The Impact of Animation-Mediated Practice on Middle School Students' Understanding of Chemistry Concepts

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Abstract

Chemation is an animation tool that allows learners to build molecular models and animations of chemical phenomena. We use Chemation to support practices of student learning including designing, interpreting and evaluating animations. We are examining the impact of the practices on student understanding including the development of content knowledge and representation ability in chemistry. Eight seventh-grade classes (271 students) were randomly assigned to one of the three treatments: (1) students design, interpret, and evaluate animations, (2) students only design and interpret animations, or (3) students only view teacher-made animations and interpret the animation. The results of the pre- and posttest data indicate a significant treatment effect, revealing the educational value of instructional animation aligning with student-centered practices.

Introduction

Animation can serve as an instructional aid to support visualization of dynamic processes or abstract relationships that might otherwise be difficult to depict. Weiss, Knowlton, & Morrison (2002) discussed five functions of instructional animation, including (1) cosmetic functions that make instruction attractive to learners, (2) attention gaining functions that signal salient points of a topic, (3) motivation functions that provide feedback to reinforce correct responses, (4) presentation functions that provide concrete reference and a visual context for ideas, and (5) clarification functions that clarify relationships through visual means. However, researchers have difficulty to establish the instructional value of animation. Empirical studies have shown mixed results for the effect of instructional animation on student learning (Hegarty, Kriz, & Cate, 2003; Lewalter, 2003; Rieber, 1989; Stasko, Badre, & Lewis, 1993; Tversky, Morrison, & Betrancourt, 2002).

Few studies focus on the role of instructional animation other than serving a presentation role. A study found that the positive effect of animation is more apparent in open, interactive learning situations than in less open-ended situations (Kehoe, Stasko, & Taylor, 2001). Studies indicate that animation alone may not be enough to amplify student understanding (Hubscher-Younger & Narayanan, 2003; Rieber, 1990a). Researchers have started to address different methods to use animation to promote understanding (Mayer & Anderson, 1992; Mayer & Moreno, 2002; Vermaat, Kramers-Pals, & Schank, 2003). While the presentation approach has its value, in this study we argue for the use of computer models to go beyond the conventional presentation or motivation roles that computer models play. The purpose of our present study is to explore how an animation tool can be used to support different practices of student learning and how these practices may impact middle school students' understanding of chemistry concepts. Specifically, we are exploring the use of Chemation, a new animation program that allows students to build 2-D models and flipbook-style animations of chemical phenomena at the molecular level. Chemation runs on handheld computers for portability and pervasive access of student artifacts. We engage middle school students in the use of Chemation in practices including designing, interpreting and evaluating animations, and examine the impact of the animation-mediated practices on student understanding including content knowledge and representation ability in chemistry.

The research questions addressed in this paper include: Does the animation-mediated practice have a main effect on students' development of chemistry content knowledge and representation skills including constructing, interpreting and evaluating molecular representations? Is the treatment effect uniform across teachers? The results of the study will indicate effective practices and appropriate conditions for the use of animation to facilitate learning, revealing the educational value of instructional animation aligning with student-centered practices. Furthermore, the results will provide information about design principles for multimedia designers to consider enabling computer models or animations to play a more active role in educational settings.

Empirical and Theoretical Foundation

Research on the Role of Instructional Animation in Student Understanding

A study explored the effect of computer animations on college students' understanding of the particulate nature of matter (Williamson & Abraham, 1995). The researchers compared college students who viewed animations of molecular models as a supplement to the lecture with a control group who received only the lecture. The result indicated that the group who viewed animations showed significantly higher conceptual understanding of the particulate nature of matter. Another study also found that college students who viewed animations of diffusion of perfume molecules and osmosis of water molecules had better understanding of random and constant movement of particles than the students who did not view the animations (Sanger, Brecheisen, & Hynek, 2001). Similarly, a study comparing student responses to a prediction question before and after viewing animation found that students did learn from viewing animation (Hegarty et al., 2003).

However, the effect of animation may be not significant when compared to other media such as static visuals. Several studies found no superior effect of animation over static visuals (Hegarty et al., 2003; Lewalter, 2003; Rieber, 1989; Stasko et al., 1993). One important factor that influences the impact of animation is students' prior knowledge or ability. Hegarty et al. (2003) conjectured that the students who received static visuals in their study were able to construct a dynamic mental model on their own, thus viewing an external animation was not essential to students' learning. Conversely, Rieber (1989) indicated that exceedingly demanding tasks and the inability of students to attend properly to the information of the animation eliminated the positive impact of animation. The study was replicated later with two modifications: lesson difficulty was reduced and cues were developed to gain students' attention to the animation. This time positive effects of animation over other media were found (Rieber, 1990b).

The studies discussed above indicate the important role of students' prior knowledge in the use of instructional animation. A second factor is the method of animation use. A study found that the positive effect of animation is more apparent in open, interactive learning situations than in less open-ended situations (Kehoe et al., 2001). When the students were given the assessment tasks and supporting animations at the same time and allowed to use the animations in a "homework" learning scenario with no maximum time limit or particular sequence specified, the study found positive effects of animation that the earlier study failed to find. A third factor is animation may have benefits but the measurement may not be sensitive enough to discern those benefits. For example, the effect of animation is more likely to be found by items that assess procedural operations, but not items that assess factual knowledge (Kehoe et al., 2001). To sum up, three plausible factors affect studies to find significant benefits of using animation, including students' prior knowledge or experience, the approach to using animation in educational settings, and the quality of measurements.

Theoretical Perspectives for Instructional Animation

The theoretical foundation for the use of instructional animation has not been firmly established (Weiss et al., 2002). Researchers (Mayer & Moreno, 2002; Rieber, 1990a) view animation as a subset of visual representations. They delineate the cognitive theory of animation based on assumptions suggested by cognitive research on static visual representations, such as dual coding model (Pavio, 1971, 1986, 1991). Pavio (1971, 1986, 1991) proposes that human minds possess separate cognitive channels for processing verbal and nonverbal (visual or pictorial) information. Visual representations are hypothesized to have superior effects on learning because they are more likely to be coded in the two channels than verbal information. Another cognitive model, sensory-semantic model (Nelson & Castano, 1984; Nelson, Reed, & McEvoy, 1977), also suggests the superiority of visual representations over textual representations because visual representations stimulate activation of meaning directly whereas textual representations require phonemic analysis before activation of meaning. However, animation has the capability of simulating movement and trajectory in ways that static visual representations cannot. Theory that supports the use of static visual representations might not fully describe the benefits of animation, leaving questions about the cognitive and social processes that animation may foster.

A perspective from social practice may be applied to instructional animation. Practice constitutes one important component in learning environments. It refers to social activities involving actions of participants, and interactions between participants and resources (Barab, Hay, Barnett, & Squire, 2001; Lave & Wenger, 1991). Interactions in practices of technology-rich learning environments include two types: the *informatic* (e.g., teacher-technology-student) and the *normal social* (e.g., teacher-student or student-student) interactions (Roschelle, 2003). When we consider the Chemation study, we conjecture that the practice of students designing or evaluating animation encourages more informatic interactions than does the practice of viewing animation. For example, when in the designing or evaluating practice the teacher uses the technology to demonstrate or interpret the task and guide students' performance while students use the technology to generate an artifact individually or collectively. By comparison, the informatic interaction between student and technology is not essential when students simply view animations. Therefore the practice of designing or evaluating may have a better effect on student learning than does the practice of viewing. This hypothesis is consistent with the notion that social interaction plays an important role in individuals' cognitive development (Vygotsky, 1978). In addition, research indicates that meta-level activities, such as students planning and evaluating inquiry projects, invite students to examine their inconsistent ideas and reflect on the product they generated (Davis & Linn, 2000; Schwarz & White, 2005; White & Frederiksen, 1998, 2000). Such reflective processes help students develop integrated understanding.

Research Context: The Tool and Learning Activities

The Animation Tool

Chemation contains five modes (Figure 1): (1) Atom mode: Chemation provides an atom palette that contains 21 different atoms, each a different color from which students can choose and drag to the main screen. (2) Link mode: The link mode is used to connect between atoms. (3) Molecule mode: Once atoms are drawn and connected, they are viewed as a group of atoms in a molecule. Students can use the molecule mode to copy, paste, rotate, and flip the whole molecule. (4) Label mode: Labels are free form text boxes that allow students to document their model. (5) Animation mode: After building molecular models, students can develop a series of frames to animate the models to articulate the details of a chemical or physical process (Figure 2).

Although several computer programs have been well developed to engage students in learning with dynamic molecular visualizations, such as "MultiMedia and Mental Models" (4M: Chem) (Kozma, Russell, Jones, Marx, & Davis, 1996; Russell et al., 1997), ChemSense (Coppola & Kiste, 2004; Schank & Kozma, 2002; Vermaat et al., 2003), eChem (Wu, Krajcik, & Soloway, 2001) and Molecular Workbench (Tinker, n.d.), the need for a new technology tool in this study arises due to the issues of content and hardware accessibility. First of all, a technology tool that makes the concept of the particulate nature of matter accessible to middle school students is needed. Many current computer programs involve complex chemistry concepts such as the dynamic aspect of chemical equilibrium, 3-D structures of molecules, or different types of bonds.

Such complexity may impede younger students' sense-making activities. Middle school students may be overwhelmed by rich functions in those programs that involve advanced chemistry concepts. Thus a simple program that addresses the learning goals of a seventh grade chemistry curriculum is needed.

Second, tools on alternative platforms that allow pervasive access to student artifacts are needed. Due to the cost of desktop computers, the ratio of students to computers is 4-7 to 1 in K-12 classrooms (Soloway et al., 2001). Students often need to share the computer with others so that not all students have direct access to the program. In addition, desktop computers are often located in the lab rather than in the classroom. The use of the computer may not immerse in the classroom activity. Among many media that can overcome the limitation of desktop computers, the program used in this study, Chemation, works on a handheld device. Compared to desktop computers, handheld devices are relatively inexpensive and have a significant advantage of portability (Soloway et al., 1999). Due to the one-to-one nature, handheld computers encourage continual, individual work, increasing students' ownership of their artifact. Portability and pervasive access of handheld computers enable students to retrieve their artifact almost anywhere and at anytime.

Learning Activities Related to Student Use of the Animation Tool

Chemation is currently used in a seventh-grade inquiry-based chemistry curriculum. In the eight-week curriculum, students conduct experiments to investigate macroscopic phenomena such as boiling, mixing and chemical reaction, and are guided to use Chemation to explain the phenomenon at the molecular level. In addition, we provide curricular material (i.e., student worksheets) to initiate the target animation-mediated practices including designing, interpreting, and evaluating animations. In the practice of designing each student is provided with one Palm computer and is prompted to plan and construct animations to represent a given phenomenon at the molecular level. In the practice of interpreting students are guided to generate meanings from their animation and to explain and reason about the phenomenon using the animation. In the practice of evaluating students exchange animations and evaluate their classmate's animation by following a set of guidance and criteria; then they receive feedback and revise their own animation. We detail the definition and activity for each practice in Table 1. A detailed description regarding the classroom activities for different treatments in this study is presented in the "Research Methods" section.

Research Methods

Study design

We investigated the impact of the target animation-mediated practices on student understanding by comparing student learning in three treatments: (1) students design, interpret, and evaluate animations, (2) students design and interpret animations, and (3) students view teacher-made animations and interpret the animation (Table 2). This design is a variation of the quasi-experimental design, i.e., the combination of the untreated control group design and the reversed-treatment nonequivalent control group design with pretest and posttest (Cook & Campbell, 1979; Shadish, Cook, & Campbell, 2002). To counterbalance the instructional method effect, each teacher in the study taught all treatments. In addition, the instructional method in each treatment follows the constructivist perspective: students are engaged in inquiry-based learning activities.

Participants

Our study involved eight seventh-grade classes (n= 271) taught by three teachers at three public middle schools in the Midwest (Table 2). The teachers had had at least three years of experience with Chemation and the chemistry curriculum. Originally each teacher had three seventh-grade classes participating in the study. Each class was randomly assigned to one of the treatments so that every teacher taught all three treatments. The purpose of this restricted random assignment is to counterbalance the potential effect of instructional methods. However, after the school year started Teacher C lost one of her seventh-grade classes (the third treatment) due to her change of assignment to teach eighth-grade science. As a result, a total of eight seventh-grade classes (271 students) participated in the study.

In addition, the third treatment (View-Interpret) of Teacher B consisted of students selected by the school for their better mathematical ability than the other students in the same grade. However, the prior knowledge in chemistry among the students in Teacher B's three treatments was comparable since a test of mean differences revealed no significant difference on the pretest scores [$F(2, 67)=0.828$, $p=0.441$]. The result indicates low diversity of the participants' prior content knowledge in chemistry in different treatments. The majority of the students are African American or Hispanic students. All students were Palm-literate when they started the chemistry unit since they had used Palms in a previous inquiry-based air quality unit.

<u>Classroom Activities</u>

Students were engaged in the technology-mediated modeling practices in three lessons of the chemistry curriculum. In Lesson 5 students used Chemation to build or view molecular models of water and urea and animations of the process of urea mixing into water. The learning goal for this lesson is students learn that a substance is made of the same type of atom or molecule throughout and a mixture contains more than one type of atom or molecule. In Lesson 9 students built or viewed animations that show the molecular view of the chemical reaction of copper and acetic acid to learn that in a chemical reaction atoms rearrange. In Lesson 14 students built or viewed animations of another chemical reaction: baking soda and hydrochloric acid. By examining the numbers and types of atoms before and after the chemical reaction students were guided to explain the principle of conservation of matter. The animation-mediated practices recur three times (Lesson 5, 9 and 14) during the curriculum. The learning activities for each treatment during the three lessons were described as follows.

<u>*Treatment 1: Design-Interpret-Evaluate*</u>

In the phase of designing animation, students were prompted by the curricular material to plan the animation before they construct. They wrote on the worksheet the purposes of their animation, steps to make the animation and types and numbers of objects included in the animation. After that each student was provided with one Palm computer to construct the animation using Chemation. A set of tips for construction was listed on the worksheet and students were asked to check whether they used the features mentioned by the list. Following constructing is the phase of interpretation. Students wrote on the worksheet to explain the meaning of the animation, relate it to the macroscopic phenomenon, and reason about any problem involved. After that, in the phase of evaluation, students beamed their animation to their classmate and received one from the classmate to evaluate each other's work. They wrote down their evaluation following the prompts and questions on the worksheet, followed by sharing the evaluation verbally. Students' final task was to revise their animation based on what they have learned from the evaluation process. This treatment took about two to three class periods and was about 25 to 40 minutes (a half to one class period) longer than the other treatments.

Treatment 2: Design-Interpret

Students were provided with the same worksheets as those for the first treatment but without the evaluation part. Students planned, constructed and interpreted their animation but did not exchange and evaluate each other's animations. This treatment took about one to two class periods.

Treatment 3: View-Interpret

Students did not plan and construct animations. Instead, they viewed and interpreted teacher-made animations. The teacher made two animations to represent the same concept (for example, urea water and sugar water for the mixing process) in advance and had students beam the animations to every Palm computer. During class each student was provided with one Palm computer and viewed the teacher-made animation. Following viewing animations students wrote on the worksheet to explain the meaning of the animation, relate it to the macroscopic phenomenon, and reason about any problem involved. The purpose of viewing two animations for the same concept is to compensate for the time needed for each treatment. This treatment took about one to two class periods

Data Collection

We collected data including pre- and posttests, classroom videotapes, student interviews, and student-generated artifacts (including student worksheets and animations generated during class). However, due to the scope issue we focus the present paper on the pre- and posttest data that indicate the close effect (Ruiz-Primo, Shavelson, Hamilton, & Klein, 2002) of different treatments on student understanding of chemistry concepts and principles.

Items in the pre- and posttests are identical, including five multiple-choice, five mixed (choose an answer and explain why), and five open-ended questions. The multiple-choice items measured only content knowledge, whereas the mixed and open-ended items measured combinations of content knowledge and representation skill. The content knowledge measured included chemical reaction, substance versus mixture, conservation of mass, macroscopic phenomena versus their molecular view, and chemical representation. The representation skill measured included student construction, interpretation, and evaluation of molecular models. For construction, we measured student ability to draw 2-D molecular models to illustrate a given phenomenon. For interpretation, we measured student ability to generate meaning out of a visual molecular representation and to reconstruct related concepts or principles. For evaluation, we measured student ability to critique a visual molecular representation in light of its adequacy. These skills correspond to those promoted in the animation-mediated practices. We performed item analysis by content knowledge and representation skill (Appendix A) to ensure the construct validity (Atkin, Black, & Coffey, 2001).

Data Coding

The multiple-choice items were coded by correctness: one point was given to a correct response and zero point to an incorrect one. For each sub-question of the mixed and open-end items, two points were given to a completely accurate response, one point to a partially accurate response, and zero point to an incomplete or inaccurate response. The first author coded all the pre- and posttest data. In addition, we randomly sampled 10% of the pre and posttest data and a second independent rater coded them. We calculated the estimate of interrater reliability by percent agreement. As a result, the interrater reliability was above 95% (98.3%) for the pre- and posttest data.

We weighted each item and its sub-question based on the level of complexity (Table 3). For example, an item that assessed a single area of content knowledge only, such as a multiple-choice item, was assigned to the lowest level of complexity, level one. The complexity increases by one level when an item assessed multiple areas of content knowledge or representation skill, and by two levels when an item assessed coordination between content knowledge and representation skill. For example, compared to a level-one question, an item that assessed multiple areas of content knowledge and a single area of representation skill was assigned to Level 4 because the complexity increases when the item requires students to apply multiple areas of content knowledge (adding one level) and also coordinate between the content knowledge and representation skill (adding another two levels). The original rated point was weighted based on the level of complexity so that the highest possible point is the same for all questions at the same level of complexity. For example, item 14 and 15 of the pre- and posttests were level-five questions. The highest possible point for each item was 6 and 4 points originally. After weighted the highest possible point for both questions was 5. The total possible score on the test was 66 points.

Data Analysis

We included only students who completed both pre- and posttests in the analysis. Due to high absenteeism in the urban schools, only 178 students took both of the tests. The number of students included in the analysis for each teacher and treatment is shown in Table 4. Of the missing data (n=93), 62 students missed the pretest, and 31 students did not miss the pretest but missed the posttest. In the missing data analysis we focused on the 31 students to examine whether the absenteeism of the students not in the pretest but in the posttest may create any bias to the result. Among them, 12 students are in the first treatment, 13 in the second treatment, and six in the third treatment. Their mean scores on the pretest are 5.4 (*SD*=2.6), 4.8(*SD*=2.4), and 6.8 (*SD*=3.7) respectively for each group. The differences of the mean scores among groups did not reach statistical significance [$F(2, 28) = 1.022$, $p = .373$]. The result indicates that the students missing the posttest were homogeneous in their background knowledge in chemistry. It is unlikely that the statistical result was influenced by the missing data.

We employed two-factor ANCOVA (analysis of covariance) to examine the effect of different treatments on students' test scores. "*Treatment*" (Design-Interpret-Evaluate, Design-Interpret, or View-Interpret) and "*teacher"* (Teacher A, B, or C) are the independent variables. "*Posttest*" is the dependent variable. We used "*pretest*" as a covariate to reduce a potential bias related to students' prior knowledge on students' learning outcomes. An α level of .05 was used to test for significant effects and interactions. In addition to total test scores, we clustered the test items into items that measured (1) only content knowledge, (2) content knowledge and constructing ability, (3) content knowledge and interpreting ability, and (4) content knowledge and evaluating ability. Again, we employed two-factor ANCOVA to examine the effect and interaction of treatment and teacher on students' test scores for the four areas.

Results

Treatment Effect on Total Test Scores

The results of ANCOVA indicate a significant main effect for treatment on students' total test scores [$F(2)=13.56$, $p<.005$] (Table 5). The impact of the treatment on students' chemistry achievement is significant. We used paired comparisons with a modified Bonferroni correction to identify the sources of significant differences. As a result, there is a significant difference between Treatments 1 and 2, and 2 and 3, but no significant difference between Treatments 1 and 3. The combination of the designing, interpreting, and evaluating practices has a significantly better effect on the students' achievement than does the combination of the designing and interpreting practices. The combination of the viewing and interpreting practices also has a significantly better effect on the students' achievement than does the combination of the designing and interpreting practices. The results favored the use of instructional animation with a combination of practices including designing, interpreting and evaluating animations. Conversely, engaging students in only designing and interpreting animations without peer-evaluation may have a least positive effect on student development of chemistry understanding. In addition, the results indicate no significant *treatment* by *teacher* interaction [$F(3)= 2.181$, $p=.092$]. Therefore the treatment effect is uniform across the different teachers.

Treatment Effect on Content Knowledge

In addition to total test scores, I conducted ANCOVA for students' test scores of content knowledge only and three aspects of representation skill (constructing, interpreting and evaluating molecular models). For content knowledge, the results indicate a significant treatment effect [$F(2)=7.353$, $p=.001$] (Table 6). The impact of the treatment on student development of content knowledge is significant. Again paired comparisons with a modified Bonferroni correction were used to identify the sources of significant differences. As a result, there is a significant difference between Treatments 1 and 2, and 2 and 3, but no significant difference between Treatments 1 and 3. The students in the first and third treatments developed chemistry content knowledge better than did the students in the second treatment.

In addition, the results indicate a significant *treatment* by *teacher* interaction [$F(3)= 7.714$, $p<.005$]. I examined the 95% confidence intervals for the mean scores among the classes and found no significant difference among Teacher A's classes, but significant differences among Teacher B and C's classes. For Teacher B, the students in the third treatment outscored those in the second treatment, and for Teacher C the students in the first treatment outscored those in the second treatment.

Treatment Effect on Constructing Skills

The results of ANCOVA indicate a significant main effect for treatment on students' scores of items measuring the ability to construct molecular models [$F(2)=13.83$, $p<.005$] (Table

7). The impact of the treatment on students' constructing ability is significant. Paired comparisons with a modified Bonferroni correction indicate that there is a significant difference between Treatments 1 and 2, and 1 and 3, but no significant difference between Treatments 2 and 3. The results indicate that the students engaged in the full combination of the technology-mediated modeling practices performed significantly better in their abilities to construct molecular models than the other students engaged in part of the practices. However, the students in the second (Design-Interpret) and third (View-Interpret) treatments did not show significant differences in this representation skill. In addition, the results indicate no significant *treatment* by *teacher* interaction [$F(3)= 1.397$, $p=.246$]. Therefore the treatment effect is uniform across the different teachers.

<u>Treatment Effect on Interpreting Skills</u>

The results of ANCOVA on students' test scores on items measuring students' ability to interpret molecular models indicate a significant main effect for treatment [$F(2)=9.916$, $p<.005$] (Table 8). The impact of the treatment on students' interpreting ability is significant. Paired comparisons with a modified Bonferroni correction indicate that there is a significant difference between Treatments 1 and 2, and 2 and 3, but no significant difference between Treatments 1 and 3. The results indicate that the students engaged in either designing, interpreting, and evaluating practices or viewing and interpreting practices performed better in their interpreting abilities than the students engaged in only designing and interpreting practices without peer-evaluation. This effect is uniform across the teachers because there is no significant *treatment* by *teacher* interaction [$F(3)= 1.651$, $p=.18$].

Treatment Effect on Evaluating Skills

The results of ANCOVA indicate a significant main effect for treatment on students' scores of items measuring the ability to evaluate molecular models [$F(2)=9.845$, $p<.005$] (Table 9). The impact of the treatment on students' evaluating ability is significant. Paired comparisons with a modified Bonferroni correction indicate that there is a significant difference between Treatments 1 and 2, and 2 and 3, but no significant difference between Treatments 1 and 3. Again, the students engaged in either designing, interpreting, and evaluating practices or viewing and interpreting practices performed better in their evaluating abilities than the students engaged in only designing and interpreting practices without peer-evaluation. This effect is uniform across the teachers because there is no significant *treatment* by *teacher* interaction [$F(3)=.546$, $p=.651$].

Discussions and Concluding Remarks

The results of the pre- and posttest data partially support the hypothesis of the close effect of the treatment on student development of chemistry understanding. We hypothesized that the students engaged in the full combination of the target practices (the first treatment) would perform better in their abilities to construct, interpret and evaluate molecular models than the other students engaged in part of the practices (the second or third treatment), and that the students in the second treatment would develop better representation skills than the students in the third treatment in which students only view and interpret teacher-made animations. The results favored the use of instructional animation with a combination of practices including designing, interpreting and evaluating animations. Conversely, engaging students in only designing and interpreting animations without peer-evaluation may not have a similar effect. Also engaging students in only viewing and interpreting animations may not have a least effect.

Three possibilities might explain the results. First, due to the quasi-experimental nature of this study the third treatment of Teacher B consisted of students who had better mathematical ability. Those students may be more capable or have higher motivation of learning than the students in the other treatments. Second, the design of Chemation considers students' prior knowledge. The complexity of molecular model representations is reduced in Chemation. As a result, the animation made in Chemation is accessible for the seventh-grade students even when they only view the animation. Engaging students in inquiry-based curricular with the use of an age-targeting representation tool might compensate for the viewing approach. The results of this study support the ideas that enhancing students' experience in practices (Bowen & Roth, 2002; Roth & Bowen, 1994; Roth, Bowen, & McGinn, 1999) and using representations meeting students' knowledge (Mayer & Anderson, 1992; Mayer & Gallini, 1990; Winn, 1993) may support students in overcoming learning difficulties such as interpreting representations. Third, the measurement may not be sensitive enough to discern the benefits between the designing and viewing approaches.

Although in this paper we did not focus on the other data we collected such as the student interview data and student worksheets, the results of our analysis of the student interview data revealed that 80% of the interviewed students of the third treatment showed fragmented conceptual framework, and 80% of them generated static visualizations of chemical reaction. In comparison, only 30% of the interviewed students of the second treatment demonstrated fragmented models or generated static visualizations. Only 10% of the interviewed students of the first treatment demonstrated the fragmented model and none of them generated static visualizations. While the students of the third treatment demonstrated competent knowledge of chemistry and abilities of interpreting and evaluating molecular models through paper-and-pencil tests, in-depth examination through student interviews indicates that they might not be able to form coherent conceptual framework. Also by viewing animation in class might not support students in developing dynamic visualizations of the presented concept.

The results of this study suggest that engaging students in designing and evaluating their own animations have a significantly positive effect on student development of conceptual understanding. However, engaging students in designing own animations without the social practice of peer-evaluation may not have a similar effect on student development of conceptual understanding, since successful modeling requires recursive processes of model formation, testing and revision (Buckley, 2000). Research indicates that engaging students in explicit modeling practices such as building and testing own models supports students in developing epistemic understanding of models (Schwarz & White, 2005; Spitulnik, 1998). However, the research by Schwarz and White (2005) is inconclusive regarding the relation between student engagement in technology-mediated modeling practice and development of better conceptual understanding. The present study provides evidence supportive of engaging students in animated-mediated modeling practice to facilitate student understanding of content knowledge and development of modeling abilities. The present study shows an example of using animation in different activities and reveals the potential educational value of instructional animation combining with student-centered practices. Researchers indicate coupling the normal social and informatic interactions for effective use of technology to enhance student learning (Roschelle, 2003; Roschelle & Pea, 2002). Further research into the coupling between the informatic and normal social interactions during class and their impact on student learning may reveal the dynamics among all elements of the learning environment including the role of the teacher in supporting student learning with technology.

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Figures and Tables

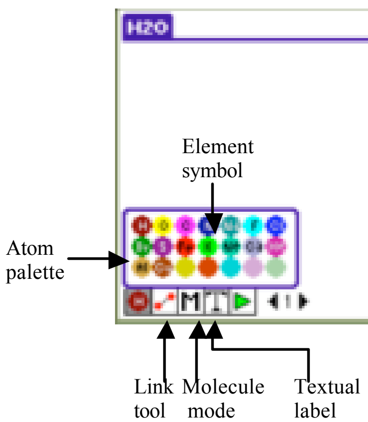


Figure 1 The atom palette (with element symbols), link tool, molecule mode and textual label of Chemation

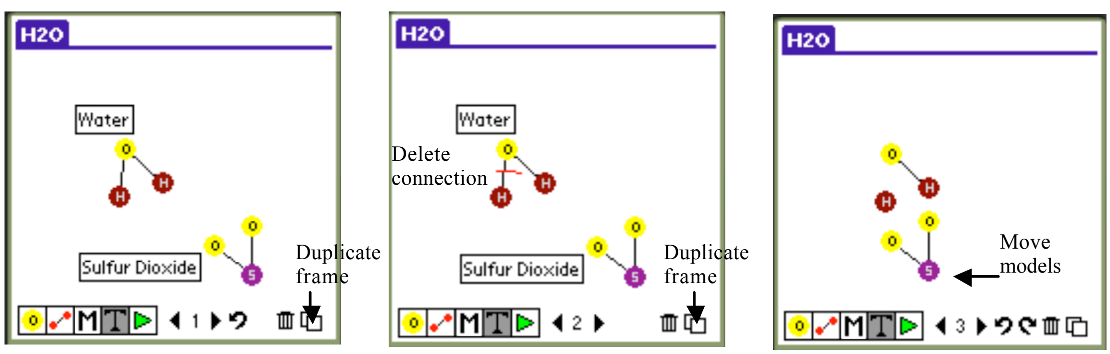


Figure 2 An example of animating a chemical reaction

Table 1 Definition and activity of the target practices

Practice	Definition	Activity
Design	*Plan* Think ahead about purposes or goals of constructing artifacts, generate ideas about steps to construct artifacts to meet the purposes, and identify objects to include in the artifact.	Students work in groups to: • Set goals for their animation by describing what they want to show with their animation, • Generate at least three steps to make the animation (break the task down into small pieces), and • Decide objects (circles, links) and numbers of objects needed in the animation.
	Construct Transform observation of a phenomenon into molecular representations.	Students work individually to: • Create 2-D molecular models, • Duplicate frames and make changes to form flipbook-style animations, and • Use text to label or describe the representation.
Interpret	Generate meanings from the representation and explain and reason about the phenomenon using molecular representations.	Students work in groups to: • Explain the meaning of their or teacher-made animation, • Relate to the macroscopic phenomenon the animation represents, and • Reason about the phenomenon using the animation.
Evaluate	Make comments to and judge the quality of students' own and each other's artifacts.	Students work in groups to: • Determine the adequacy of the types and numbers of models in classmates' animation, • Compare the trajectory of movement in each other's animation, and • Make suggestion to help improve the quality of the animation.

Table 2 Numbers of students from each teacher in each treatment

	1. Design-Interpret-Evaluate	2. Design-Interpret	3. View-Interpret
Teacher A	38	36	37
Teacher B	31	32	37
Teacher C	32	28	N/A
Total	101	96	74

Table 3 Level of complexity for the pre-posttest items

	No CK[1]	Single CK	Multiple CK
No RS[2]	N/A	Level 1	Level 2
Single RS	N/A	Level 3	Level 4
Multiple RS	N/A	Level 4	Level 5

Rules for adding the level:
* From single to multiple: +1 level
* Coordinate between content knowledge and representation skill: +2 level

Level 1: Single content knowledge (1)
Level 2: Multiple content knowledge (1+1)
Level 3: Single content knowledge and single representation skill (1+2)
Level 4: Multiple content knowledge and single representation skill (1+1+2)
Single content knowledge and multiple representation skill (1+2+1)
Level 5: Multiple content knowledge and multiple representation skill (1+1+2+1)

[1]. CK: content knowledge
[2]. RS: representation skill

Table 4 Numbers of students included in the ANCOVA analysis

	1. Design-Interpret-Evaluate	2. Design-Interpret	3. View-Interpret
Teacher A	24	30	20
Teacher B	16	18	26
Teacher C	24	20	N/A
Total	64	68	46

Table 5 Means and standard deviations (in parentheses) for total test scores

Treatment	T1	T2	T3	*F* value and paired comparisons
Teacher A	34.83 (12.38)	23.44 (12.37)	22.34 (10.33)	The treatment effect:
Teacher B	25.58 (11.39)	17.03 (12.92)	25.44 (11.90)	F=13.56 [a]
Teacher C	26.76 (9.27)	11.55 (5.50)		Treatment1/Treatment2[b];
Total	29.49 (11.65)	18.35 (12.01)	24.09 (11.22)	Treatment1/Treatment3; Treatment2/Treatment3[b].

* a: $p < 0.05$; b: significant difference at the .05 level

Table 6 Means and standard deviations (in parentheses) for scores of content knowledge

Treatment	T1	T2	T3	*F* value and paired comparisons
Teacher A	4.38 (.77)	4.27 (.83)	3.85 (.93)	The treatment effect:
Teacher B	3.25 (.93)	2.44 (1.62)	3.50 (1.33)	F=7.353[a]
Teacher C	4.21 (1.06)	2.42 (1.22)		Treatment1/Treatment2[b];
Total	4.03(1.02)	3.25 (1.49)	3.65(1.18)	Treatment1/Treatment3; Treatment2/Treatment3[b].

* a: $p < 0.05$; b: significant difference at the .05 level

Table 7 Means and standard deviations (in parentheses) for scores of constructing skill

Treatment	T1	T2	T3	*F* value and paired comparisons
Teacher A	6.57 (3.10)	3.85 (2.91)	3.84 (2.15)	The treatment effect:
Teacher B	5.55 (2.64)	3.79 (3.22)	4.94 (2.44)	F=13.83 [a]
Teacher C	6.22 (2.26)	2.33 (1.71)		Treatment1/Treatment2[b];
Total	6.18 (2.68)	3.40 (2.77)	4.46 (2.36)	Treatment1/Treatment3[b]; Treatment2/Treatment3.

* a: $p < 0.05$; b: significant difference at the .05 level

Table 8 Means and standard deviations (in parentheses) for scores of interpreting skill

Treatment	T1	T2	T3	*F* value and paired comparisons
Teacher A	23.88 (9.61)	15.33 (9.27)	14.65 (8.48)	The treatment effect:
Teacher B	16.78 (8.57)	10.80 (8.77)	17.00 (9.79)	F=9.916 [a]
Teacher C	16.34 (7.23)	6.80 (3.72)		Treatment1/Treatment2[b];
Total	19.28 (9.13)	11.69 (8.63)	15.98 (9.22)	Treatment1/Treatment3; Treatment2/Treatment3[b].

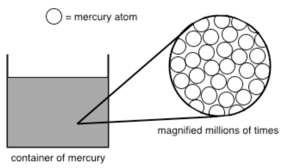
* a: $p < 0.05$; b: significant difference at the .05 level

Table 9 Means and standard deviations (in parentheses) for scores of evaluating skill

Treatment	T1	T2	T3	*F* value and paired comparisons
Teacher A	2.59 (2.74)	.72 (1.45)	1.96 (2.25)	The treatment effect:
Teacher B	2.14 (2.38)	.79 (1.26)	1.51 (1.70)	F=9.845 [a]
Teacher C	2.92 (2.73)	.57 (0.75)		Treatment1/Treatment2[b];
Total	2.60 (2.62)	.70 (1.22)	1.70 (1.95)	Treatment1/Treatment3; Treatment2/Treatment3[b].

* a: $p < 0.05$; b: significant difference at the .05 level

Appendix A: Examples of item analysis by content knowledge and representation skill

Item	Content knowledge	Representation skill
(An example of a multiple-choice question) 1. To determine if a chemical reaction occurred, you should measure and compare which of the following? A. volume of the materials B. shape of the products C. properties of the substances D. mass of the reactants	***Chemical reaction:*** New substances generate during chemical reaction; property helps identify a substance and distinguish the new substance from the old one.	***None***
(An example of a mixed question)  7. The model above represents which of the following? A. a phase change B. a substance C. a chemical reaction D. a mixture (7.1) Why?	***Substance:*** A substance is made of the same type of atom throughout.	***Interpret***: generate meaning out of the representation that the model represents a same type of atom throughout, and reconstruct the concept that a substance is made of the same type of atom throughout.
(An example of an open-ended question) 13. Oxygen gas is made of oxygen molecules (O_2). (13.1) Draw molecules to represent oxygen gas. Air has oxygen in it. It also has other gases, such as nitrogen (N_2). Air is mostly made up of two gases- oxygen and nitrogen. For every one oxygen molecule, there are four nitrogen molecules. The ratio of the two gases in the air is about 1 (oxygen) to 4 (nitrogen). (13.2) Draw models to represent the molecules in the air. (13.3) Compare your drawings of oxygen and air. Is oxygen a substance or mixture? Why? (13.4) Is air a substance or mixture? Why?	(13.1)***Substance:*** oxygen gas is a substance which is made of the same type of molecule throughout (13.2)***Mixture***: air is a mixture which contains more than one type of molecule. ***Macro vs. micro***: relationships between the concept that the ratio of nitrogen to oxygen gas in air is about 4 to 1, and the molecular view of gas. (13.3)***Substance vs. Mixture***: a substance is made of the same type of molecule throughout whereas a mixture is more than one type of molecule. (13.4)***Substance vs. Mixture***: a substance is made of the same type of molecule throughout whereas a mixture is more than one type of molecule.	(13.1)***Construct***: draw 2-D molecular models to represent oxygen gas. (13.2)***Construct***: draw 2-D molecular models to represent molecules in the air. (13.3)***Interpret***: generate meaning out of the representation to decide whether oxygen is a substance or mixture. (13.4)***Interpret***: generate meaning out of the representation to decide whether air is a substance or mixture.