Chapter 11
The Roles of Multimedia in the Teaching and Learning of the Triplet Relationship in Chemistry

Mei-Hung Chiu and Hsin-Kai Wu

Abstract Ever since Johnstone (1993) addressed the three levels of chemistry (symbolic, macro, and microscopic or so called submicro currently), many studies investigate how multimedia could support constructing, developing, and evaluating students' mental representations of chemistry at the three levels. This chapter focuses on how multimedia could enhance chemistry learning of the triplet relationship and discusses theories and empirical studies from the following perspectives: (1) multimedia as a modeling tool (discussing multiple representations and mental models in learning and teaching chemistry), (2) multimedia as a learning tool (introducing tools such as 4M:Chem, eChem, and ChemSence), (3) multimedia as an assessment tool (such as presenting computerized two-tier diagnostic instruments), and (4) multimedia as an instructional tool (linking findings of students' mental representations to the development of teachers' pedagogical content knowledge in chemistry). Implications for chemical education are discussed in terms of theoretical and practical approaches.

Introduction

Ever since Johnstone (1993) addressed the three levels of chemistry (symbolic, macro, and microscopic, called submicro currently), many studies have investigated how multimedia could support the construction, development, and evaluation of students' mental representations of chemistry at the three levels. The studies in the previous chapters mention that the representations of the macro–submicro–symbolic relationship play important roles in chemical concept learning.

This chapter draws attention to the role of multimedia in learning, teaching, and assessing chemical education. In particular, this chapter focuses on how multimedia can enhance chemistry learning of the relationship between the symbolic, macro, submicro levels of chemistry and discusses theories and empirical studies from the following perspectives: (1) multimedia as a representational modeling tool

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(discussing multiple representations and mental models in learning and teaching chemistry), (2) multimedia as a learning tool (introducing tools such as 4M:Chem, ChemSense, Molecular Workbench, and Connected Chemistry), (3) multimedia as an assessment tool (for example, presenting computerized two-tier diagnostic instruments), and (4) multimedia as an instructional tool (linking findings of students' mental representations to the development of teachers' pedagogical content knowledge in chemistry). It concludes with a discussion of the implications for chemical education, which are considered in terms of theoretical and practical approaches.

Multimedia as a Modeling Tool

Representations are ways to express phenomena, objects, events, abstract concepts, ideas, processes, mechanisms, and even systems. They have various or alternative purposes to *re*-present the real, hypothetical, or imaginative entity, regardless of its nature. Along with the different purposes of representations are different formats for depicting an entity. For instance, ethanol can be expressed as C_2H_5OH to show its nature, C_2H_6O to show its components, or its structure. However, things become more complex when we investigate the molecular structures in 3D to form an internal representation and then manipulate it mentally (such as deciding C_2H_5OH is an organic compound, stereo-isomers). In addition, the nature of scientific concepts per se (having a dynamic, abstract, complicated, and nonobservable nature) makes learning chemistry conceptually difficult (Wandersee, Mintzes, & Novak, 1994).

Craik (1943), the pioneer of mental models, depicts a mental model as a kind of dynamic representation or simulation of the world from which one can make inferences, generate actions, or relate symbols to the world. Johnson-Laird (1983, p. 470) commented that a primary source of mental representations is perception. Internal representations may encode relatively superficial features of the world. Human's phenomenological experience of the world is a result of natural selection. The vast range of mental models must be constructed by finite means—using primitive symbols and the basic processes that operate on the symbols. Vosniadou and Brewer (1992) consider that mental models are dynamic structures that are formed while answering questions or solving problems or when confronted by some situation. Gilbert, Boutler, and Elmer (2000) point out that the construction of mental models and the presentation of expressed models of scientific phenomena are central to understanding any phenomenon or body of information. Grosslight, Unger, and Jay (1991) state that students need more experience using models as intellectual tools and more time to reflect on the experience.

In science classrooms, it is essential to emphasize the role and purpose of scientific models and then provide examples of or opportunities to construct model-based cognitive tools for learning science (Treagust, Chittleborough, & Mamiala, 2002). Buckley and Boulter (2000) propose a framework that explains the interactive nature of the relationships among expressed models, mental models, and phenomena. In this way, the purpose of modeling and models in science education can be categorized and regarded as helping with understanding scientific contents, thinking logically and creatively, constructing a knowledge structure, communicating, cultivating problem-solving skills, and making evaluations in the course of scientific learning.

Going one step further with the interactive nature of mental models, modeling and models should be capable of forming a bridge between science education and technology in many ways (Gilbert et al., 2000). Hennessy, Deaney, and Ruthven (2006) advocate that multimedia simulation is considered one of the most powerful applications of information and communication technologies to science at present. Simulations are perceived to add value to learning activities, overcoming some of the constraints of regular classes. Gilbert (2007) claims that visualization, via multimedia, incorporates mental imagery, which is produced in the process of perceiving an object that is seen or touched, into a phenomenon. Model-based teaching and learning facilitate the construction of mental models through a recursive process of formation, use, version, and elaboration (Buckley, 1995; Buckley and Boulter, 2000). Therefore, multimedia is one of the tools that is considered to be effective in learning scientific concepts.

A study (Chan, 2002) conducted in the first author's research lab shows how one under discussion in this paper was designed to elaborate on the role of multimedia and multiple representations in learning scientific concepts and to investigate the effectiveness of dynamic representations on students' learning. Chan (2002) developed a computer-based set of dynamic analogies. The research investigated 53 eighth graders who were learning chemical equilibrium. The students were randomly assigned to three groups: control group (C); analogy and instruction group (A); and analogy, instruction, and animation with dynamic analogy group (D). Six target students were chosen from each group to be interviewed for their conceptual change via learning with model-based animation and dynamic analogy instruction. The design of the experiment is shown below (Fig. 11.1).

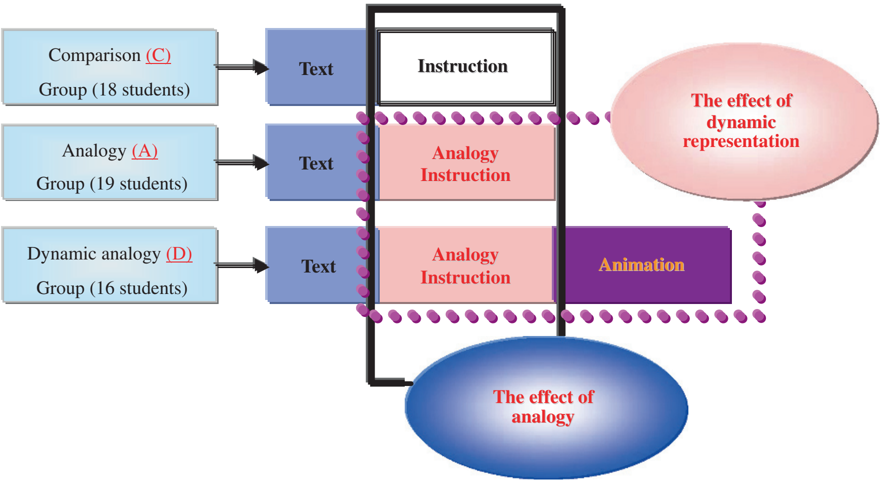


Fig. 11.1 The design of the experiment (Chan, 2002)

The target concept to be learned in the study was chemical equilibrium. The context is adding SCN^- into Fe^{3+} solution to show how the color changes over a period of time. The analogy used in the simulation was a ballroom containing some boys and then inviting girls to the stage. Over a period of time, there are a constant number of boys and girls. Which person is on the stage might be different over time but the platform keeps a maximum number of persons on the stage. In this analogy, it is implied that the girls represent the Fe^{3+} and the boys represent the SCN^- particles. At saturation situation point, the total amount of ions (Fe^{3+}, SCN^-, and $FeSCN^{2+}$) of the solution was kept the same. The students saw the animated dancing couples as well as observed how the analogy was matched with the representation of a chemical reaction, as shown in Fig. 11.2.

The results show that the students' performance in the three groups was not significantly different at the pretest (Fig. 11.3). However, the posttest revealed both analogy group A and dynamic analogy group D outperformed the control group C and that D group performed better than A group on the gained scores. The two groups did better than the control group on the posttest as well as on on the retaining test. Between analogy group A and dynamic analogy group D, there were significant differences on the pretest and the posttest.

From the qualitative analysis, Chan found that students' mental models could be categorized into three types: initial, synthetic, and scientific mental models (Fig. 11.4). The initial model refers to the static model, which had only solute dissolved into the solution and then stopped at the saturation point. The synthetic model refers to the coexistence of two models: the unidirectional model and

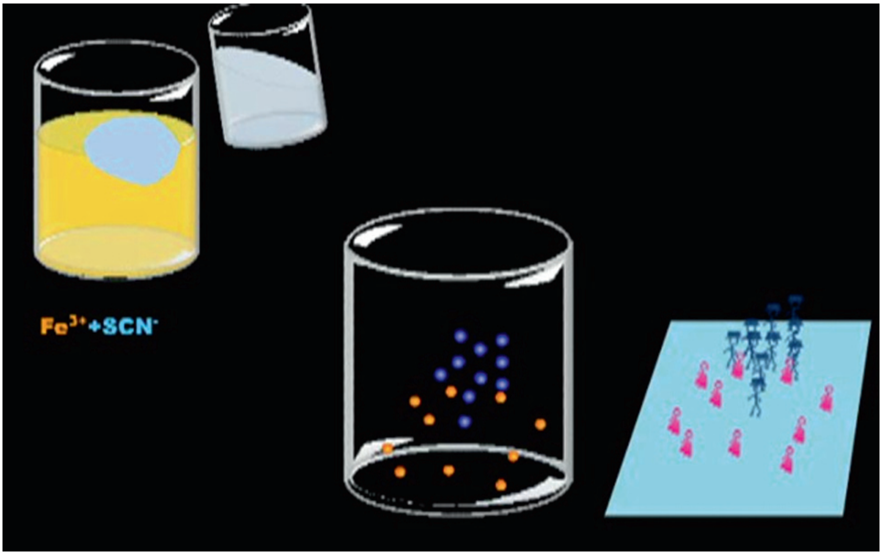
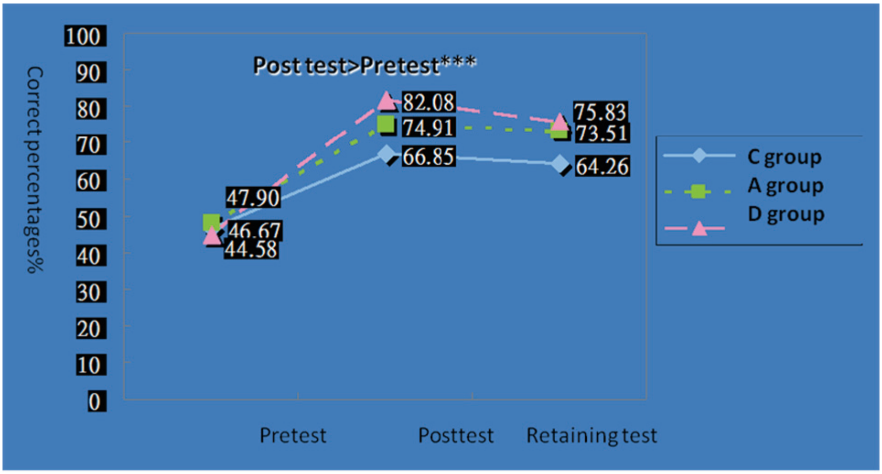


Fig. 11.2 The analogy representation in the study



*p < .1 ; **p < .05 ; ***p < .001

Fig. 11.3 The quantitative result of the study

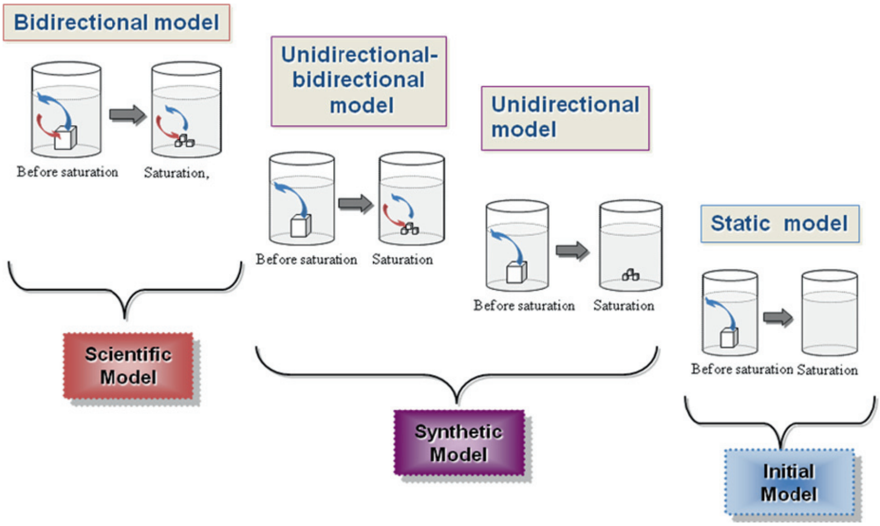


Fig. 11.4 The qualitative analyses of the students' mental models of chemical equilibrium

the unidirectional–bidirectional model. Finally, the scientific model refers to the bi-directional movement of the particles model before and at the saturation situation point. From the analysis, we found that the students benefited from the multiple representations activities that helped them construct correct mental models via the simulation activities presented to them.

Summary

The difficulty of learning science can be attributed to the nature of scientific concepts, which are complex and unobservable. The use of multimedia—dynamic, simulated, or analogical representations that depict the essence of the concepts in an attempt to match the scientific concepts with expressed or external models to help learners develop concepts or ideas about phenomenon—could play a role in explaining phenomena. It helps the imagination extend a repertoire of abstract knowledge that makes science meaningful to learners. In the example discussed above, we found that the students connected chains of the multiple representations of chemical equilibrium and a mix of their personal conceptions and analogies. The involvement of the multiple representations from personal experiences with the submicroscopic interactions among particles suggests that the dynamic analogies used in this study provide a channel for students to construct a model to be manipulated while expanding their conceptual repertoire of chemical equilibrium. In addition, we also found that not only did the multimedia allows the learners to see each individual particle motion but it also displays a collective motion of particles. This is an essential nature of particle motion. This also implies that students need even more opportunities and active scaffolding to make connections between their experiences and formal science concepts introduced at school.

Multimedia as a Learning Tool

This section focuses on how multimedia tools could support students' learning of the triplet symbolic–macro–submicro relationship. It has been well documented that students at the secondary school level have difficulty comprehending and translating submicro and symbolic representations (Keig & Rubba, 1993). Most of them are unable to represent chemical concepts at the submicro and symbolic levels (Krajcik, 1991), to visualize the interactive and dynamic nature of chemical process by viewing symbols and equations (Ben-Zvi, Eylon, & Silberstein, 1988), and to form three-dimensional (3D) images by visualizing two-dimensional (2D) structures (Tuckey, Selvaratnam, & Bradley, 1991). To ease students' difficulties, various multimedia tools have been designed to help students visualize imperceptible chemical entities (e.g., atoms and molecules) represented by chemical symbols and to develop their understanding of the triplet relationship (Ardac & Akaygun, 2004; Ealy, 2004; Pallant and Tinker, 2004; Stieff and Wilensky, 2003; Wu, Krajcik, & Soloway, 2001).

In this section, multimedia tools refer to computer-based systems that integrate multiple symbol systems (Salomon, 1979), such as text, audio, video, graph, and animation, to demonstrate chemical entities and/or processes at the macro, submicro, or symbolic levels. In the following, we review four multimedia tools—4M: Chem, ChemSense, Molecular Workbench, and Connected Chemistry—and use the design principles suggested by Wu and Shah (2004) to summarize how these tools support students in learning chemistry.

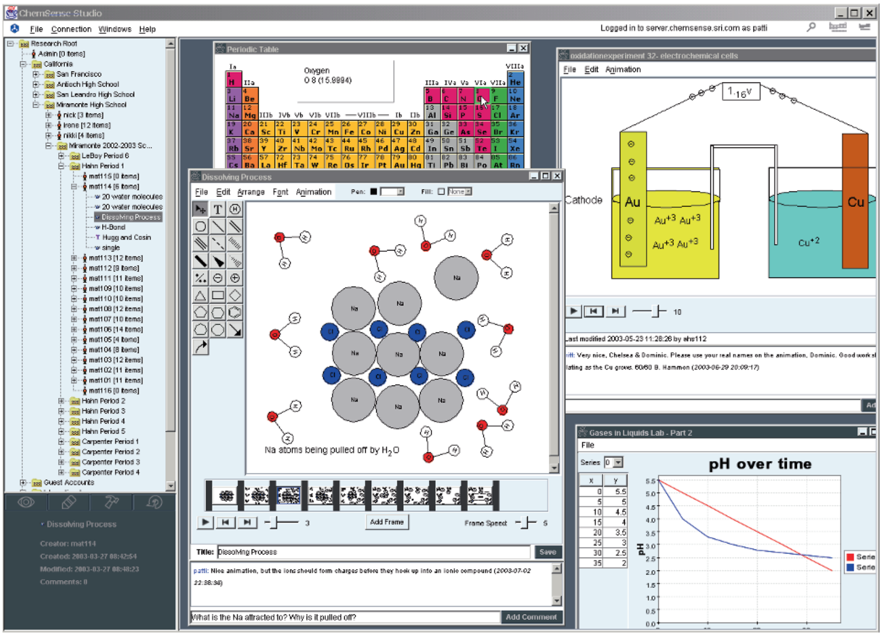
4M:Chem

MultiMedia and Mental Models (4M:Chem) developed by Kozma and Russell (Kozma & Russell, 1997; Kozma, Russell, Jones, Marx, & Davis, 1996) was designed to help students recognize relationships among chemical entities at different levels and comprehend representations by underlying concepts instead of surface features. For example, to present a chemical equilibrium process, $2NO_2(g)$ (brown)$\leftrightarrow$ $N_2O_4(g)$ (colorless), 4M:Chem uses a fourfold divided screen that displays a video segment showing the change of color within a enclosed tube under different temperatures, an equation with chemical formulas and symbols, an animation showing the interaction and movement of molecules at the microscopic level, and a graph showing how the concentrations of two gases changed over time. These four representations are shown simultaneously and linked to each other. A newer version of 4M:Chem, SMV:Chem (Synchronized Multiple Visualization of Chemistry), is distributed by John & Wiley.

When using 4M:Chem, students are encouraged to identify the referential links among the four representations. Kozma (2000) found that to make sense of these representations, students engaged in thoughtful discussions about concepts and established relationships among the macro, submicro, and symbolic levels. Additionally, this multimedia tool encourages students to construct a dynamic model of chemical processes, and their understanding of a phenomenon is shaped by the unique characteristics of a symbol system (Kozma, 2000; Salomon, 1979). For example, the animation-only group performed significantly better than the graph-only group on test items that involved the dynamic nature of chemical equilibrium. However, Kozma (2000) also showed that the group receiving all three media and the video-only group did not score significantly higher than the other groups. Processing multiple representations simultaneously may be highly demanding of cognitive resources (Cook, 2006). Reducing cognitive load by making visual and verbal information explicit and integrated is particularly critical for students who have low visualization skills (Wu and Shah, 2004).

ChemSense

To provide students with opportunities to practice various representational skills (e.g., translating and interpreting chemical representations) and help them represent chemical concepts at the submicro level, ChemSense (http://chemsense.org/), developed by SRI International, integrates features of modeling and multimedia tools (Fig. 11.5). This learning environment offers a set of tools such as a notepad, a spreadsheet, a graphing tool, and an animation tool (animator) to support students' hands-on investigations with Probeware (Novak & Gleason, 2000). Different from 4M:Chem, in which the videos, graphs, and animations are prebuilt and students cannot alter and create visual representations to meet their learning needs, ChemSense allows students to construct models, collect data, make graphs, and



Dissolving Process

Creator: mat114

Created: 2003-03-27 08:42:54

Modified: 2003-03-27 08:48:23

Comments: 0

Na atoms being pulled off by H_2O

Title: Dissolving Process

patti: Nice animation, but the ions should form charges before they hook up into an ionic compound (2003-07-02 22:38:38)

What is the Na attracted to? Why is it pulled off?

Last modified 2003-05-23 11:28:26 by ahs112

Very nice, Chelsea & Dominic. Please use your real names on the animation, Dominic. Good work

lating as the Cu grows. 60/60 B. Hammon (2003-06-29 20:09:17)

x	y
0	5.5
5	5
10	4.5
15	4
20	3.5
25	3
30	2.5
35	2

Fig. 11.5 The ChemSense environment contains a set of tools

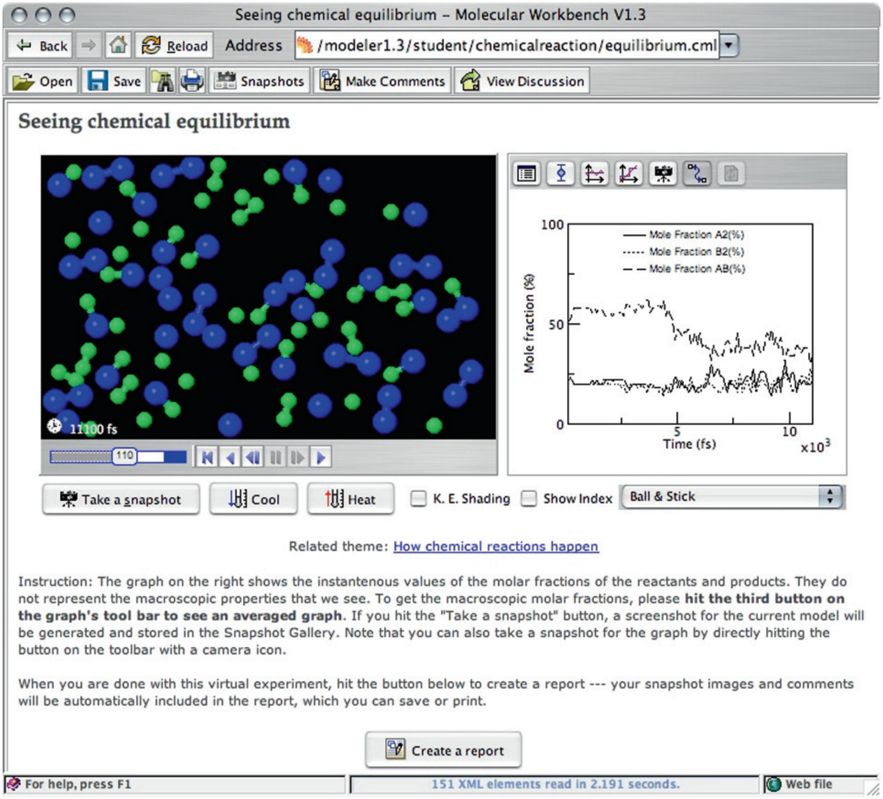
create animations (Schank and Kozma, 2002). Through generating models and illustrations of their understanding about submicro scale interactions, students focus their attention on molecular motions and move back and forth among the three levels. Additionally, while students can use most multimedia tools only individually, ChemSense provides a sharing tool that encourages students to construct representations collaboratively in a social context and to review each other's work by way of commentary.

Schank and Kozma (2002) found that with ChemSense, high school students demonstrated more representational skills such as creating drawings and using animations to externalize their thinking. They also developed a deeper understanding of the structure of a molecule and the interactive aspect of a chemical reaction. Additionally, through creating animations and models on ChemSense, students seemed more focused on the dynamic process of a chemical reaction and demonstrated significantly better performance when representing scientific phenomena at the submicro level (Schank and Kozma, 2002).

Molecular Workbench

Molecular Workbench (MW) is a two-dimensional molecular dynamics application written in Java and created by Concord Consortium (http://workbench.concord.org/). It provides multiple representations and molecular dynamic simulations that allow students to manipulate parameters, such as atomic/molecular mass, position, diameter, attractive force, and initial velocity of particles. Additionally, while the tools and interfaces embedded in 4M:Chem and ChemSense cannot be changed by teachers, MW provides teachers and curriculum developers with an easy-to-use authoring tool for designing user interfaces, creating guided activities, and revising and expanding the existing topics and learning activities on MW. This authoring capability that provides flexibility for teachers to create new simulations and activities can be viewed as an important characteristic of the second generation of multimedia and computer-based tools, which can also be seen in the TELS learning environment (http://www.telscenter.org/) and Connected Chemistry.

With MW, students can interact with the interface (Fig. 11.6) and visualize what happens to collections of interacting atoms and molecules under different conditions and rules (Xie & Tinker, 2006). MW can also help increase students' understanding of submicro scale phenomena through developing more scientifically accurate mental models of atoms and molecules (Pallant and Tinker, 2004). These models, in turn, could support students to effectively predict or explain chemical phenomena at different representational levels.



Seeing chemical equilibrium

Related theme: How chemical reactions happen

Instruction: The graph on the right shows the instantenous values of the molar fractions of the reactants and products. They do not represent the macroscopic properties that we see. To get the macroscopic molar fractions, please **hit the third button on the graph's tool bar to see an averaged graph**. If you hit the "Take a snapshot" button, a screenshot for the current model will be generated and stored in the Snapshot Gallery. Note that you can also take a snapshot for the graph by directly hitting the button on the toolbar with a camera icon.

When you are done with this virtual experiment, hit the button below to create a report --- your snapshot images and comments will be automatically included in the report, which you can save or print.

For help, press F1

151 XML elements read in 2.191 seconds.

Fig. 11.6 Molecular Workbench simulation of chemical equilibrium

In their initial studies, Pallant and Tinker (2004) found that after learning with the molecular dynamic models, 8th and 11th grade students were able to relate the difference in the state of matter to the motion and the arrangement of particles. They also used atomic or molecular interactions to describe or explain what they observed at the macroscopic level. Additionally, students' interview responses included fewer misconceptions, and they were able to transfer their understanding of phases of matter to new contexts. Therefore, Pallant and Tinker (2004) concluded that MW and its guided exploration activities could help students develop robust mental models of the states of matter and reason about atomic and molecular interactions at the submicro level.

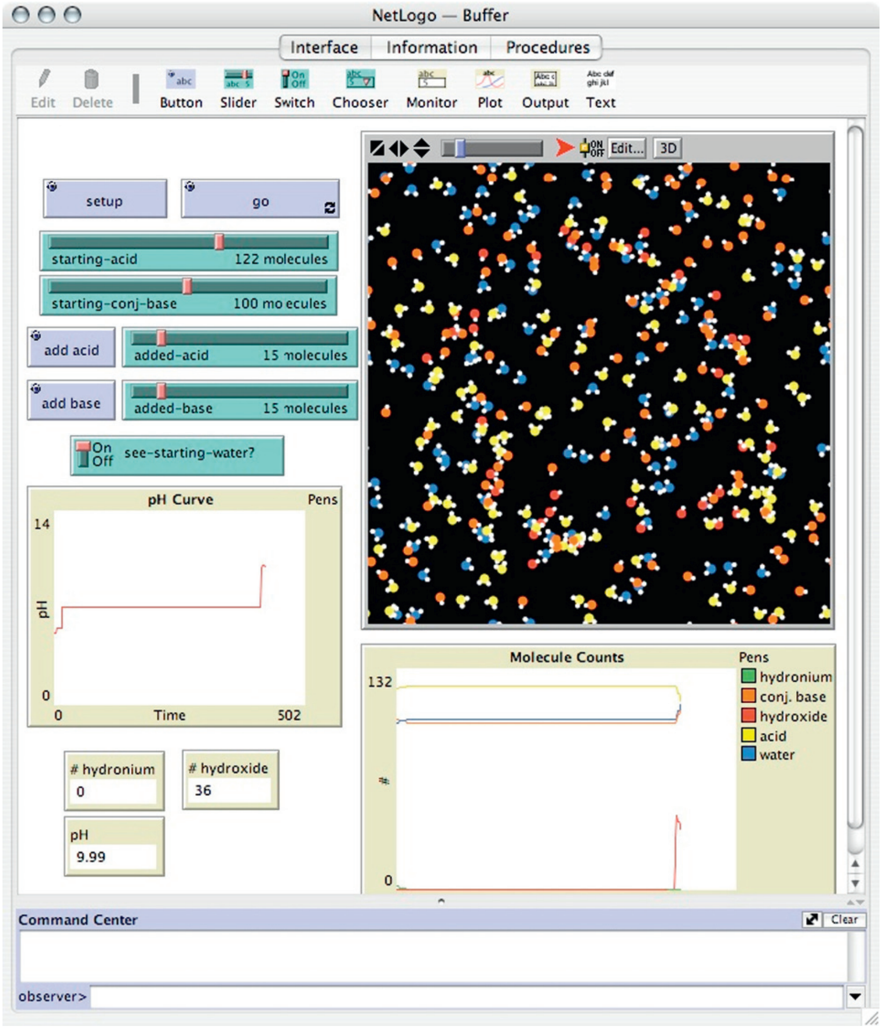
Connected Chemistry

Connected Chemistry (CC) is a modeling and simulation package implemented inside the NetLogo modeling environment (http://ccl.northwestern.edu/netlogo/ models/). Similar to Molecular Workbench, CC is created to present how a macroscopic event in chemistry results from molecular interactions at the submicro level. It allows students to explicitly observe the connections between the submicro, macro, and symbolic levels of chemistry and to explore the interactions by setting various parameters such as concentration, Ka/Kb value, temperature, and number of particles (Fig. 11.7). Taking a "glass box" approach (Wilensky, 1999), CC allows students not only to explore the behavior of prebuilt simulations designed to focus on some target concepts, but also to test and change the underlying rules that control the individual elements of a simulation. With CC, students can add and remove variables from the interface window, alter the NetLogo programming code to change the molecular behavior, and have "virtually unlimited opportunities to interact with and to manipulate a simulated molecular world to gain a deeper understanding of core chemistry concepts and phenomena" (Stieff and Wilensky, 2003, p. 285).

In Stieff and Wilensky (2003), six college students majoring in science were interviewed regarding concepts of chemical equilibrium. The study showed that during the interview, with the use of CC simulations, students demonstrated a dramatic change in conceptions, articulation, and problem solving. Their understanding of the dynamic nature of chemical equilibrium improved and they were able to explicitly link multiple representations and levels in order to gain a deeper understanding when using Connected Chemistry.

Summary

Based on a comprehensive review of chemistry education literature, Wu and Shah (2004) suggest five principles for designing multimedia tools that help students understand concepts and develop their representational skills (e.g., making translations among representations, creating representations to externalize thinking, and



starting-acid 122 molecules

starting-conj-base 100 molecules

added-acid 15 molecules

added-base 15 molecules

On Off see-starting-water?

hydronium 0

hydroxide 36

pH 9.99

Fig. 11.7 Connected Chemistry simulation of a buffer solution

visualizing the interactive and dynamic nature of chemical reactions): (1) provide multiple representations and descriptions, (2) make linked referential connections visible, (3) present the dynamic and interactive nature of chemistry, (4) promote the transformation between 2D and 3D, and (5) reduce cognitive load by making information explicit and integrating information for students.

All of the four multimedia tools reviewed in this section have features to support the first three principles; all of them include multiple and linked representations at the macro, submicro, and symbolic levels, such as texts, graphs, chemical symbols, animations, and videos. Not only do they present the dynamic and interactive nature of chemical phenomena, but they also allow students to explore and manipulate various parameters and to answer "what if" questions. The empirical studies also showed that all the tools can support students in understanding the triplet relationship through interactions with the tools. Yet, only Connected Chemistry offers a 3D view to promote the transformation between 2D and 3D representations, and not all tools address the issue of cognitive load. As the use of multimedia tools increases, students with limited spatial ability may be disadvantaged in learning chemistry, especially if the multimedia tools add another burden to their cognitive capabilities (Cook, 2006).

Multimedia as an Assessment Tool

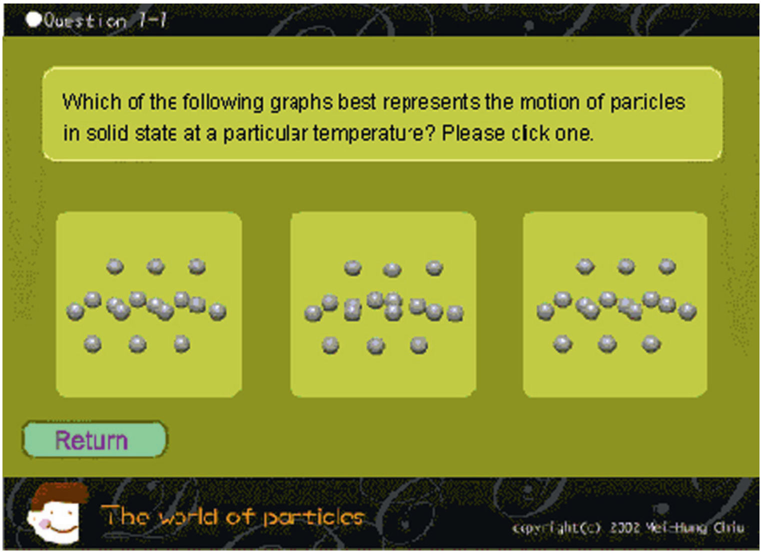
Learning is a complex cognitive activity, where the construction of knowledge requires integrating information from past experiences with the current context and instruction. In order for assessments to provide valid and reliable information for improving the teaching of science, the creators of multimedia tools must align learning trajectories with teaching. The increase in the use of information and communication technologies (ICT) allows educators to change their assessments of learning from those that are based on a traditional approach to ones based on an innovative approach.

Most of the cases we have looked at involve the use of multimedia for teaching and learning purposes. This section introduces two cases that use a similar format: a two-tier multiple-choice diagnostic instrument with multimedia to investigate the characteristics of students' conceptions about matter and particles. It also looks at the reasons for their responses to a particular problem.

Case 1

Chiu, Chiu, and Ho (2003) employed a two-tier testing technique proposed by Treagust (1988, 1995), extending this approach to a computerized simulation to obtain the knowledge structure of solid, liquid, and gas held by 39 10th graders (15–16-year-olds). The study involved two parts: first, they conducted open-ended and several semi-structured interviews. This part also involved drawing and the use of Styrofoam, followed by a paper-and-pencil test covering the arrangements and behaviors of particles in three states (solid, liquid, and gas). They gathered 40 students' explanations for each open-ended question in order to develop multiple-choice test items based on the learners' understanding of chemistry.

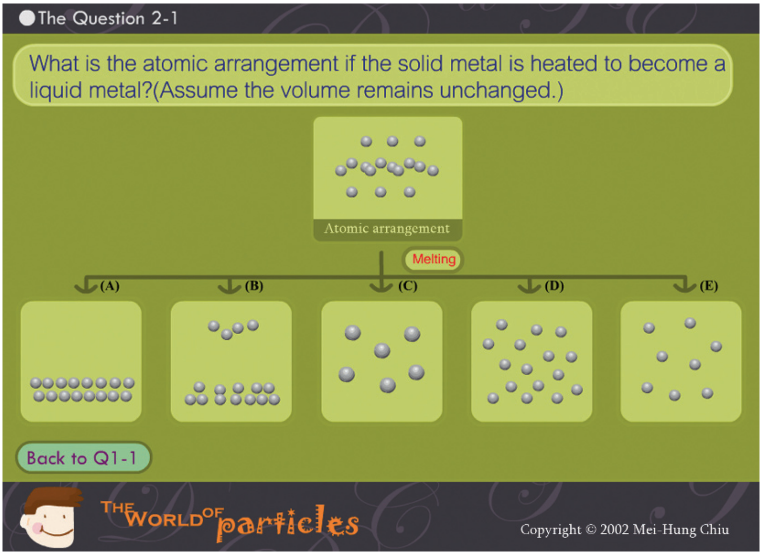
Second, using the results from the first stage, they designed a software program with dynamic representations (each choice was analyzed from the students' verbal or written explanations) to help them investigate what representative knowledge the learners had of chemistry concepts and how they explained the concepts. For instance, three types of students' conceptions about the motion of particles in solid state were found as shown in Fig. 11.8. To show the dynamic movements and



Question 1-1

Which of the following graphs best represents the motion of particles in solid state at a particular temperature? Please click one.

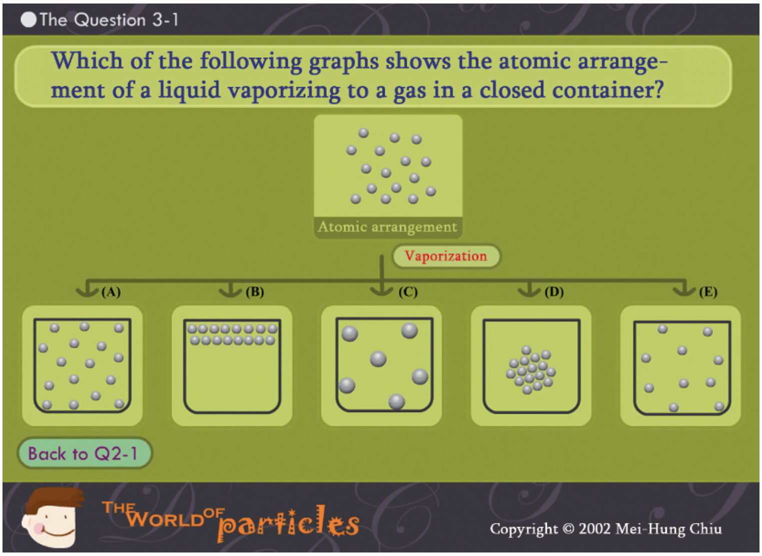
Fig. 11.8 Question 1-1 in the test
Note: Although these three pictorial representations look exactly the same, the particles actually acted differently in still motion than when vibrating.



The Question 2-1

What is the atomic arrangement if the solid metal is heated to become a liquid metal?(Assume the volume remains unchanged.)

Fig. 11.9 Question 2-1 in the test



The Question 3-1

Which of the following graphs shows the atomic arrangement of a liquid vaporizing to a gas in a closed container?

Fig. 11.10 Question 3-1 in the test

structures of particles, they used FLASH, a computer application tool, to present particles' motions in the three states. The students, who did not learn the concepts and never saw these types of dynamic test items before, were tested individually in a computer lab. In total, there were 12 test items validated by the chemists. Three sets of questions were designed as shown in Figs. 11.8, 11.9, and 11.10. Each set of questions focused on factual knowledge first and then prompted for the reason for the chosen item.

Set 1:
(1-1-1) Which of the following graphs best represents the motion of particles in solid state at a particular temperature? Please click one.
(1-1-2) The one you have chosen is shown below. Please explain your answer.
(1-2) Is there anything between the atoms? Why?
(1-3) If there is another solid metal that consists of the same materials at the same temperature, would the atoms be arranged in the same way? Why or why not?
Set 2:
(2-1-1) Which of the following graphs shows the atomic arrangement of a solid melting to form a liquid (assuming that the volume remains constant)? Why?
(2-1-2) Your choice is shown below. Please explain your answer.
(2-2-1) Which of the following graphs best represents the movement of particles in a liquid?
(2-2-2) Your choice is shown below. Please explain your answer.
Set 3:
(3-1-1) Which of the following graphs shows the atomic arrangement of a liquid vaporizing to form a gas in a closed container?

(3-1-2) Your choice is shown below. Please explain your answer.
(3-2-1) Which of the following graphs best represents the movement of particles in a gas?
(3-2-2) Your choice is shown below. Please explain your answer.

The main findings were,

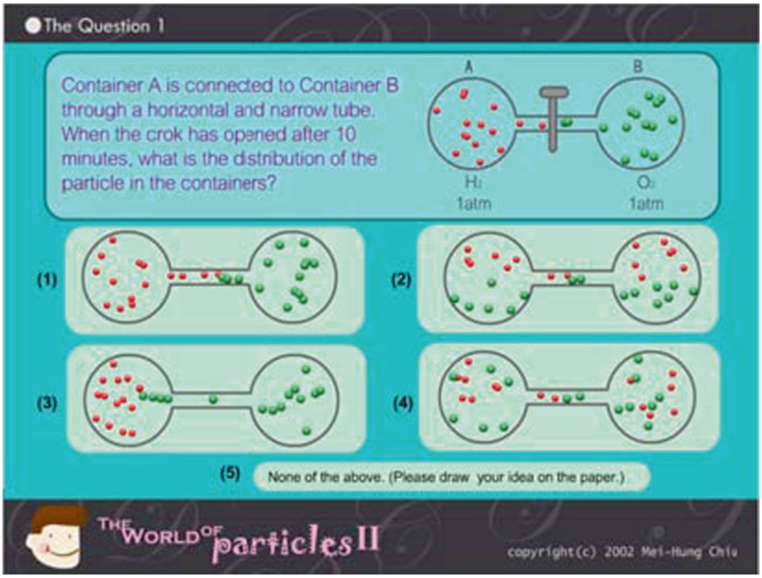
(1) The majority of students were able to provide correct answers to their choices about the atomic arrangement of solid and liquid.
(2) Six students thought that the particles stayed still at the solid state and 13 students thought that there was no space between the atoms. This result is consistent with Griffith & Preston (1992) study.
(3) Six students claimed that the attractive force decreases to allow the particles to fill in the entire container.
(4) Few students believed that the size of the particles increases when the temperature increases.
(5) Some students thought that atoms sink to the bottom of a container (choice A) when something changes from the solid to the liquid state, or some float on the surface (choice B).
(6) The students who chose the same figure that best represented their conception of particulates in gas often offered different explanations for their choices.

With the design of a two-tier test format, we served three purposes: First, we interviewed the students to obtain their explanations of the phenomena that were presented to them in a dynamic representational form. Second, we were able to transform their explanations into graphical representations in order to conduct a relatively large sample size of students. Third, the outcomes of their performance on the diagnostic items revealed their internal representation of knowledge about particles in three states. More importantly, we were able to make inferences about how the students linked their understanding of a macroscopic phenomenon in a context to a microscopic representation that they could hardly grasp using a traditional assessment instrument.

Based on this experience, a computerized program was further developed on related topics to examine how students solved problems in particle distribution with a different orientation of the apparatus and pressures of gas particles. Case 2 below states the major design and findings of this follow-up study.

Case 2

Liang and Chiu (2003) investigated what junior high (8th and 9th) students' mental models were when they confronted distribution problems with different amounts of pressure of gases and a different orientation of the apparatus. Participating in this study were 102 9th graders and 93 8th graders in Taipei. They were normally distributed into classes based on their academic ability. Each student was allotted one computer and 25 minutes for completing the test work. Six test items were

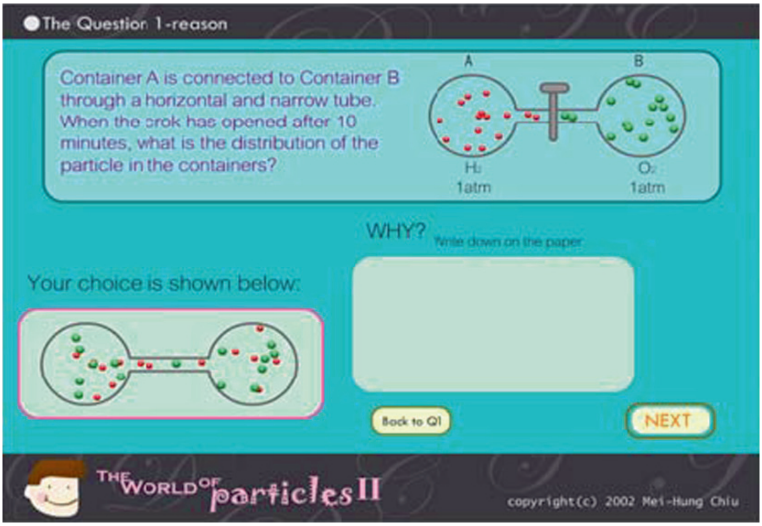


The Question 1

Container A is connected to Container B through a horizontal and narrow tube. When the crok has opened after 10 minutes, what is the distribution of the particle in the containers?

(5) None of the above. (Please draw your idea on the paper.)

Fig. 11.11 The first tier of Question 1



The Question 1-reason

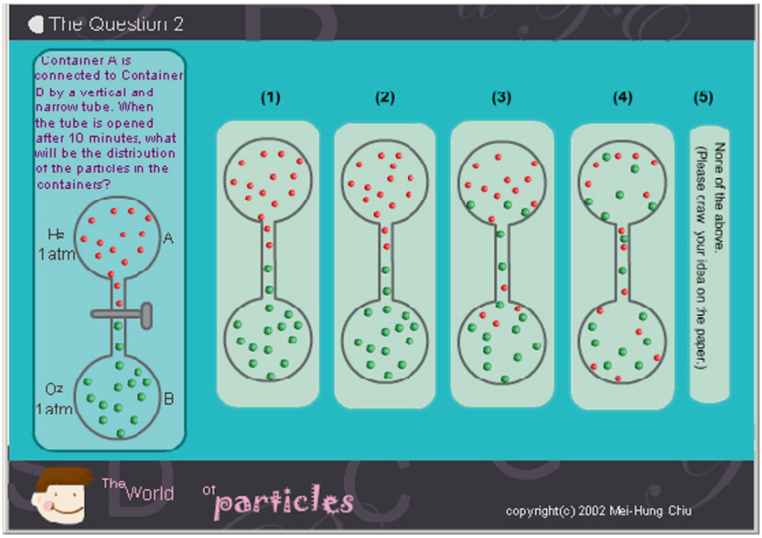
Container A is connected to Container B through a horizontal and narrow tube. When the crok has opened after 10 minutes, what is the distribution of the particle in the containers?

WHY? Write down on the paper

Your choice is shown below:

Fig. 11.12 The second tier of Question 1

developed and categorized into two sets based on the horizontal and vertical configuration of the apparatus (Figs. 11.11, 11.12, 11.13, 11.14, 11.15, 11.16, and 11.17). Students were asked to decide what would happen to the gases when the faucet connecting the two round containers was open and to provide the reasons for their choices.



The Question 2

Container A is connected to Container B by a vertical and narrow tube. When the tube is opened after 10 minutes, what will be the distribution of the particles in the containers?

None of the above. (Please draw your idea on the paper.)

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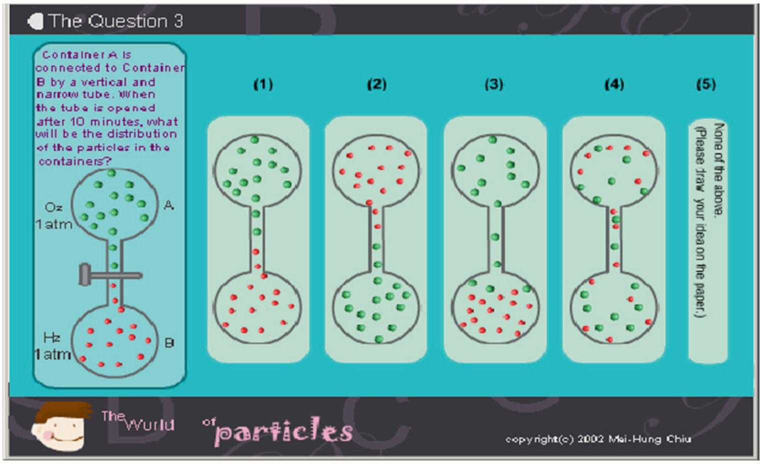
Fig. 11.13 The first tier of Question 2



The Question 3

Container A is connected to Container B by a vertical and narrow tube. When the tube is opened after 10 minutes, what will be the distribution of the particles in the containers?

None of the above. (Please draw your idea on the paper.)

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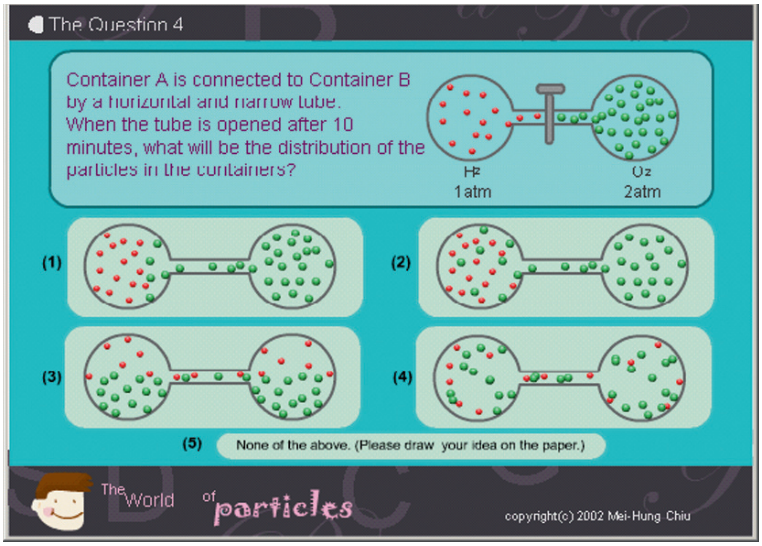
Fig. 11.14 The first tier of Question 3

The results revealed that only 26% of the ninth grade students answered all six questions correctly, whereas 20% of eighth graders answered all six questions correctly (Table 11.1). On average, the students performed better when the amount of gas pressure, regardless of whether the apparatus was set horizontally or vertically, was equal to the gases at different pressure situations. Concerning the effect of orientation of the apparatus, the result did not show salient differences in eighth and ninth grade students.

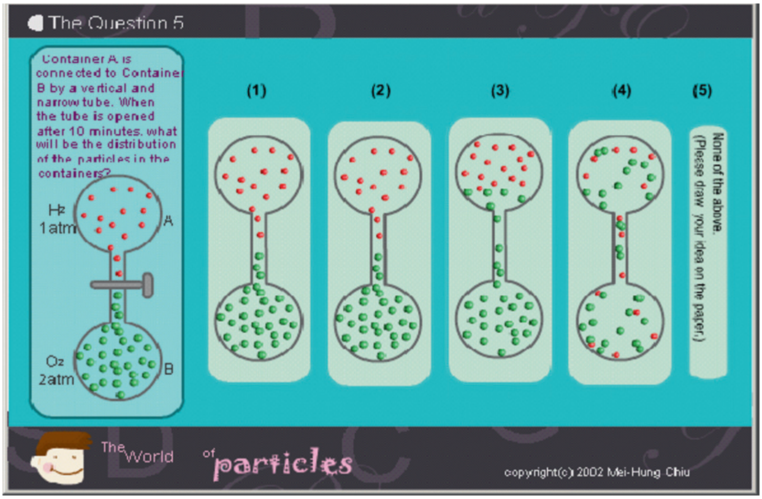


The Question 4

Container A is connected to Container B by a horizontal and narrow tube. When the tube is opened after 10 minutes, what will be the distribution of the particles in the containers?

None of the above. (Please draw your idea on the paper.)

Fig. 11.15 The first tier of Question 4

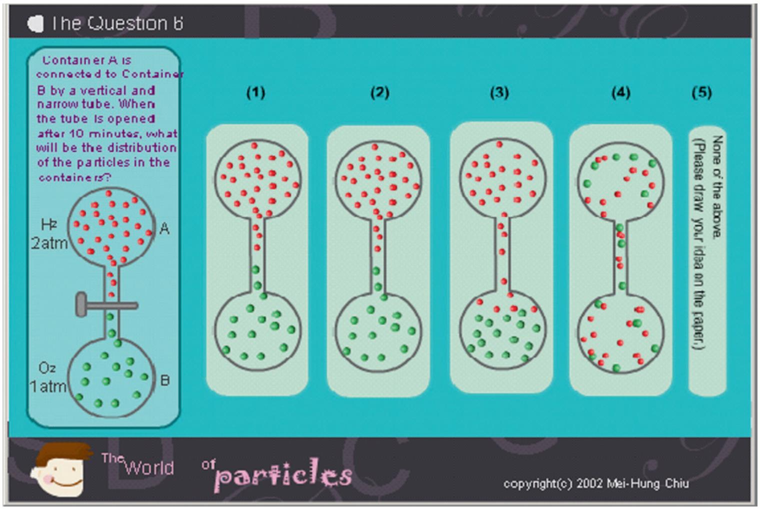


The Question 5

Container A is connected to Container B by a vertical and narrow tube. When the tube is opened after 10 minutes, what will be the distribution of the particles in the containers?

None of the above. (Please draw your idea on the paper.)

Fig. 11.16 The first tier of Question 5


The Question 6

Container A is connected to Container B by a vertical and narrow tube. When the tube is opened after 10 minutes, what will be the distribution of the particles in the containers?

None of the above. (Please draw your idea on the paper.)

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Fig. 11.17 The first tier of Question 6

Table 11.1 The correct percentage of students' performance in all questions

	The same pressure			Different pressure			
situation	Q1	Q2	Q3	Q4	Q5	Q6	Q1–Q6
grade	H	V	V	H	V	V	
8th	26	15	23	13	14	26	20
9th	40	23	30	17	20	27	26

H: Horizontal, V: Vertical

In addition, Liang and Chiu found that the students held four mental models: weight model (WM), size model (SM), pressure model (PM), and scientific model (SCM). Students who held WM thought that the way gas particles were distributed depended on their weight. For instance, in the horizontal situation, students thought that the lighter gas particles (H_2) would float in the top part of the container and the heavier gas particles (O_2) would sink to the bottom of the container. In the vertical situation, students thought that the lighter gas particles would stay in the top part of the container and the heavier gas particles would stay in the lower container. Students who held SM thought that the larger gas particles would push their way toward the smaller gas particles. Students who held PM thought that the gas particles would move from a higher pressure to a lower pressure. Finally, students holding SCM believed that the gas particles would become randomly distributed in the container regardless of their weight or pressure. Students who held WM thought that the way gas particles were distributed depended on their weight. For instance, in the horizontal situation, students thought that the lighter gas particles would float on the upper part of the container and the heavier gas particles would sink to the bottom of the container. In the vertical situation, students thought that the lighter gas particles would stay in the upper container and the heavier gas particles would stay in the lower container. Given this result, it was easy to conjecture why the students considered the weight of the gas particles attributed to their distribution in the container. Students who held SM thought that the larger gas particles (O_2) would push their way toward the smaller gas particles (H_2). Students who held PM thought that the gas particles would move from a higher pressure to a lower pressure. Finally, students holding SCM believed that the gas particles would become randomly distributed in the container regardless of their weight or pressure. These models were also represented as choices for each question and validated by more students from the empirical study.

In summary, we found that the students received lower scores on items that were at different pressures than on items with the same amount of pressure. Also, we found that although the students learned the concept of diffusion in their seventh grade biology class, they did not generate the conception of diffusion in a submicroscopic manner. Instead, they tended to conceptualize the diffusion of the particles in a more intuitive way (the heavier object sinking to the bottom of the container) than in a scientific model that was designed to delineate the random nature of the particle motion.

Detailed analyses of each student's responses were conducted in order to understand how consistently students used their mental representations with different types of questions that shared similar concepts. For instance, questions 1 (Q1) and 4 (Q4) showed an identical horizontal apparatus, the only difference being the pressure of the oxygen gases. The analysis revealed that given the change of pressure, 80% of the students who held the correct model in Q1 switched to the wrong models (WM or PM) in Q4. In addition, Q2 and Q5 showed identical vertical apparatuses, again the only difference being the pressure of the oxygen. The same transformations resulted. Therefore, the change of pressure played a major role in influencing students' decisions about the distribution of gas particles, regardless of the orientation of the containers. We also found that the students changed their mental models according to the situation that was presented to them. Therefore, this assessment method uncovered students' internal representations of particles in an explicit way and allowed us to diagnose how consistently the students used their internal representations to solve similar problems.

How well did our teachers know their students' conceptions about the distribution of the particles? In order to answer this question, 31 physical science teachers in junior high schools were asked to predict student performance on the same six items discussed above (Liang & Chiu, 2004). The results revealed that 12% of science teachers believed that students would choose correct answers in the same-pressure situation (Q1–Q3), and 10% of science teachers believed that students would choose correct answers in a different-pressure situation (Q4–Q6). They fully understood the difficulty of generating submicroscopic points of view about particle movement because of the format of the test items were quite unique to them to test submicroscopic nature of the concepts. However, they were not able to predict which items the students preferred. Accordingly, science teachers seem to think that the orientation of the apparatus is more of a factor than the change of pressure. However, researchers found that the effect of pressure is more difficult for students.

With regard to science teachers' predictions in Q1 and Q4, 48% of science teachers thought that students would choose WM in Q1. Fifty-three percent of teachers believed that students would still choose WM in Q4, and 33% believed that students would choose PM in Q4. Researchers found that students' performance is quite similar, regardless of whether it is a horizontal or vertical situation. It seems that science teachers underestimate the effect of the change of the pressure in a horizontal situation for students. As for the consistency prediction by the teachers, one-third of science teachers thought that students should have a consistent mental model in a similar problem situation, whereas only 8–13% of students could use a consistent model (PM) when they faced questions involving the change of pressure. The most striking result was that science teachers are over-optimistic in thinking that students would use a consistent model for solving questions.

Case 3

Chi (2007) and Chiu and Chung (2007) further developed a set of computerized diagnostic items to examine students' conceptions about the movement and distribution of gas particles. All the test items were categorized into contextualized or non-contextualized as well as macroscopic or microscopic levels of questions. An entire class with 33 11th graders was involved in a multiple modeling activities situation (including dynamic models for particle motion, needle and balloon experiment, computer simulation experiment, role play, animation instruction, and formula introduction for integration) as a treatment group, whereas 26 11th grade students were treated as a comparative group with normal multiple modeling activities in chemistry class.

Comparing the treatment group to the control group, the ANCOVA statistics show that there was no significant difference between the two groups in the pretest; however, there exists a significant difference between the treatment and control group in the gained scores between the posttest and the pretest. The results show that in terms of the three facets, both groups significantly improved after multiple modeling activities. Also, the treatment group significantly outperformed the control group in the *correctness* and *completeness* perspectives. The results also reveal a significant difference between the two groups in the *consistency* perspective. From the data analysis, we also found that students' mental models of mixed gases were categorized into six models: scientific, molecular weight, volume, attractive force, kinetic, and activity models. Among them, 10 submodels were also identified. The result shows that close to 50% of the students in the treatment group changed to a scientific model after multiple modeling activities; however, 42.3% of the students in the control group still believed that the diffusion of gas particles was due to their kinetic energy rather than random movement in a container at a constant temperature.

Summary

Ravitz (2002) claims that technology in assessment practice could enhance our knowledge of students' performance in various ways that are needed for the twenty-first century, including thinking skills, teamwork skills, communication skills, and collaborative skills. Quellmalz and Kozma (2003) propose an ICT assessment framework that incorporates the explicit examination of technologies in supporting, extending, and transforming students' learning. This research-based model, the Coordinated ICT Assessment Framework, covers the consideration of subject matter domain (content knowledge and problem-solving demands) and ICT tools and strategies. In particular, using technology to support a formative assessment could be seriously considered.

In the cases we discussed above, students revealed their lack of knowledge of the random distribution of particles, which was consistent with much previous research. This study not only revealed the mis-representation of the diffusion of gases, but also showed the inconsistent mental models that the students held while solving the problems. The result provided some evidence in favor of research that attributes students' learning in relation to the context while facing various types of questions. However, this result does not support Vosniadou's framework theory (1994), which implies a consistent mental model used by learners in her study.

Accordingly, descriptive or pictorial representations in current textbooks may not explain the dynamic and random nature of particles accurately or sufficiently or may introduce more alternative concepts about the distribution of particles. In addition, these studies suggest that the gap between students' performance and teachers' predictions should be appropriately filled in. For instance, the studies discussed above reveal that teachers have over-estimated students' performance on the submicroscopic conceptions that were rarely stated explicitly in science teaching. Science teaching at the lower secondary schools still emphasizes the macroscopic level of understanding rather than the interaction between symbols, phenomenon, and submicroscopic representations. How we could link these triplet representations via multimedia activities is a challenge to science educators as well as to science researchers. In the future, it is necessary to let teachers know via various channels about students' possible misconceptions. In this way, teachers may avoid some inappropriate teaching strategies and analogies. Besides the examples we presented above for assessing students' conceptual understanding of particles, there exist more cases that apply ICT in assessing students' learning in science.

Multimedia as an Instructional Tool

As many researchers have pointed out, models provide some means of visual representation (Woody, 1995), development of historical models in science (Oversby, 2000; Justi, 2000), and linkage between phenomena, expressed models, and mental models (Buckley and Boulter, 2000). Models and modeling play central roles for chemists in their mental activities as well as in their laboratory work. However, the role of models in chemistry has been underestimated in school teaching. Given the way models are used in science classrooms, it is not surprising that students lack experience developing, using, revising, and evaluating their modeling ability. It is also understandable that students have difficulties with models in chemistry learning (Gilbert & Rutherford, 1998). Therefore, multimedia could serve as an instructional tool to help students develop their conceptions of models, to access the models they construct in their minds, and to appreciate the roles of models in chemistry learning both in the classroom and in the laboratory. The following introduces some researchers' work for creating an environment with multimedia for instructional purposes.

Jones (1999) claims that learning chemistry requires not only reading about but also designing and constructing the world of fundamental principles and complex phenomena. She suggests that the use of The Exploring Chemistry lessons, multimedia computer-based simulated laboratory experiments, can provide students with the opportunity to design and carry out many experiments in chemistry in order to enhance their learning of concepts and laboratory techniques in a short period of time. Jones and Persichitte (2001) question whether or not all students benefit equally from the use of a multimedia Goal-Based Scenario (GBSs, Schoenfeld-Tacher, Persichitte, & Jones, 2001) lesson that supports a constructivist approach to learning by matching needs and preexisting knowledge through the use of a realistic context within which the concepts can be assimilated. Agapove, Jones, Ushakov, Ratcliffe, and Martin (2002) further encourage that secondary school students learn chemistry through ChemDiscovery, design activities offered in a technology-based and inquiry-oriented learning environment. The curriculum provides a structured learning environment that allows students to work together in pairs or in cooperative learning groups to conduct inquiry activities. Study results show that students not only work independently, but they become more successful learners with active learning strategies, organizing and reviewing their knowledge and monitoring their understanding when using this curriculum.

Multimedia-Based Instruction Environment

Ardac & Akaygun (2005) designed a multimedia-based instruction environment (films, pictures, drawings, video, and molecular animations), incorporating additional dimensions (visual elaboration and presentation mode), to investigate how instructional conditions could facilitate students' understanding of properties of matter (its nature as well as physical and chemical changes and the relationship among macro, submicro, and symbolic representations. The most prominent feature of the instructional software was based on visual elements that enabled students to relate changes at macro and submicro levels. Three instructional conditions were itemized as follows:

- Condition 1: Dynamic visuals (multimedia) depicting macro-(sub)micro-symbolic representations are presented on an individual basis.
- Condition 2: Dynamic visuals (multimedia) depicting macro-(sub)micro-symbolic representations are presented through whole class instruction.
- Condition 3: Static visuals (multimedia) depicting macro-(sub)micro-symbolic representations are presented through whole class instruction.

The result of ANCOVA using pretest scores as a covariate indicates a significant main effect for instruction. The students who worked under condition 1 and condition 2 significantly outperformed the students in condition 3. In other words, the students who worked with the dynamic representations showed significantly higher gains than the students who worked with the static visuals. However, as long as the dynamic visual displays were used, no significant difference was found. In addition, the majority of students (75%, 12 students) in condition 1 were consistent in their use of particulate drawings in representing matter at the molecular level, whereas less than one-half of the students in condition 2 (44%, seven students) and condition 3 (47%, eight students) were able to make consistent use of particulate drawings in their work. Furthermore, and most inspiring for both dynamic groups, the frequency of the responses was highest for "congruent (if all presentations were correct and in agreement with each other)" responses for conditions 1 and 2 compared with the other two perspectives, contradictory and incomplete–incorrect. The students under condition 3 showed a high frequency for choosing "incomplete–incorrect" responses. Students who used dynamic visuals on an individual basis (condition 1) produced fewer "contradictory" responses compared with the students who received whole class instruction (condition 2). This study, then, revealed two major contributions of the multimedia environment that was designed: it promoted students' conceptual understanding at both the macro and submicro levels and it helped students develop a consistent and correct structure of matter mentally.

Hypermedia

Multimedia and hypertext have been around for a while now. The combination of multimedia and hypertext for the purpose of creating a meaningful hypermedia environment in chemical education might be of some value. Ebenezer (2001) elaborates on the features and values of a hypermedia environment to elicit students' understanding of the solution process of table salt. The environment Ebenezer designed allows students to use a drawing program to show their own visual representations of dissolving and to link three levels of chemical knowledge, including: "macroscopic" aspects, such as table salt dissolving in water; "submicroscopic," theoretical concepts and models like the chemical structure of sodium chloride and water (the dissolution process at the particulate level); and the "symbolic system," $NaCl_{(s)} + H_2O- \rightarrow Na^+{}_{(aq)} + Cl^-{}_{(aq)}$. In addition, the students were given a booklet called "Personal Chemistry Journal" in which to record their answers, understandings, and feelings. The design of the hypermedia environment also enabled the students to go forward and backward to see connections among different types of knowledge in chemistry: macroscopic, submicroscopic, symbolic, and solution process. The results showed that the hypermedia environment allowed the students to express and represent their conceptions about dissolving with the assistance of animation—to visualize how melting is different from dissolving, how ions are formed, and how hydration takes place. The use of limited-text hypercards provided students with the opportunity to learn from the text as well as to become active learners by generating personal links of the content knowledge. In particular, in subsequent lessons, students were successful in translating their understanding of table salt dissolving in water to the dissolution of other ionic solids in water. In summary, the students indicated a conceptual change in their learning with the hypermedia environment, the use of chemical terms in their written explanations, and the relationship among models and symbols. Nevertheless, there were still three areas of difficulties that the students encountered within the environment: (a) the ion formation, (b) the polar nature of water molecules, and (c) the hydration process.

Other researchers draw more general attention to the possible development of inquiry skills using a multimedia instructional environment. For instance, Lin (2000) claims that the general science curriculum fails to promote learning in science in many countries in part because it is not designed to promote inquiry but, rather, is decreed. Based on the previous studies from the Computer as Learning Partner project (Linn & Hsi, 2000), Linn developed Knowledge Integration Environment (KIE) activities to provide a scaffolding environment to improve students' inquiry skills and to promote lifelong learning that could elicit scientific understanding. The KIE partnership wanted to use the growing wealth of Internet resources to promote an integrated understanding of science. Linn criticized the typical science materials for often ignoring or contradicting the ideas of students and textbook writers and focusing, instead, on providing the right answers. KIE allows students to link, connect, distinguish, organize, and structure their models of scientific phenomena.

Linn further extended her KIE model to the Scaffolded Knowledge Integration (SKI) approach, which offers guidelines to help designers create materials that promote integration. The four guidelines of knowledge integration for the SKI framework are: make science accessible, make thinking visible, help students learn from each other, and promote lifelong science learning. Each feature aims to bring personally relevant materials to one's learning, to make thinking explicit, to enhance one's contribution via online interaction, to promote autonomy, and to link personally relevant problems to class topics using an inquiry process in various contexts. In her series of studies (Linn, Shear, Bell, & Slotta, 1999; Linn, Clark, & Slotta, 2003; Hoadley & Linn, 2000), the use of multimedia materials extend students' scientific literacy to technology literacy and also serve to facilitate the integration of various disciplines, the generation of explanations or arguments relating to evidence in science learning, and the promotion of the collaborative exchange of ideas among learners.

Monaghan & Slotta (2001) notice that despite the amount of literature on the understanding of students' preconceptions as well as on the pedagogy for assisting students' conceptual change, the majority of middle school and high school science teachers still employ more traditional approaches to teaching science. Monaghan and Slotta used the Web-based Integrated Science Environment (WISE) to design an online community for teachers to actively discuss issues concerning constructivist pedagogy and the use of WISE and other technologies as well as to offer support for the use of WISE activities.

In Europe, the Practical Experimentation by Accessible Remote Learning (PEARL) project aims to develop a system to enable students to conduct real-world experiments as an extension of computer-based learning. To use the PEARL system, teachers must be familiar with how to provide tutor–student and student–student interactions for discussion, reflection, and experiment activities. This distance learning with technology also opens an avenue for learning lab work in science.

Technology Pedagogical Content Knowledge (TPCK)

Shulman (1986), a pioneer, introduced the notion of pedagogical content knowledge (PCK)—a teacher's knowledge of how to integrate and transform complex knowledge of learning activities to generate specific knowledge in teaching. Many other researchers have extended his concept of PCK to diverse domains, including subject matter knowledge, contextual knowledge, learners' prior knowledge, and other knowledge related to pedagogical instruction (e.g., Grossman, 1990). Although PCK is well studied in teacher education (Fenstermacher, 1994), it has received relatively little attention in the area of educational technology (Margerum-Leys and Marx, 2004).

Koehler and Mishra (2005) introduce technological pedagogical content knowledge (TPCK) as a way of improving teachers' professional expertise—to help teachers become aware of the complex web of relationships between technologies, content, and pedagogy. They claim that the development of TPCK is necessary to teach technology in contexts that honor the rich connections between technology, the subject matter, and the ways of teaching with technology.

Crawford, Zemba-Saul, Munford, and Friedrichsen (2005) find that prospective teachers hold unaccepted ideas initially. After the use of technology, they are able to acknowledge their own alternative conceptions and become aware of the critical importance of developing a deep, scientifically aligned understanding of their own science content. Margerum-Leys and Marx (2004) investigated how a student-teacher and an in-service teacher, acting as a mentor, developed their professional expertise through constant access to technology. The results revealed that the student-teacher introduced technologically infused activities, which gave the in-service teacher an increased ability to interact with her students electronically during nonschool hours. Hennessy et al.'s (2006) observation of teachers using simulations when they teach found that although the students enjoyed "hands-on" use of the simulation and valued being able to replay experiments and to manipulate variables of an experiment, the students' contribution was limited, and highly structured tasks played a central scaffolding role in the lesson.

As discussed above, there are many ways to make good use of multimedia materials in science teaching. However, teachers did not access resources as we would have expected. Also, the use of high-level technology is still surprisingly low (Ertmer, 2005). In order to teach effectively, a teacher has to know things about the power of technology—not technological content knowledge per se but, rather, a special understanding of technology that provides different functions and channels for meaningful learning.

Summary

Learning chemistry is a complex cognitive activity that requires imagination—a mental effort of constructing and manipulating symbols and models internally in order to link phenomena to abstract concepts. Many studies have made evident the power of multimedia in learning these abstract and complex concepts in chemistry as well as in empowering teachers' instruction. The instructional environments discussed above have features and values covering many perspectives, for instance, animation of the chemistry concepts to depict the submicroscopic nature of particles, dynamic visuals to bridge a phenomenon and the submicroscopic behavior of particles, and hypertext and visuals to relate different representations of a chemistry concept. With these characteristics and values, the instructional environment provided various opportunities for students, for example, to incorporate a substantive amount of information in multimedia that requires students to extract, analyze, manipulate, conceptualize, modify, and evaluate their internal structure of the knowledge. The studies reviewed above indicated that well-designed instruction can foster students' understanding through the use of visual displays that depict representations of chemical phenomena. However, it is not limited only to engaging students in a cognitive activity: well-designed instruction also helps teachers to act as facilitators, helping students to extract and process information more efficiently and meaningfully.

Concluding Remarks and Implications

In the twenty-first century, knowing about and using technology is a universal challenge for all citizens in all parts of the world. School science teachers have the responsibility to cultivate students' literacy in science as well as in technology. Science teachers' knowledge about the role of multimedia in learning, assessment, and instruction should be addressed and emphasized in preservice and in-service professional development. The multimedia studies discussed in this paper have shown evidence of their successful innovation in school science teaching, in particular in chemistry, when they were introduced into schools. The authors intend again to draw readers' attention to the four roles that multimedia effectively play in chemistry education: as a modeling tool, as a learning tool, as an assessment tool, and as an instructional tool to improve school chemistry learning and teaching. Implications for these four areas are elaborated below.

Implications for Multimedia as a Modeling Tool

Many researchers have claimed the importance of models for chemists to develop scientific theories and design laboratory work (e.g., Greca & Moreira, 2000). Schwarts and White (2005) claim that knowledge of modeling includes knowledge of the following: the nature of models, the nature or process of modeling, the evaluation of models, and the purpose or utility of models. One characteristic of modeling ability is that a learner begins to think like a chemist. Developing such a competency takes a long time—and there is no guarantee of success. So, besides traditional methods of teaching, what else can we do to promote mental representations that facilitate learners' understanding of complex phenomena?

To promote understanding, and then act as a scaffolding/modeling tool for learners to construct mental representations, we recommend a well-designed multimedia environment that takes into account theories in cognitive psychology and epistemology, such as the nature of models, mental models, multiple representations, and visualization. Taking students' existing knowledge into account is also crucial for designing multimedia as a modeling tool. Providing multiple representations as one of the advantages of multimedia is important and necessary in order to meet different individuals' needs in learning. Besides these considerations, deep analysis of students' internal representations is also required to improve the quality of learning outcomes while using multimedia. Furthermore, we have to be aware that the multimedia is not going to replace teachers in classrooms, instead it acts as a modeling tool to assist teachers as well as students to construct a coherent and interwoven form in classroom. It has to pinpoint the relationship among different kinds of representations—that is the triplet relationship in chemistry education. It is not a simple job: To construct a relevant context for fundamental and advanced learning in chemistry in a multimedia environment is filled with challenges.

Implications for Multimedia as a Learning Tool

Multimedia technologies have the capability to enhance chemistry learning and support students' understanding of the triplet relationship. Yet, several issues need to be considered when using multimedia tools in chemistry classrooms.

First, each medium uses different symbol systems to convey information. For example, animations can easily show the interactive and submicro nature of chemical changes, and videos allow students to observe macroscopic phenomena that cannot be reproduced in classrooms. Thus, designers and educations need to appreciate the advantages of different media and carefully select them when developing multimedia tools to better support students' learning.

Second, there are student characteristics involved in multimedia learning. Wu et al. (2001) indicate that students prefer to represent chemical entities in certain ways. Additionally, visuospatial abilities play an important role in chemistry learning, and many multimedia tools are highly demanding of cognitive resources (Wu and Shah, 2004). The design of multimedia tools should take students' preferences and visuospatial abilities into consideration so that the tools support all students in learning about the triplet relationship.

Third, teaching practices might also be a factor that affects the effectiveness of multimedia tools. When using technological tools, students could benefit more from teachers who provide timely feedback, articulate expectations, model desired activities, and solve technical problems (Hoffman, Wu, Krajcik, & Soloway, 2003).

Implications for Multimedia as an Assessment Tool

Over 7,700 articles in science education are devoted to examining students of different ages and genders and at different levels with numerous alternative conceptions in science (Duit, 2007). Many types of formats of assessment were developed and utilized, such as traditional methods of multiple choices, open-ended, short answers, and essay, in order to understand how students think, what their structures look like, and what the nature of knowledge is. More recently, Treagust (1988, 1995) proposed two-tier test diagnostic items to push the design of assessment one step further: to collect students' understanding in science. We believe that multimedia is ideal for collecting data as well as individual differences in knowledge structure. Multimedia allowed us to diagnose the components and structure of students' content knowledge and to further analyze students' responses in a more holistic manner. With the merits of multimedia, we were able to design more sophisticated question formats for each individual, accounting for different competencies in learning science. Accordingly, we are able to promote positive outcomes of learning and direct teachers to support science learning. However, it is not easy to capture students' thinking without careful items designed for assessing purposes in science domain. Without knowing the patterns of students' conceptions and flawness of their understanding, even with the flexibility and other advantages of multimedia environment, one still could not create good quality of test items for assessing students' conceptions in science!

Implications for Multimedia as an Instructional Tool

Multimedia has shown its power and value for modeling, learning, and assessment perspectives because of its nature of visualization, multiple links, and multiple and dynamic representations. These characteristics foster conceptual understanding and connections between symbolic representation and problem solving (Kozma et al., 1996). Unfortunately, not many teachers are willing to take this possibility for making their teaching style changed because of their fear or reluctance for changes in classroom (Dori & Barnea, 1997), particularly in technology, which frequently and rapidly changes over a short period of time. We urge teachers to pay more attention to the technology which could serve as a modeling tool, a learning tool, an assessment tool, of course, and as an instructional tool to enhance school science teaching. In addition, teachers must be aware of the ways to adopt multimedia in their teaching. For instance, navigating or surfing around a program's materials might cause students to lose focus. Teachers should be acquainted with the pros and cons of using multimedia as a teaching aid. In particular, teachers should make explicit connections between macroscopic, submicroscopic, and symbolic representations while using multimedia as an instructional tool.

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