factor ANCOVA) was performed to independently examine the effect of the instructional approaches on post- and retention-CAT. It indicated that the effects for instructional approaches were significant on both post-CAT scores ($F = 45.86$, $p = 0.000$) and retention-CAT ($F = 4.71$, $p = 0.04$). Thus, the students' post- and retention-CAT were significantly affected by the instructional approach. The post-hoc analysis for main effect suggests that the experimental group performed significantly better than the conventional group (experimental group >conventional group, $p_{(\text{post})} = 0.000$, $p_{(\text{retention})} = 0.034$) on post- and retention-CAT (Table 3).

Table 2
Multivariate analysis of covariance (MANCOVA) of post- and retention- of combustion achievement test scores

Source of variance	Wilk's Λ	Hypothesis d.f.	Error d.f.	Multivariate F
Covariates				
Pre-test scores	0.66	2	57	14.95^{**}
Group memberships				
Instructional approaches	0.54	2	57	24.54^{***}

Note. $N = 61$; $^{***}p < 0.0001$, $^{**}p < 0.001$, $^{*}p < 0.01$.

Table 3
MANCOVA and ANCOVA of instructional approaches and 2-levels of scientific reasoning of post- and retention- of combustion achievement test scores

	Wilk's Λ	Univariate F		Post-hoc
		Post-test	Retention-test	
Instructional approaches	0.54^{***} (0.000)	45.86^{***}	4.71^{*}	Post: experimental group > conventional group (0.000) Retention: experimental group > conventional group (0.034)

$^{***}p < 0.0001$, $^{**}p < 0.001$, $^{*}p < 0.05$.

6.2. Scientific Reasoning Test (SRT)

Table 1 presents the descriptive statistics for the pre-, post-, and retention-SRT. The experimental group outperformed the conventional group in the post- and retention-SRT scores. Only experimental group students made significant progress from pre- to post-SRT ($T_{(\text{post–pre})} = 2.18$, $P = 0.037$).

One-factor MANCOVA showing that was conducted to examine the effects of instructional approaches and using post- and retention-SRT scores as the dependent measures, and pre-test scores as the covariate. Table 4 summarizes the results of the one-factor MANCOVA, instructional approaches (Wilk's $\Lambda = 0.95$, $p = 0.212$) did not reach a statistically significant effect on the performance of post- and retention-SRT.

6.3. Combustion Dependent Reasoning Test (CDRT)

Table 1 presents the descriptive statistics for the pre-, post-, and retention-test of the CDRT. The experimental group outperformed the conventional group in the post- and retention- of CDRT scores. The experimental group students made significant progress from pre- to post-CDRT ($T_{(\text{post–pre})} = 7.39$, $P = 0.000$), in contrast, the conventional group made significant progress from post to retention-CDRT ($T_{(\text{retention–post})} = 2.07$, $P = 0.048$).

One-factor MANCOVA was conducted to examine the effects of instructional approaches and using post- and retention-CDRT scores as the dependent measures, with pre-CDRT scores as the covariate. Table 5 summarizes the results of the one-factor MANCOVA, indicating that instructional approaches (Wilk's $\Lambda = 0.71$, $p = 0.000$) reach a statistically significant effect on the performance of post- and retention-CDRT. Therefore, the following main effect for the instructional approach was performed.

The univariate F (one-factor ANCOVA) was performed to independently examine the effect of the instructional approaches on post- and retention-CDRT. It indicated that the effects for instructional approaches on both post-CDRT scores ($F = 20.09$, $p = 0.000$) and retention-CDRT scores ($F = 11.94$, $p = 0.001$) were significant. Thus, the students' post- and retention-CDRT were significantly affected by the instructional approach. The post-hoc analysis for main effect suggests that the experimental group performed significantly better than conventional group (experimental group >conventional group, $p_{(\text{post})} = 0.000$, $p_{(\text{retention})} = 0.001$) on post-test and retention-test (Table 6).

Table 4
Multivariate analysis of covariance (MANCOVA) of post- and retention- of scientific reasoning test scores

Source of variance	Wilk's Λ	Hypothesis d.f.	Error d.f.	Multivariate F
Covariates				
Pre-test scores	0.53	2	57	25.00^{***}
Group memberships				
Instructional approaches	0.95	2	57	1.59

Note. $N = 61$; $^{***}p < 0.0001$, $^{**}p < 0.001$, $^{*}p < 0.01$.

Table 5
Multivariate analysis of covariance (MANCOVA) of post- and retention- of combustion dependent reasoning test scores

Source of variance	Wilk's Λ	Hypothesis d.f.	Error d.f.	Multivariate F
Covariates				
Pre-test scores	0.52	2	57	26.61^{***}
Group memberships				
Instructional approaches	0.71	2	57	11.44^{***}

Note. $N = 61$; $^{***}p < 0.0001$, $^{**}p < 0.001$, $^{*}p < 0.01$.

Table 6
MANCOVA and ANCOVA of instructional approaches and 2-Levels of scientific reasoning of post- and retention- of combustion dependent reasoning test scores

	Wilk's Λ	Univariate F		Post-hoc
		Post-test	Retention-test	
Instructional approaches	$0.71^{***}(0.000)$	20.09^{***}	11.94^{**}	Post: experimental group > conventional group (0.000) Retention: experimental group > conventional group (0.001)

$^{***}p < 0.0001$, $^{**}p < 0.001$, $^{*}p < 0.01$.

6.4. Web-based learning results

The experimental group student learning from web-based dual situated learning events was analyzed for two aspects: level of scientific reasoning and degree of conceptual change.

6.4.1. Level of scientific reasoning

Table 7 summarizes the number of different levels of scientific reasoning used by students before and after the web-based learning events. It indicates that more students use the Generativity (G) level before events than after events (frequency = $475_{(before)}$: $432_{(after)}$). After events, students use more higher level scientific reasoning than before events, such as Elaboration (EL) (frequency = $101_{(before)}$:$151_{(after)}$), and Justification (J) (frequency = $27_{(before)}$:$45_{(after)}$).

In order to measure the changes of students use of scientific reasoning before and after events, the progress (PG) or maintain-correct (MTC) or retrogression (RTG) categories (Fig. 5) were used. This clearly shows that students mainly use scientific reasoning at PG and MTC categories across most of the web-based learning events. The average percentage for PG across all the events is about 31.3%, a range from about 72% to 10%. The average percentage for MTC across all events is about 54.3%, with a range from about 83% and to 25%. The average percentage for RTG across all the events is about 14.4%, with a range from 45% to 0%.

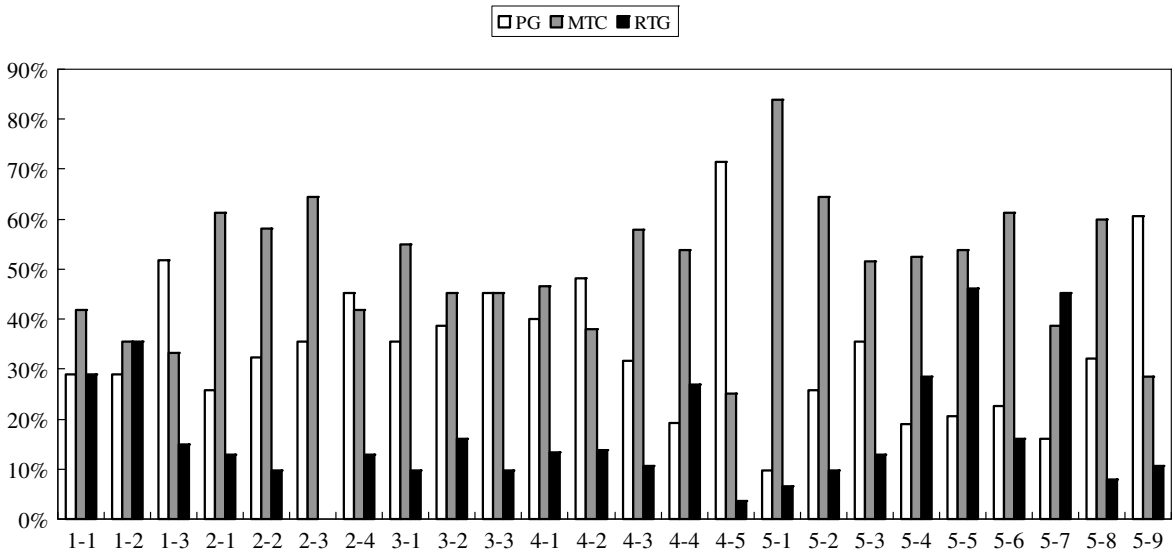
6.4.2. Degree of conceptual change

Table 8 (Fig. 6) summarizes the number and percentage of the degree of conceptual change before and after the web-based learning events. The nature of conceptual change was judged and classified into four categories according to the before and after answers: correct–correct, incorrect–correct, correct–incorrect, and incorrect–incorrect. Adding both correct–correct and incorrect–correct categories together yields the success rate of con-

Table 7
The number of students used of different level of scientific reasoning before and after the web-based learning events across all five topics

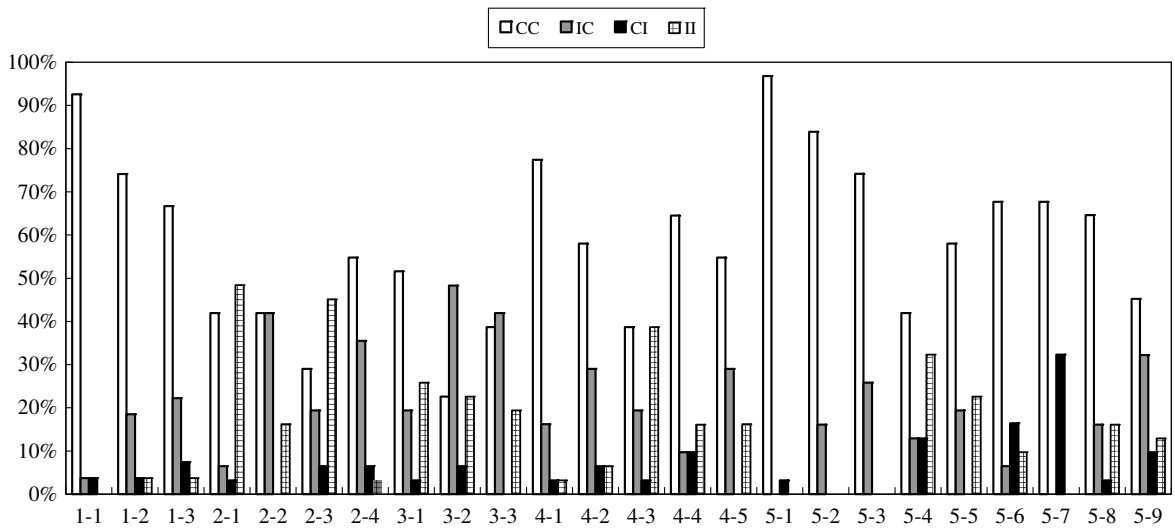
Before learning	After learning											
	N	G0	G1	G2	EL1	EL2	J1	J2	EX1	Total	χ^2	ω
N	65	11	49		14				1	140		
G0	14	40	43	1	12	1	5			116		
G1	25	17	228	7	51	2	16	2	1	349		
G2		1	4	1	3	1				10		
EL1	9	2	14	1	54	2	8			90		
EL2			1		3	5	2			11		
J1	1	1	9	2	1		11	1		26		
J2						1		0		1		
EX1					1				0	1		
Total	114	72	348	12	139	12	42	3	2	744	663.20^{***}	0.94^{***}

(1) χ^2: $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.
(2) ω: $^{*}0.1 \leqslant \omega < 0.3$, ω = small; $^{**}0.3 \leqslant \omega < 0.5$, ω = medium; $^{***}\omega \geqslant 0.5$, ω = large.



Note. RG = Progress; MTC = Maintain ; RTG = Retrogress

Fig. 5. Experimental group students' level of scientific reasoning across all the web-based dual situated learning events.



Note. CC = Correct-Correct; IC =Incorrect-Correct; CI = Correct-Incorrect; II = Incorrect-Incorrect

Fig. 6. Experimental groups' students' degree of conceptual change across all the web-based dual situated learning events.

ceptual change. Fig. 7 presents the success rate of conceptual change across all the learning events, showing that the success rate of conceptual change ranges from 75 to 100% for most of the events, although four events ranged around 50–60%.

7. Discussion and conclusions

This study reports an adaptive web learning project developed based on the Dual Situated Learning Model (DSLM) and scientific reasoning theories in order to promote elementary students' conceptual change and their scientific reasoning involving combustion. Our study makes a major step from previous web-based

Table 8
The number and percentage of the nature of conceptual change before and after the web-based learning events across five topics

	Correct–correct		Incorrect–correct		Correct–incorrect		Incorrect–incorrect		Total	
	N	%	*N*	%	*N*	%	*N*	%	*N*	%
Topic 1. Requirement of combustion										
Concept1	25	92.6	1	3.7	1	3.7	0	0	27	100
Concept2	20	74.1	5	18.5	1	3.7	1	3.7	27	100
Concept3	18	66.7	6	22.2	2	7.4	1	3.7	27	100
Topic 2. Oxygen										
Concept1	13	41.9	2	6.5	1	3.2	15	48.4	31	100
Concept2	13	41.9	13	41.9	0	0	5	16.1	31	100
Concept3	9	29.0	6	19.4	2	6.5	14	45.1	31	100
Concept4	17	54.8	11	35.5	2	6.5	1	3.2	31	100
Topic 3. Carbon Dioxide										
Concept1	16	51.6	6	19.4	1	3.2	8	25.8	31	100
Concept2	7	22.6	15	48.4	2	6.5	7	22.6	31	100
Concept3	12	38.7	13	41.9	0	0	6	19.4	31	100
Topic 4. Fire extinguish										
Concept1	24	77.4	5	16.1	1	3.2	1	3.2	31	100
Concept2	18	58.0	9	29.0	2	6.5	2	6.5	31	100
Concept3	12	38.7	6	19.4	1	3.2	12	38.7	31	100
Concept4	20	64.5	3	9.7	3	9.7	5	16.1	31	100
Concept5	17	54.8	9	29.0	0	0	5	16.1	31	100
Topic 5. Rustiness										
Concept1	30	96.8	0	0	1	3.2	0	0	31	100
Concept2	26	83.9	5	16.1	0	0	0	0	31	100
Concept3	23	74.2	8	25.8	0	0	0	0	31	100
Concept4	13	41.9	4	12.9	4	12.9	10	32.3	31	100
Concept5	18	58.1	6	19.4	0	0	7	22.6	31	100
Concept6	21	67.7	2	6.5	5	16.1	3	9.7	31	100
Concept7	21	67.7	0	0	10	32.3	0	0	31	100
Concept8	20	64.5	5	16.1	1	3.2	5	16.1	31	100
Concept9	14	45.2	10	32.3	3	9.7	4	12.9	31	100

instructional learning programs by incorporating well-developed theories and models of science education learning and pedagogy into a web learning program which has been shown to be on effective model in a traditional classroom (She, 2002, 2003, 2004a, 2004b). In addition, this SCCR also employed ideas from adaptivity web learning into the design of learning and our SSCR system also develops many unique functions such as junction, comparisons, correct answer, keyword to multipath, and frequency of correct answer to multipath for teachers to develop the web-learning content depending on the topics characteristics which make learning more efficient.

The one-factor MANCOVA indicated that the instructional approach has a significant effect on students' performance on post- and retention-test of CAT and CDRT. Post hoc analysis further suggests that the experimental group performed significantly better than the conventional group on both post-test and retention-test of CAT and CDRT. This demonstrates that SCCR web-based instruction is far more efficient than conventional instruction for promoting students' concepts of combustion and conceptual change related to combustion.

Interestingly, the one-factor MANCOVA result indicated that the type of instructional approach does not have a significant effect on students' performance on post- and retention-test of SRT. In short, the experimental group did not perform significantly better than the conventional group on the performance of post- and retention-SRT. However, the *T*-test shows that experimental group students made significant progress from pre- to post-SRT. The possible explanation 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 "combustion" unit purposely focused on broader

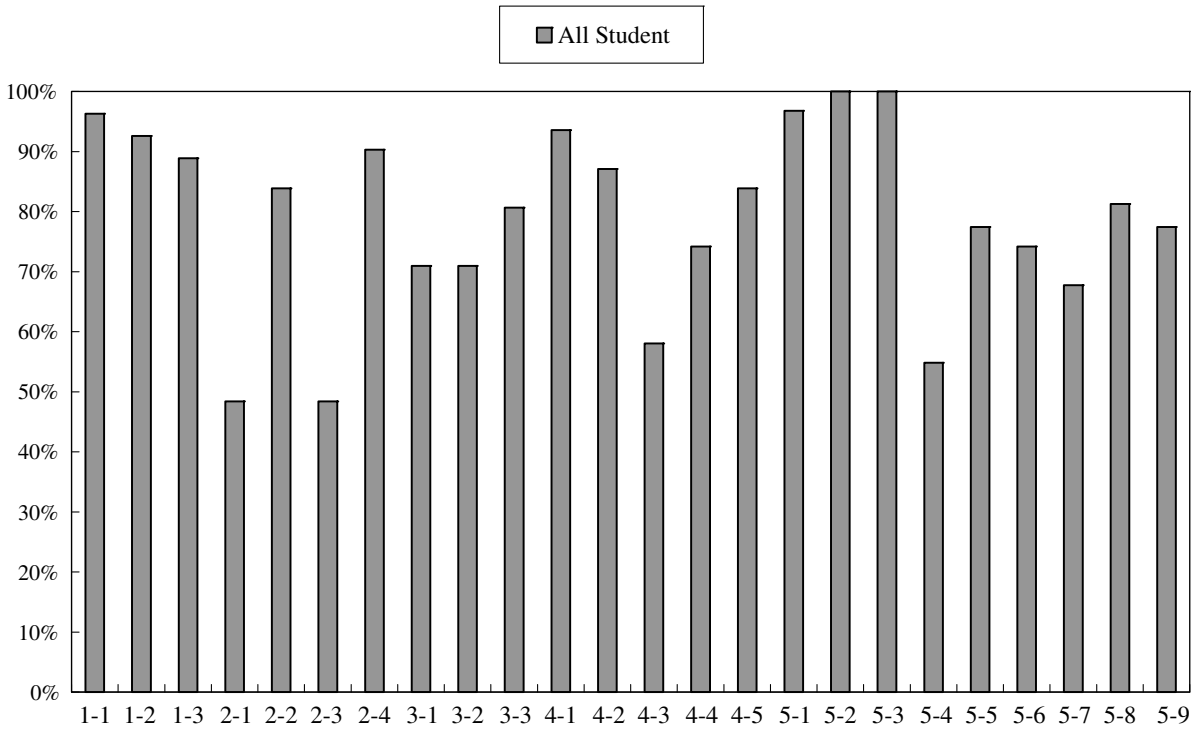


Fig. 7. Experimental group students' success rate of concept change across all the web-based dual situated learning events.

ability of scientific reasoning, which emphasizes the ability to formulate plans; analyze elements; evaluate alternative ideas; determine the consequence and hypothesis; identify variables; make inferences; make clarifications; make justifications; make conclusions based upon observation, experiment, and previous inference; process rules and general principles; judge the credibility of a source; distinguish between fact, opinion and reason judgment; weigh evidence and assess data; decide between competing theories. Moreover, the other possible explanation is that the SCCR web learning lasted for only five weeks, which may not be long enough to make a significant difference between the experimental and conventional group, although it is long enough for the experimental group to make significant progress on SRT from pre- to post-test.

The web learning events results indicated that the level of scientific reasoning used by experimental group students moved from Generativity (G) to Elaboration (EL) after learning from the program, and the use of Justification (J) also appeared more often after learning. This supports the result that experimental group students' scores of SRT made progress from pre- to post-, and CDRT made progress from pre-to post-test and then from post- to retention-test. Moreover, it further shows that experimental group students use of scientific reasoning are mainly in PG and MTC categories across most of all of the web-based learning events. The average percentage for the categories of PG, MTC, and RTG across all the events is about 31.3%, 54.3%, and 14.4%. These results demonstrate the effectiveness of specifically designing each dual situated learning event with scientific reasoning. It also demonstrates that students' scientific reasoning ability can be trained within a very short period as long as the design of learning events is good and carefully addresses the students' abilities.

The degree of conceptual change shows that the success rate for conceptual change ranged from 75% to 98% for most of the web-based leaning events, although four events ranged around 50–60%. This supports the result that experimental group students' scores on CDRT and CAT made significant progress from pre- to post- and then from post- to retention-test. It also demonstrates that well designed DSLM and scientific reasoning indeed promotes students conceptual change.

Many studies suggest there is no difference in test scores between web-based and traditional format courses, although students gain more confidence with computers in a web-based course (Leasure et al., 2000), others find that students enrolled in a web-based course perform worse than conventional students in the final exam

(Wang & Newlin, 2000), and others indicate an apparent increase in satisfaction on web-based courses (Katz & Yablon, 2002). One study suggested that computer assisted materials (CAIM) did not change students misconceptions related to photosynthesis, although they change students' comprehension and application levels of cognitive domain and attitudes (Cepni et al., 2006). The author argues that those studies can not effectively change students misconceptions or promote students science learning outcome because their instructional materials was not developed based on an effective conceptual change model or science learning model. The results of this study are quite encouraging and demonstrating that students' conceptual change can be promoted as well as their scientific reasoning ability after learning through a well designed and theory-based SCCR adaptive digital learning program.

The main limitation of this study is that the way we analyzed the level of students' scientific reasoning and conception change separately, therefore, it is hard to tell whether students' with higher level of scientific reasoning would hold correct scientific concepts as well. It is very likely often students with incorrect concepts may use higher level of scientific reasoning. Thus, it is highly recommended that future study may try to analyze both scientific concepts and scientific reasoning together, which might provide different viewpoint of the information.

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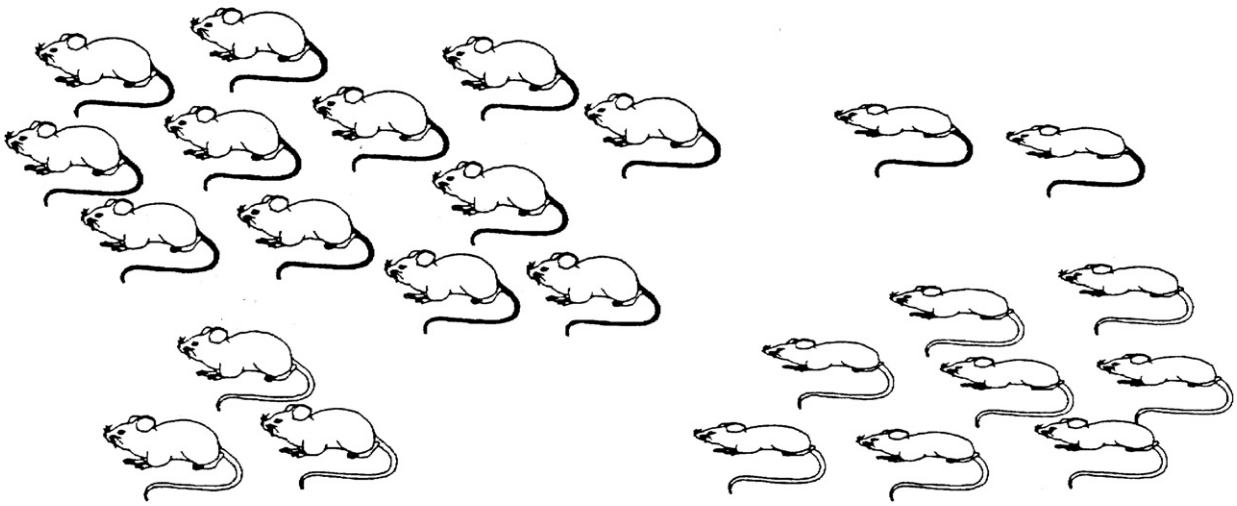
Appendix A. Scientific Reasoning Test (SRT) example question (Lawson, 2000)

1. 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.

1.1 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 B. Combustion Dependent Reasoning Test (CDRT) example question

1. Which one would rust quicker than the other? The wet nail in the bottle with pure oxygen or the wet nail in the bottle with air?
   (1) Wet nail in the bottle with pure oxygen would rust quicker than the other.
   (2) Wet nail in the bottle with air would rust quicker than the other.
   (3) Both of them would rust at the same speed.
   (4) It is hard to say which one would rust faster than the other one.

   1.1 Reasons
   (1) Rusting is due to the reaction with oxygen, and it more oxygen is available for the reaction then it would react faster.
   (2) There are many components in the air that could speed up the rusting.
   (3) The main reaction of rusting is to react with water and there is nothing to do with oxygen.
   (4) Air and oxygen are the same substance.

References

Anderson, J. R. (1990). Cognitive psychology and its implications (3rd ed.). New York: Freeman.

BouJaoude, S. B. (1991). A study of the nature of students' understandings about the concept of burning. *Journal of Research in Science Teaching, 28*(8), 689–704.

Brown, D. E. (1993). Refocusing core intuitions: A concretizing role for analogy in conceptual change. *Journal of Research in Science Teaching, 30*(10), 1273–1290.

Brusilovsky, P., & Anderson, J. (1998). ACT-R electronic bookshelf: An adaptive system for learning cognitive psychology on the Web. *WebNet 98 world conference of the WWW, Internet & Intranet, 7*(12), 92–97.

Brusilovsky, P. Eklund, J., & Schwarz, E. (1998). Web-based education for all: A tool for development adaptive courseware. In *Proceedings of Seventh International World Wide Web Conference* (pp. 291–300).

Carey, S. (1985). Conceptual change in childhood. Cambridge, MA: MIT Press.

Carro, R. M., Roberto, M., Estrella, P., & Pilar, R. (1999). Teaching tasks in an adaptive learning environment. Lawrence Erlbaum Associated, pp. 740–744.

Cepni, S., Tas, E., & Kose, S. (2006). The effects of computer-assisted material on students' cognitive levels, misconceptions and attitudes towards science. *Computers and Education, 46*(2), 192–205.

Chi, M. T. H., Slotta, J. D., & deLeeuw, N. (1994). From things to processes: A theory of conceptual change for learning science concepts. *Learning and Instruction, 4*, 27–43.

Clement, J. (1991). Nonformal reasoning in science: The use of analogies, extreme cases, and physical intuition. In J. Voss, D. Perkings, & J. Segal (Eds.), *Informal reasoning and education*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Clement, J. (1993). Using bridging analogies and anchoring intuitions to deal with students' preconceptions in physics. *Journal of Research in Science Teaching, 30*(10), 1241–1257.

Driver, R. (1985). Children's ideas in science. Philadelphia, PA: Open University Press.

Duit, R., & Treagust, D. F. (2003). Conceptual change: A powerful framework for improving science teaching and learning. *International Journal of Science Education, 25*, 671–688.

Eklund, J. & Brusilovsky, P. (1998). The value of adaptivity in hypermedia learning environments: A short review of empirical evidence. In second workshop on adaptive hypertext and hypermedia. In *Ninth ACM conference on hypertext and hypermedia* (pp. 13–19).

Hogan, K., Nastasi, B. K., & Pressley, M. (2000). Discourse patterns and collaborative scientific reasoning in peer and teacher-guided discussions. *Cognition and Instruction, 17*(4), 379–432.

Katz, Y. J., & Yablon, Y. B. (2002). Who is afraid of university Internet courses? *Education Media International, 39*, 69–73.

Lawson, A. E. (1978). Development and validation of the classroom test of formal reasoning. *Journal of Research in Science Teaching, 15*(1), 11–24.

Lawson, A. E. (2003). *The Neurological Basis of Learning. Development and Discovery*. London: Kluwer Academic Publishers.

Lawson, A. E. (2000). *Classroom test of scientific reasoning*. Arizona State University.

Lawson, A. E., & Thompson, L. (1988). Formal reasoning ability and misconception concerning genetics and natural selection. *Journal of Research in Science Teaching, 25*(9), 733–746.

Leasure, A. R., Davis, L., & Thievon, S. L. (2000). Comparison of student outcomes and preferences in a traditional vs. World Wide Web-based baccalaureate nursing research course. *Journal of Nursing Education, 39*, 149–154.

Mioduser, D., Nachmias, R., Oren, A., & Lahav, O. (2000). Web-based learning environments (WBLE) – Current technological and pedagogical state. *Journal of Research on Computing in Education, 33*(1), 55–76.

Posner, G. J., Strike, K. A., Hewson, P. W., & Gertzog, W. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*, 211–227.

Prieto, A. J. (1992). A method for translation of instruments to other languages. *Adult Education Quarterly, 43*(1), 1–14, Fall.

Schollum, B. (1982). Reaction. Learning in Science Project. Working Paper, p. 37.

She, H. C. (2002). Concepts of higher hierarchical level required more dual situational learning events for conceptual change: A study of students' conceptual changes on air pressure and buoyancy. *International Journal of Science Education, 24*(9), 981–996.

She, H. C. (2003). DSLM instructional approach to conceptual change involving thermal expansion. *Research in Science and Technological Education, 21*(1), 43–54.

She, H. C. (2004a). Facilitating changes in ninth grade students' understanding of dissolution and diffusion through DSLM instruction. *Research in Science Education, 34*(4), 503–526.

She, H. C. (2004b). Fostering "Radical" conceptual change through Dual Situated Learning Model. *Journal of Research in Science Teaching, 41*(2).

Steinberg, M. & Clement, J. (1997). Constructive model evolution in the study of electric circuits. In R. Abrams (Ed.), *Proceedings of the fourth international seminar on misconceptions research*. Santa Cruz, CA: The Meaningful Learning Research Group.

Tang, H. Y., She, H. C. & Lee, Y. M. (2005). The impact of DSLM instruction on middle school students' conceptual change involving mitosis and Meiosis. *A paper presented at the National Association for Research in Science Teaching 2005 World Conference*.

Thagard, P. (1992). *Conceptual revolutions*. Princeton, NJ: Princeton University Press.

Tuvi, I., & Nachmias, R. (2001). Current state of Web sites in science education – Focus on atomic structure. *Journal of Science Education and Technology, 10*, 293–303.

Veerman, A., Andriessen, J., & Kanselaar, G. (2000). Learning through synchronous electronic discussions. *Computers & Education, 34*(2–3), 1–22.

Vosniadou, S., & Brewer, W. (1987). Theories of knowledge restructuring in development. *Review of Educational Research, 57*(1), 51–67.

Wang, A. Y., & Newlin, M. H. (2000). Characteristics of students who enroll and succeed in psychology web-based classes. *Journal of Educational Psychology, 92*, 137–143.

Watson, J. R., Prieto, T., & Dillon, J. (1995). The effect of practical work on students' understanding of combustion. *Journal of Research in Science Teaching, 32*(5), 487–502.