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Investigation of the impact of two verbal instruction formats and prior knowledge on student learning in a simulation-based learning environment

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This study investigated how the format of verbal instructions in computer simulations and prior knowledge (PK) affected 8th graders' cognitive load (CL) level and achievement in a multimedia learning environment. Although PK was not found to significantly affect student performance and CL level, instruction format was found to impact both. Students who used narrative simulations were found to have a greater CL but also to perform better than those using simulations with on-screen text instructions. However, no significant differences were found between the cognitive efficiency of the two groups. The difficulty of the subject matter and limitations in students' prior content-related knowledge may have increased the intrinsic CL, such that students had difficulty in interpreting the content even if their PK was relatively high. The narrative instructions were more likely than the on-screen text information to reduce the extraneous CL and promote understanding of content. A new measure of cognitive processing is needed to identify the types of CL involved in e-learning and determine the properties of adequate e-learning materials. Finally, the findings of the study are discussed and suggestions for future studies and instructional design are provided.

Keywords: computer simulation; cognitive load; cognitive efficiency; multimedia learning

Introduction

In chemistry classes, chemical reactions and natural phenomena are described in textbooks and by classroom lecturers. Although hands-on activities have been designed to improve learning, students have found it difficult to understand chemical concepts using the aforementioned instructional strategies (de Jong & van Joolingen, 1998; Sanger & Greenbowe, 1997a, 1997b, 2000; Solsona, Izquierdo, & de Jong, 2003). Science educators often endorse an 'inquiry learning' approach in which students adopt scientific approaches and make their own discoveries toward developing intuitive and in-depth conceptual understanding (Mayer, 2004). Today's computers produce high-quality simulations and animations that have been found to be useful tools in facilitating effective inquiry and learning (Buesser & Ninck, 2004;

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Cowan, 2005; de Jong, 2006; McRoberts, 2005). However, a number of variables have been found to affect how well students grasp the information presented by these computer-based learning materials. Specifically, how information was encoded in the different modalities was found to affect student achievement (Mayer, 2001). Gredler (1996) argued that students' prior knowledge (PK) of both computer operations and content may impact their understanding of new material in a computer-supported learning environment. It is essential to understand how the aforementioned factors shape student learning in such environments. Accordingly, this study aims to investigate how PK and formats of verbal instruction impact how well middle school students learn oxidation–reduction principles in a computer-based multimedia learning environment designed specifically for this content.

Review of the relevant literature

Student difficulties in understanding chemical concepts following a course of instruction have previously been investigated, and the implications of these findings for classroom teaching and science curriculum development have been explored (Sanger & Greenbowe, 1997a, 1997b). Misconceptions are commonly held by students with respect to such matters as the definitions of oxidation and reduction, electron flow through either a solution or a salt bridge to complete the circuit, and the assignment of plus and minus signs to the electrodes. They frequently do not know whether the half-cell potential, or the reaction of water in a full cell, is absolute, or whether electrochemical cell potentials are independent of ion concentrations (Garnett & Treagust, 1992a, 1992b; Sanger & Greenbowe, 1997a, 1997b). Sanger and Greenbowe (1997a) argued that the use of multiple models to explain scientific behavior might contribute to students' confusion. Solsona et al. (2003) argued that students must learn to consider chemical changes at both the macroscopic and microscopic level if they are to understand them. Researchers have also found that some students were able to apply equations and formulas to solve quantitative exam questions without achieving a conceptual understanding of the chemical concepts (Liu, Andre, & Greenbowe, 2008; Sanger & Greenbowe, 1997a, 1997b). Factors such as establishing connections between concepts in physics and chemistry, revising textbooks, integrating alternate teaching strategies with the class instruction, and using computer simulations/animations to demonstrate chemical reactions at the molecular level would help students build better conceptual models in chemistry classes (Sanger & Greenbowe, 1997a, 1997b).

Gilbert and Priest (1997) defined a model as 'a representation of an idea, object, event, process, or system' (p. 751). Scientific models are used by scientists to explain data from past experiments and predict results of future experiments. A model in science is more than a simplified or replicated representation of a phenomenon; it can also be a collection of ideas that can be mentally examined to help one describe natural phenomena or processes (Giere, 1988; Kitcher, 1984). Visual representations were found to help students construct mental models of natural phenomena (Gilbert, Boulter, & Elmer, 2000; Gilbert & Priest, 1997; Renk, Branch, & Chang, 1993). A mental model represents an individual's view of the real world. It includes such items as how phenomena make sense, how things work, and how problems can be solved (Carroll & Olson, 1987; Holland, 1986; Johnson-Laird, 1993). Individuals can build scientific conceptual models based on their interpretation of visual information communicated *via* pictures, symbols, and other forms of imagery (Ballstaedt, Mandl, & Molitor, 1989; Saunders, 1994). However, a model constructed through processing new information can also interact with an individual's existing knowledge base (Seel & Strittmatter, 1989). Visual representations can provide clues that people can integrate with their PK, thereby helping them to find solutions to new problems (Paivio, 1991) and to consciously construct, correct, and solidify conceptual models.

Pictures are commonly used by science teachers to provide explanations and analogies of abstract theories or phenomena. However, some natural phenomena that are not observable with the naked eye may require one to mentally visualize their dynamic mechanisms. Today's computers, with their ever increasing computational power, have been found to be effective tools in helping the individuals construct models of natural phenomena by presenting information encoded in multimodal forms (Renk et al., 1993). Among the available computer-generated media, computer animations and computer simulations have been adopted most frequently by instructors and science educators to help students understand scientific theories and concepts. For instructional purposes, computer animations help students visualize processes or events while communicating abstract concepts and theories (Burke, Greenbowe, & Windschitl, 1998). Chemical reactions at the molecular level are much easier to comprehend when represented as a series of computer-generated dynamic images. Thus, computer animations give instructors a powerful tool for modeling students' learning of chemical reactions at the molecular level (Sanger, 2001).

Computer simulations accept input from a user and provide either verbal or visual output by applying rules for processing the input. They are particularly valuable tools because they demonstrate the changes that the models produce in virtual space before they are applied in the real world (Marks, 1982). De Jong and van Joolingen (1998, p. 180) defined a computer simulation as 'a program that contains a model of a system (natural or artificial; e.g. equipment) or a process'. Because they provide the opportunity to manipulate both a system and a process, computer simulations designed to teach scientific concepts can be seen as analogous to the models scientists use to solve scientific problems (Roschelle & Teasley, 1995). Instructional computer simulations are often used as tools in learning environments in which students can discover system properties and patterns by collecting and analyzing data or the information provided by computer programs (Kozma, 2003; de Jong, 2006). In chemistry, sets of computer animations are commonly used to represent the output of a computer simulation. For example, molecular-level chemical reactions can be observed through the creation of dynamic 'enlarged' molecules and atoms on a computer screen (Peters & Daiker, 1982). Such magnified representations help students visualize how systems operate during chemical reactions.

Although computer simulations have been widely adopted in science education, variables such as the nature of the content to be learned, students' PK, and the formats in which multimedia information are presented must be taken into consideration if computer simulations are to be used most effectively. Kozma and Russell (2005) argued that the effectiveness of multimedia learning in chemistry may vary depending on the nature of the chemical phenomena covered in the course. Mayer and Sims (1994) argued that when verbal explanations are unavailable and multimedia are used as a substitute, students must retrieve relevant knowledge from long-term memory if they are to effectively interpret the visual information provided by the computer programs. Under such conditions, students are likely to have difficulty in understanding this information if they lack sufficient PK. It has been argued that in chemical education students must develop the knowledge and skills necessary to comprehend chemical reactions that are presented at the molecular, macroscopic, and symbolic levels (Johnston, 1982). Kozma (2003) found that novices (college students) were likely to use surface/material features whereas expert chemists tended to use more fundamental features or demographics to explain the findings from their experiments on chemical substances and reactions. He suggested that showing animations and illustrations of surface, molecular, and symbolic levels could help novices build scientific conceptual models of chemical reactions. However, further investigation is needed to determine whether students lacking sufficient PK can interpret such information.

Information is commonly encoded in different multimedia forms such as on-screen text, narration, static pictures, and animation. The visual information that people usually process while looking at a computer screen can be encoded in a variety of ways. Cognitive load (CL) theory (Sweller, 1994) suggests that the modality in which information is presented in a learning environment can affect a student's cognitive workload. Mayer (2001) argued that units of information encoded visually and verbally are processed through visual and verbal channels, respectively. On-screen text competes with pictures in the viewer's cognitive system because the two are processed through the same visual channel. This fact led Mayer (2001) to suggest that verbal information coded in a narrative format benefits students by reducing their cognitive workload while they are processing multimedia information. The reason is that narration is processed through the verbal channel, whereas pictorial information is processed through the visual channel. Kalyuga, Ayres, Chandler, and Sweller (2003) argued that the impact of multimedia on learning fades as the expertise of the learner increases. Thus, the format in which material is presented seems to interact with students' existing knowledge to affect their learning in multimedia learning environments.

To summarize, researchers have explored a variety of variables that can affect student learning in multimedia environments. The findings of these studies seem to imply that both information format and PK play an important role in affecting student achievement in multimedia learning. Also, different designs may be required for instructional multimedia for diverse purposes, and the effectiveness of multimedia may vary depending on the nature of the content. When computers are employed in education, these interwoven issues and variables can potentially make it more complicated to design and utilize effective instructional material. Thus, further research is needed if we are to understand how the aforementioned issues affect student learning in multimedia environments. This need led us to conduct an investigation of how the format of verbal instruction and PK impact student performance in a multimedia learning environment designed to facilitate understanding of the principles involved in oxidation–reduction reactions.

Methodology

Participants and design

A quasi-experimental design was utilized for the study. Because 'oxidation–reduction reactions' is one of the topics included in the 'Nature and Living Technologies' course for 7th grade students in Taiwan, eight classes with a total of 262 middle school students, typically 13- and 14-years old, were initially selected for the study.

Four classes were assigned as the rich media (RM) group to a rich media environment including both pictorial and narrative information; the other four classes were assigned as the simple media (SM) group to a simple media environment in which only visual information was presented. Students in the course learned basic principles of electrochemistry, such as the nature of electrolytes and the acid/base of everyday substances. To assess students' prior understanding of the content in this study, they were given a test on basic electrochemical concepts. In each experimental group, the students whose scores on this test fell in the top and bottom 27% of the distribution were identified as high (mean = 46.90, SD = 13.41) and low (mean = 8.13, SD = 4.44; $t = 22.125$, $p < 0.001$) on PK, respectively (Kelly, 1939). As a result, the RM group had 32 high- and 32 low-PK students, and the SM group had 33 high- and 33 low-PK students. Two middle school science teachers participated in the study as subject matter experts whose task was to validate the teaching materials and the test items for the overall instructional unit.

The design of the study was a 2 × 2 between-groups factorial with presentation format (RM/SM) and PK (high/low) as the independent variables. To measure cognitive efficiency (CE), students' performance (*P*) and CL level were combined using Paas and van Merriënboer's (1993) computational method. These three measures served as the dependent variables.

Instructional materials

The computer simulations developed for this study to teach oxidation–reduction were based on the related units in the course textbook. Four sets of computer simulations were used: 'conductivity of solutions,' 'oxygen and magnesium ions,' 'dissolving calcium chloride,' and 'electrolytes.' The dynamic nature of chemical reactions was illustrated by computer animation. The 'conductivity of solutions' simulation allows students to test the conductivity of solutions with various solutes, such as sugar, sodium chloride, alcohol, hydrochloride, and calcium carbon oxide (see Figure 1). The volume of the solution can be manipulated so students can see whether changing it affects the solution's conductivity.

The 'oxygen and magnesium ions' animation demonstrates the formation and structure of oxygen and magnesium ions (see Figure 2), and the 'dissolving calcium

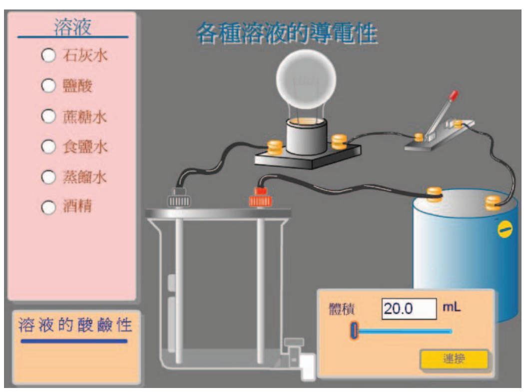

Figure 1. The 'conductivity of solutions' simulation screen.

chloride' animation shows the formation of calcium and chloride ions when calcium chloride is dissolved in water (see Figure 3). In the 'electrolytes' simulation, students are allowed to select different chemicals such as hydrogen chloride, sulfuric acid, sodium hydroxide, calcium hydroxide, sodium chloride, calcium chloride, and alcohol as solutes in water (see Figure 4). If the selected chemical is an electrolyte, the student can choose whether to represent the positive and negative ions as symbols or ball structures. The random movement of the particles is demonstrated for each chemical selected.

The RM group watched these simulations along with verbal explanations in a narrative text format, whereas the SM group watched the same simulations with verbal explanations encoded as on-screen text.

Measures

Two tests were developed to test student's knowledge of oxidation reactions before and after the course. The test items initially selected were examined by two science teachers to ensure face validity, and items were retained for the final tests only if both teachers agreed on their validity.

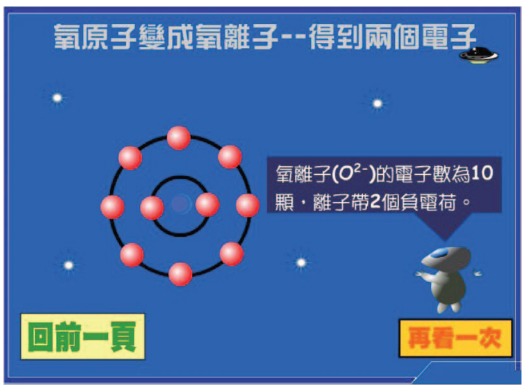

Figure 2. The 'oxygen and magnesium ions' simulation screen.

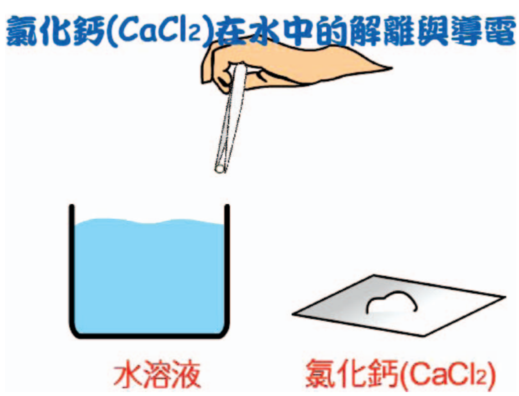

Figure 3. The 'dissolving calcium chloride' simulation screen.

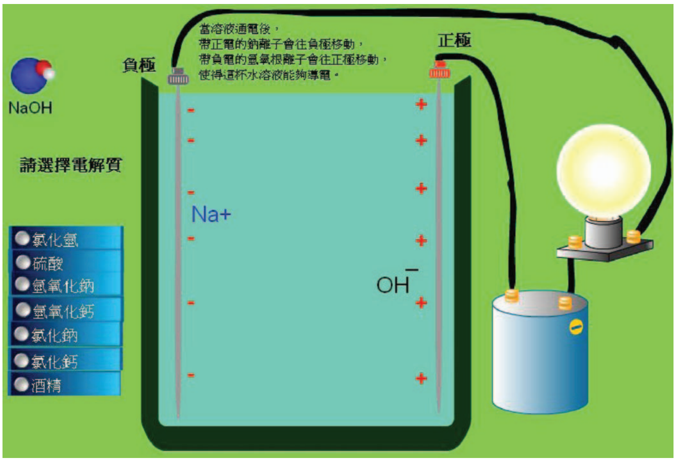

Figure 4. The 'electrolytes' simulation screen.

Prior knowledge test

This 13-item (5 true/false questions and 8 multiple-choice questions) test was developed to test students' PK of the principles of oxidation–reduction reactions. Cronbach's α, derived from the data collected for the experiment, is 0.769, indicating acceptable internal consistency for the items.

Achievement test

This 27-item (12 multiple-choice questions and 15 fill-in-blank questions) test was developed to test students' knowledge of oxidation–reduction acquired from the course. Cronbach's α, again obtained from the test data, is 0.794, showing acceptable internal consistency for the items.

Cognitive load question

A self-report question based on Pass and van Merriënboer's (1993) CL survey was developed to measure students' mental effort. Students were asked to rate the effort they invested in attempting to learn the assigned material from very, very low (1) to very, very high (9). The question was given to the participants' right after they finished the learning task.

Performance

Students' scores derived from the achievement test were used as their performance. The achievement test was composed of 12 multiple-choice questions and 15 fill-in-blank questions for determination of students' understanding of electrochemistry principles. Each multiple-choice question has four alternative answers. Students gained 3 scores if they selected the correct answer and scored 0 if selected the incorrect answer for the multiple-choice questions, whereas students gained 3 scores if filled in the correct answer and scored 0 if filled in the incorrect answer for the fill-in-blanks questions.

Procedure

The PK test was given to students 1 week before the class. For the class, both the science teachers and the students used the simulations as supportive instructional materials for learning the oxidation–reduction principles described in the textbook. The teachers first lectured on the topic and then the students spent 90 min for manipulating the computer simulations.

Handouts were given to the students as the tutorials to help them manipulate the simulations right after each introductory lecture. The first part of each handout contained instructions on how to set up an experiment in the simulation. The instructions on the handout were followed by guiding questions to give students hints and guidance to answer the questions by manipulating the simulations on the computer. Participants were required to answer these questions and perform the assigned tasks by analyzing the information provided by the computer-based environment.

The students completed the CL test questionnaire as soon as they finished the computer-based learning task. The achievement test was given 1 week after the class.

Results

Adapting Pass and van Merriënboer's (1993) measurement procedure, a CE score was calculated for each student by subtracting the mental effort (R) score from the standardized performance (P) score and dividing by the theoretical standard deviation: $CE = (P - R)/\sqrt{2}$. CE was rated as 'efficient' if CE was greater than 1; otherwise, it was rated as 'inefficient' (Kalyuga & Sweller, 2005).

A one-way analysis of variance was performed to assess the difference between the RM and SM groups on PK levels, but the result was nonsignificant, $F = 0.99$, $p = 0.32$. A significant positive correlation was found between scores on the PK and achievement tests, $r = 0.34$, $p < 0.01$. As a result, a general linear model (Maxwell & Delaney, 1993) with PK and experimental group (SM or RM) as predictors was applied to performance, CL level, and CE as dependent variables. We were primarily interested in the effect of the interaction between PK and multimedia presentation format on the effectiveness of students' learning.

The impact of students' prior knowledge and media format on student performance

No significant interaction on student performance was found between media format and PK, $F = 0.37$, $p = 0.55$. Although low PK group had a higher mean achievement score than high PK group, there were no significant differences between the achievement scores of the high and low PK groups, $F = 0.02$, $p = 0.89$ (see Table 1). However, significant differences were found between the groups using the different computer simulations, $F = 4.08$, $p = 0.046$ (see Table 2).

The principles of electrochemistry, especially electrical charges and the reactions among particles such as ions and molecules, were totally new to the participants. This conclusion also applies to the concepts on the PK test (such as the conductivity of various aqueous solutions), which focused on the very basic electrochemical principles that students are likely to see manifested in everyday life. Moreover, the material likely to be presented in simulation-based learning environments is apt to be difficult for students regardless of their PK. The aforementioned issues might have contributed to the relatively small differences found in the performance of the two PK groups, specifically their inability to connect this knowledge with the class content. The RM group used computer simulations supplemented by narrative verbal explanations to minimize the redundancy effect, thereby decreasing the extraneous CL. These narrative instructions may have provided students in the RM group with more supportive information about the electrochemical principles than was available to the SM group, thereby leading to the superior performance of the RM group.

The effect of prior knowledge and media format on cognitive load

The general linear model revealed no significant interaction between PK and media format on CL, $F = 0.48$, $p = 0.49$. Also, there were no significant differences between the CLs of the high- and low-PK groups, $F = 1.14$, $p = 0.29$ (see Table 1). However, Table 2 shows a significant difference between the two groups that used different computer simulation formats, $F = 4.58$, $p = 0.034$. Students in the RM group reported higher CL ($M = 5.27$, SD = 1.60) than did students in the SM group ($M = 4.73$, SD = 1.67).

Mayer (2001) proposed replacing redundant printed text with narrative verbal explanation in multimedia learning to avoid the redundancy effect that can occur when two verbal information formats present the same content. However, the results of this study reveal no differences between the CL levels of the two PK groups. As discussed earlier, it is likely that the content was so difficult that even the high-knowledge group might not have had sufficient PK to make sense of the class content. As a result, both knowledge groups had to invest a relatively large amount of mental effort in accomplishing the learning task.

Table 1. Mean scores on student performance, cognitive load, and cognitive efficiency as a function of prior knowledge level, with prior knowledge scores controlled.

	M (SD)			
	High PK	Low PK	*F*	*p*
Performance	31.14 (12.02)	55.91 (20.50)	0.02	0.89
Cognitive load	5.61 (1.32)	4.38 (1.73)	1.14	0.29
Cognitive efficiency	−0.68 (0.74)	0.68 (1.17)	0.66	0.42

Criterion α for significance = 0.05.
High PK, High prior knowledge; Low PK, Low prior knowledge.

Table 2. Mean scores on student performance, cognitive load, and cognitive efficiency as a function of media format, with prior knowledge scores controlled.

	M (SD)			
	RM	SM	*F*	*p*
Performance	46.89 (22.65)	40.26 (18.55)	4.08	0.046
Cognitive load	5.27 (1.60)	4.73 (1.67)	4.58	0.034
Cognitive efficiency	−0.0044 (1.29)	0.0043 (1.10)	0.13	0.72

Criterion α for significance = 0.05.
RM, Rich media; SM, Simple media.

The findings also show that students using narrative simulation seemed to experience a greater CL than those who were not given narratives. Although the narrative verbal explanations were designed to reduce the extraneous CL, the RM group was not given the option to replay them. This finding suggests that supportive feedback seems to be essential for students' comprehension when the material presented in the class is foreign to them. In contrast to the RM group, the SM group was given opportunities to refer to the on-screen textual explanations when they encountered difficulty in understanding the content. Rollins and Hendricks (1980) argued that concurrent auditory information can be difficult to process and suggested displaying one of them visually. Because on-screen textual information was lacking for students who used simulations with narrated instructions/explanations, these students seemed to invest more mental effort in accomplishing the learning tasks than did the other students. Another possible explanation of these findings is that students in the RM group invested more mental effort in determining the meaning of the simulations. In other words, students using narrative simulation performed better than those who used simulations with on-screen instructions because they were more likely to invest the mental effort needed to determine the meaning of the class material.

The impact of prior knowledge and media format on cognitive efficiency

The interaction between PK and media format was found to have no significant effect on CE, $F = 0.654$, $p = 0.42$. Also, there were no significant differences in CE between the high- and low-PK groups, $F = 0.66$, $p = 0.42$, or between the RM and SM groups, $F = 0.13$, $p = 0.72$ (see Tables 1 and 2). However, the results seemed to indicate a flooring effect on the participants' CE for the learning tasks (see Tables 1 and 2).

Sweller (1994) argued that the difficulty of the subject matter and PK are the factors that determine intrinsic CL. As mentioned earlier, the content in the present study was new to the participants; therefore, the intrinsic CL caused by the difficulty of the material could have been high for both high- and low-knowledge participants, especially because the knowledge that students brought with them to the class for determining the meaning of the incoming information was limited. The high intrinsic of the learning tasks might also result in the participants' low CE. However, the overall results show that the RM group not only performed better than the SM group, but that they also invested more mental effort to accomplish the simulation-based learning tasks. Because the CE was derived from the difference between student performance and CL level, it is not surprising that the RM group did not demonstrate more CE than the SM group with the raise on both performance and CL level.

Discussion

In the semester prior to the study, the students had been introduced to the basic principles regarding the conductivity of solutions created by dissolving a variety of commonly used solutes, such as sugar, salt, and soda in water. The PK test tested students' understanding regarding the aforementioned learning content. Although the high PK group performed significantly better than the low PK group on the PK test, students' PK of the subject matter in this study was limited to the macroscopic or surface level of chemical reactions. The simulations used in the study were designed to help students understand the molecular-level process of hydrolysis, which involves interactions among different ions. The participants' prior understanding of the macroscopic-level chemical reactions might not have been enough to enable them to discover the meaning of chemical reactions at the molecular level. Therefore, the difficulty level of the content and students' insufficient prior understanding were likely to have increased the intrinsic CL of the learning tasks (Sweller, 1994) and thereby resulted in the lack of a difference in the performance of the students coming to the class with different levels of PK.

Johnstone (1982) argued that students need to understand chemical processes at multiple levels – macroscopic, molecular, and symbolic – to build conceptual models of chemical reactions. However, the use of both symbolic and molecular levels of representation in constructing mental models from the on-screen scenarios presented in computer simulations may require a great deal of mental effort. The complexity of the visual presentations might have increased the CL and thus hindered learning, irrespective of how the information was formatted.

The findings showed, instead, that the format of the simulations was the main factor influencing student understanding of the content. Recall that students using narrative simulations performed better than those using simulations with on-screen textual instructions. In conformance with Mayer's (2001) redundancy principle, the narration used in the computer simulations was designed to reduce extraneous CL. However, the results show that although the RM group invested more mental effort in carrying out the learning tasks, they demonstrated no greater CE than did the SM group. It is possible that the RM group invested more of their mental effort in discovering the meaning of the visual representations with the assistance of the narration and for that reason performed better than the SM group. According to Sweller's (1994) CL theory, total CL is assumed to be the sum of extraneous, intrinsic, and germane CL. Because of the participants' lack of relevant PK, the difficulty of the class content was likely to render the intrinsic CL constant for all the students. As a result, reducing the extraneous CL could have saved students' cognitive capacity for meaning determination (the germane load). Although the RM group experienced a higher CL than the SM group, the superiority of the RM group's performance seems to indicate that the reduction of the extraneous CL by the use of narrative simulation might have lead students in the RM group to primarily invest their mental effort in meaning determination (the germane load).

In this study, the participants were not restricted on their exposure time during the learning tasks, the complexity of the visual representations might have also affected the time students spent on using the simulations. Future studies should investigate how exposure time compensates the high level of intrinsic CL caused by the learning material. Meanwhile, researchers have argued that the learners' PK should be taken into consideration when giving control of the learning pace in multimedia learning environments (Clark & Mayer, 2008). In this study, high PK group was not given the control for replaying the narrations in the simulation. How learner control on the pace of multimedia information affects learners' performance as well as their CE also worth further investigations. In addition, because we cannot identify what type of CL the students experienced, and when and how they acquired it during the class activities, these retrospective findings are the only resources available for reaching conclusions about the impact of the verbal format on student understanding in multimedia learning. A new approach, such as the use of eye-tracking technology, might help researchers acquire information in real-time about students' cognitive activity and how they invest their mental effort in learning tasks to build mental models of the learning content (Wickens & Hollands, 1999). This information, in turn, would further our understanding of how media formats affect student performance in multimedia learning environments.

Conclusion

This study investigated how the format of verbal instruction/explanation in computer simulations and students' PK affect learning. No significant interactions were found between media format and PK on student performance, nor were there any significant differences in the performance of groups high and low on PK of topics covered in the class. However, there was evidence suggesting that the narrative instructions and explanations incorporated in the computer simulations engaged the students in mental effort to determine the meaning of the class content, which resulted in improved performance. Therefore, we conclude that to achieve effective multimedia learning, one should evaluate learning outcomes with respect not only to test results, but also to the cognitive processes employed in dealing with multimedia information. Future multimedia studies could vary content difficulty to better gauge the impact of intrinsic CL on the effective use of instructional multimedia. In addition, a more objective and non-intrusive method for identifying different types and levels of CL would be beneficial in understanding which particular attributes of multimedia presentations really contribute to effective learning. Different formats of media presentation should be carefully developed and geared to the student's PK as a way to reduce CL and promote the understanding of concepts in multimedia learning environments.

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