Using Visualization to Link Abstract Science and Everyday Experience

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Discussant: TBD
Organizers: Ji Shen, Hsin-Yi Chang

Abstract: This interactive poster symposium features research groups investigating how visualizations and aligning instructional approaches promote students' deep understanding of physical sciences. The participating studies take advantage of computerized visualizations to bridge abstract science concepts and students' intuitive ideas of physical phenomena. These studies reveal how the visualizations help students improve their understanding of science over time by employing mixed methods such as data from student performances on pre-post tests and student practices during the learning process. These posters provide insights about how students learn from visualizations and propose effective design approaches to augment the impact of computerized visualizations.

Introduction

A major challenge that educators face is that student learning and understanding of subject areas often occurs at a superficial level (e.g., Krajcik & Blumenfeld, 2006). Many teachers and researchers recognize the difficulty of promoting meaningful learning and deep understanding due to limited time, resources, tools and instructional strategies. However, with the rapid development of technology, research has emerged to provide promising evidence for how advanced technology tools can effectively transform teaching and learning practice to benefit student learning and promote deep understanding (e.g., Blumenfeld, Fishman, Krajcik, & Marx, 2000; Goldstone & Wilensky, 2008; Linn, Clark, & Slotta, 2003; Wieman, Adams, & Perkins, 2008). Specifically, this collection of studies examines the role of computerized visualizations in supporting students' understanding of physical sciences. Computerized visualizations such as simulations and dynamic models allow students access to unseen processes and abstract concepts in science. These external visualizations and models can help students form complex understandings of a given concept or phenomenon (Buckley, 2000). However, the process of student interacting with visualizations to form integrated understanding is not straightforward. Students' prior knowledge may influence their perception of phenomena and understanding of the external models (Rohr & Reimann, 1998). Moreover, students need to integrate multiple types of knowledge and skills in order to make sense of the visualizations and successfully perform their learning tasks using the visualization. Students often need guidance to interact productively with visualizations. In this symposium, eight studies investigated how students developed coherent understanding of science using computerized visualizations with various types of support. This symposium will engage participants in discussing diverse viewpoints concerning the roles, effective strategies, and beneficial features of computerized visualizations to promote deep science learning.

Purpose and Objectives

We organize this interactive poster symposium to provide a platform for the presenters and the audience to discuss how computerized visualizations can promote strong conceptual connections between classroom science and the physical world. Research suggests that many natural science concepts (e.g., atomic interactions, acceleration, electricity) are abstract and challenging for students because they cannot meaningfully connect these concepts to real observations and concrete experiences. A wide range of computerized visualizations has been created to help students learn these difficult concepts. Many of these visualizations show effectiveness in improving students' science understanding. Through the collection of the studies we aim to answer the following questions surrounding the use of computerized visualizations in science classrooms:

- *How can dynamic visualizations make science relevant to students' life?* Students encounter everyday experience such as heat and temperature, electric circuits, and physical motions. The visualizations presented in the symposium aim to embed abstract disciplinary science knowledge (e.g., atomic models, Newtonian mechanics) in contexts that are familiar with students.
- *How can visualizations help students distinguish spontaneous ideas gained from everyday experiences and scientific ideas learned in class?* As students form intuitive ideas to explain observations they make about the world, visualizations can help students distinguish and link the spontaneous ideas from scientific ideas by

providing access to unseen processes (e.g. molecular interactions) and unattainable situations (e.g. frictionless worlds).

- *How to facilitate students in developing deep understanding and inquiry skills necessary in solving complex problems?* The studies in the symposium use complex problems in the physical world such as the mechanism of airbags, global warming, and hydrogen fuel cell cars. Associated dynamic visualizations offer opportunities for students to formulate, investigate and experiment with variables, construct and evaluate explanatory models, and collaborate with peers to tackle complex problems.

To investigate these questions about using visualizations in learning science, the researchers employed different combinations of a variety of scaffolding strategies. These include sequencing physical experiments with virtual experiments, combining students' drawings with computer models, critiquing visualizations, overlaying gameplay dynamics with formalized representations, coordinating multiple visualizations, and embedding key prompts. Through the interactive symposium, we further seek the answers to the question "*what are the criteria of using different supporting strategies under certain conditions in different science content areas*?"

Session Structure and Participating Presentations

The session is planned as an interactive poster session, chaired by Prof. Marcia Linn. She will briefly introduce the session (~5m). Each presenter will then summarize their own research in one minute (~10m). Attendees will then circulate and interact with individual presenters (~50m). Presenters will bring computer-based demonstrations of the technologies used in their research. After the interaction between the presenters and the attendees, the discussant will comment on the presentations (~10m) and moderate a conversation that allows presenters and attendees to share their insights (~15m). The following section will summarize each individual presentation and list participants.

Investigating the Role of Physical and Virtual Experiments in Developing Integrated Understanding of Thermal Conductivity and Equilibrium

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Understanding science requires students to integrate multiple types of knowledge and abilities to form a coherent structure (National Research Council [NRC], 1996; Olsen, 2003). One indicator of integrated understanding is students being able to integrate scientific concepts with everyday events (NRC, 1996). Indeed, when learning the concepts of thermal conductivity and equilibrium students may show resistance to change ideas stemming from personal experience of heat and temperature (Clark & Linn, 2003; Paik, Cho, & Go, 2007). For example, students often think that metal objects have lower temperatures than wood objects and resist the idea that objects eventually become the same temperature as the room's temperature (Clark & Linn, 2003). A second indicator of integrated understanding is students being able to explain a phenomenon or scientific process in light of its mechanism. For example, when explaining thermal conductivity a core concept involves understanding of heat transfer by collisions of atoms and molecules (American Association for the Advancement of Science [AAAS], 1993). However, many middle or high school students have little or fragmented knowledge of atoms and molecules (Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993; Nakhleh, Samarapungavan, & Saglam, 2005). It is unclear how to best support students in learning the mechanism of heat conductivity and equilibrium at the molecular level.

In this study we used a week-long Web-based Inquiry Science Environment [WISE] module on thermodynamics that has been proven effective to students' science understanding (Clark & Linn, 2003) and argumentation abilities (Clark & Sampson, 2007). We particularly examine one physical and one virtual experiment activities to discern the roles of physical versus virtual experiments in developing different aspects of student understanding of thermal conductivity and equilibrium. In the physical experiment students are guided to choose six objects made of different materials to predict and measure their temperature in the classroom. We hypothesize that this physical experiment provides direct experiences and evidence for students to connect and sort scientific and personal ideas. In the virtual experiment students are guided to change parameters such as different materials to observe what happens to the atoms and molecules when heat transfers from one object to another. We hypothesize that this virtual experiment supports students in building their understanding of the mechanism of heat transfer. We implemented the Chinese version of the module in five eighth-grade classes (n=154) in South Taiwan. Data collected include pre-post test data, and learning process data including students' written responses to the prompting questions embedded in the activities, and students' action and discussion videos when students worked on the activities. Pretest to posttest gains indicate medium to large effect sizes of the module, similar to what was found in the American runs (Chang & Linn, in preparation). In-depth examination of the learning process data indicates the patterns of students' strategies in the physical and virtual experiments, the aspects and extents of student understanding mediated by the physical and virtual experiments, and the relationships between the learning process and pre-posttest phases.

Promoting Links and Developing Students' Criteria for Visualizations by Prompting Judgments of Fidelity

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Chemistry students struggle to bridge molecular, symbolic, and molecular representations of chemical phenomena. For example, students view chemical equations, such as $2H_2 + O_2 \rightarrow 2H_2O$ as math problems to solve instead of breaking and forming bonds among atoms (Krajcik, 1991). Research demonstrates that powerful visualization tools can help students add normative ideas about phenomena on a molecular level (Pallant & Tinker, 2004). However, students need support to connect these ideas to symbolic and everyday ideas, develop criteria for these ideas and sort and refine the links among ideas to build coherent understandings of complex phenomena (Linn & Eylon, 2006). Past studies show that students have rich intuitive abilities to critique representations, do well reacting to representations in design settings but have trouble articulating their ideas (diSessa, 2002). We hope to build upon these existing capabilities to help students link pre-designed, interactive visualizations to the real world and promote the development of criteria for these connections.

This poster investigates how prompting students to judge and explain how strongly the visualization relates to the real world can help students connect molecular visualizations to macroscopic ideas as well as develop criteria about visualizations. Approximately 140 high school chemistry students from two teachers participated in a week-long technology-enhanced curriculum unit about chemical reactions. As part of this curriculum, students interacted with molecular visualizations from *Molecular Workbench* and greenhouse effect visualizations in *NetLogo*. After each visualization step, students were prompted to judge the visualization as "not at all related", "somewhat related" or "very related" to the real world and then explained their choice. Significant gains from pretest to posttest items demonstrate students made connections among molecular and macroscopic levels. Analyses of students' embedded explanations show that many students judge visualizations as related to the real world because of particular examples, such as specific chemicals or reactions. Many students also articulate ideas about the fidelity, usability, and learnability of the visualizations. Overall, the data suggests that students make connections from the visualizations to the real world but but need support to build from their rich intuitive ideas and develop more sophisticated criteria for visualizations.

SURGE: Intended and Unintended Learning in Digital Games

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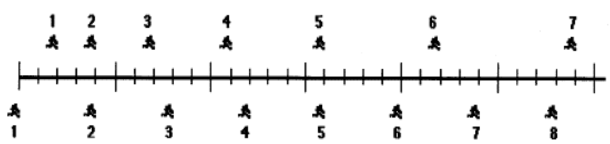
Well-designed video games can support learners in building accurate intuitive understandings of the concepts and processes embedded in the games due to the situated and enacted nature of good game design (Gee, 2007). Most commercial games fall short as platforms for learning, however, because they do not help students articulate and connect their evolving intuitive understandings to more explicit formalized structures that would support transfer of knowledge to other contexts. In Thought and Language, Vygotsky (1986) discusses the potential for leveraging intuitive understandings from everyday experience ("spontaneous concepts") with instructed scientific concepts to build robust understandings. The SURGE project (Scaffolding Understanding by Redesigning Games for Education) focuses on integrating and overlaying popular gameplay dynamics with formal physics representations and visualizations (see Figure 1 (a) for a snapshot). The design combines cognitive processing-based design and socio-cognitive scripting with design principles and mechanics of popular commercial video games such as Mario Galaxy, Switchball, Tiger Woods PGA Tour, Orbz, and Portal.

The first SURGE study analyzed 24 university students playing SURGE. The pre-post test data support the potential of games for learning, but also underscore their potential to reinforce alternative conceptions. The game actually resulted in a significant pre-post test decrease ($\chi 2 = 4.75$, $p = .029$) in correct answers for one question by unintentionally focusing students' attention on another physics relationship (we had not yet added all of the intended functionality to the interface relevant to projectile motion and the independence of the x and y components of an object's velocity), but the students demonstrated significant ($p = .037$) gains on the rest of the posttest. In post-interviews, students' understanding of the concepts and vector representations demonstrate the ways in which students' ideas evolve during the game. The results suggest that players learn about the formal instructed concepts in a manner that transfers to Force Concept Inventory items (Hestenes, Wells, & Swackhamer, 1992; Jackson, 2007), but the results also caution that the ideas that students take away from games aren't always the ones intended by the designers. A second study in November 2009 will analyze 330 students in Taiwan and Minnesota playing SURGE. Students will be randomly assigned to conditions that display or remove the overlaid vector representations. Interview data will explore how the students make use of the vector representations and visualizations within the game as well as the ways in which the game connects with students' other interests and identities outside of school.



19. While you and your friend are running, your science teacher takes measurements. Later he makes this drawing. The little stick figures show where both of you are (your positions) at every second of time. You're both running to the right.

Are you and your friend ever running at the same speed?

(A) No.

(B) Yes, at the 2nd second of time (that is, at the 2nd stick figures).

(C) Yes, at the 5th second of time (that is, at the 5th stick figures).

(D) Yes, at the 2nd and 5th seconds of time.

(E) Yes, at some time between the 3rd and 4th seconds.

Figure 1. (a) Screenshot of SURGE environment (b) A sample item from FCI.

How Do Interactive Graphing Tools Help Students Interpret Virtual Experiments about Car Collisions?

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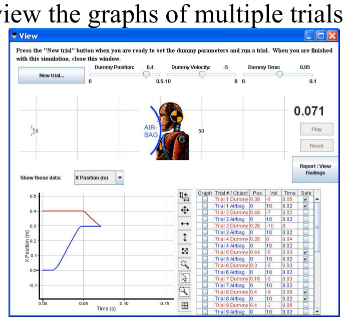
This study examines how experimentation using a visualization featuring coordinated animated and graphical representations of motion can help students reach sophisticated insights about car collisions. Airbags: Too Fast, Too Furious? is a one-week high school physics investigation about airbag safety that addresses students' understanding of motion graphs. The design of Airbags builds on research that recommends using visual representations to scaffold inquiry-based learning (Quintana et al, 2004), particularly investigations concerning motion (White, 1993). Airbags incorporates dynamic visualizations that aim to help students understand events in a car collision that occur too quickly to be observed in real time. The visualizations present coordinated animated and graphical representations that are each designed to help support students' understanding of the other (Ainsworth, 1999; Kozma, 2003).

I designed the final Airbags visualization (Figure 2a) to model the crash test videos (Figure 2b) students observe in previous activities. Students use this visualization to experiment with three motion variables to investigate what factors put drivers at increased risk for injury. The visualization allows students to categorize trial outcomes and view the graphs of multiple trials to aid in the interpretation and comparison of trial outcomes.



(a)

(b)

Figure 2. (a) Experimentation visualization (b) Crash test video used in early activities

Students (n = 168) in five diverse high schools studied Airbags in dyads. Students responded to pretests and posttests on motion graphs and embedded assessments about the airbags situation. We also videorecorded the experimentation of 12 dyads, capturing their discussions and gestures during the experimentation activity. Significant pretest to posttest gains on understanding of motion graphs demonstrate that students were able to generalize knowledge about motion graphs in Airbags to other situations. Reponses to embedded assessments show that many students achieved a sophisticated understanding of the airbags situation that involved the role of threshold values in determining collision outcomes. This poster will present case studies that illustrate how the interactive graphing tools helped students interpret their experiments in meaningful ways that extended their everyday understanding of airbags.

Transformative Modeling in Learning Current Electricity: A Case Study of Preservice Teachers

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Research finds that students have many ideas on electricity not aligned with scientific notions (e.g. Eylon & Ganiel, 1990; Thacker, Ganiel, & Boys, 1999; Osborne, 1983; Shen, Gibbons, Wiegers, & McMahon, 2007; Shepardson & Moje, 1994). It is challenging to change these conceptions. Different strategies have been employed by science educators to help students learn current electricity (e.g., Benseghir & Closset, 1996; Shaffer & McDermott, 1992; Gibbons et al., 2003; Shen & Linn, submitted). This paper presents a teaching experiment that incorporates a variety of environments including computerized modeling tools (e.g., WISE, Phet), hands-on activities, role playing, and formative assessments (see Figure 3). The activities are designed based on the transformative modeling framework (TM) used to describe, analyze, and inform learning processes (Shen, submitted). TM delineates learning and teaching as a process of modeling the natural world through chains of operations on materials. At the center of the operations are a set of transformations that alter the nature of physical or symbolic objects by adding or suppressing information (Shen, in press; Shen & Confrey, 2007). The transformed materials, as well as the operations on these materials, render potential for future learning (Shen, submitted).

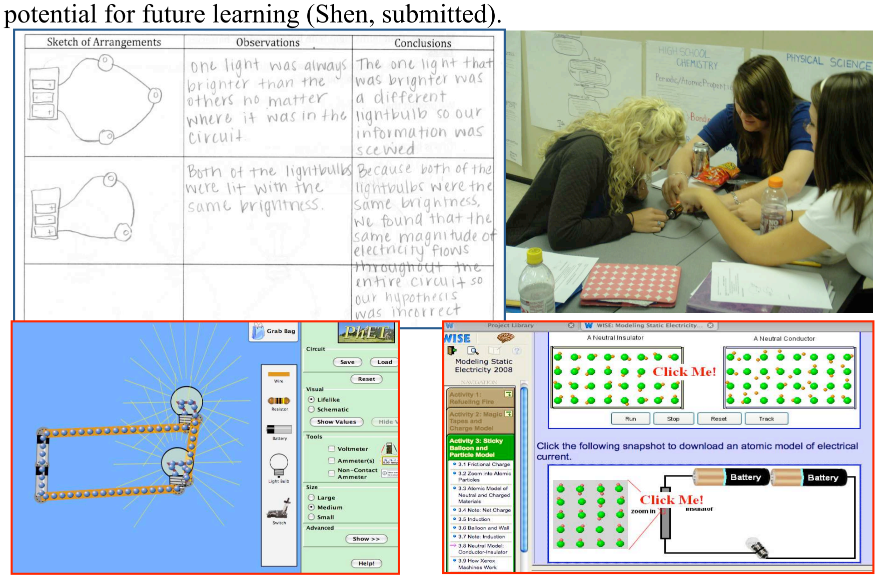

Figure 3. Students' work on current electricity.

The participants include 18 preservice middle grades teachers (17 female, 1 male). Their science background is weak based on the results of a pretest measuring general physics knowledge (25% correct). The teaching experiment lasted 2 weeks (15hours in a total). We collected online responses, videotapes, students' artifacts and formative assessment results to examine the learning processes. Preliminary findings suggest, among many others, the following message. The transformations among different forms of representations of knowledge challenge students to understand the underlying mechanism of scientific processes (e.g., transforming from a physical set-up to a computerized circuit to an electrical diagram to role play). Different models inform each other and together they help students form scientific understanding. The breakdowns of transformative links create conceptual difficulties for students on the on hand, and provide teachable moments on the other hand. The mechanism, types, and characteristics of these transformations and their implications in classroom teaching will be discussed.

Using Interactive Models to Support Content Learning through Scientific Reasoning

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This work examines how students learn scientific concepts related to the greenhouse effect by participating in scientific reasoning activities with an interactive model. A longstanding issue in science education research is the tension between teaching scientific content vs. scientific process or reasoning. Following instruction and experience, students are able to engage in valid scientific reasoning in *familiar or simple* contexts (Chen & Klahr, 1999, Kuhn & Angelev, 1976). However, there is still concern about overtaxing students' cognitive resources when they are required to engage in activities that involve using scientific reasoning strategies to learn *new* scientific content. Models are "dynamic representations and provide a visual explanation of the underlying causal mechanisms and processes underlying scientific phenomena which are not directly observable because of their scale" (Gobert, 2005). Using *interactive* models to teach science can help address the content versus process issue by allowing students to practice reasoning about scientific phenomena in rich contexts. In this study, students use an interactive model to learn about the greenhouse effect. Instruction prompts them to use a control variables strategy as they conduct multiple experiments with the model. The main goal of this work is to measure changes in students' content knowledge and scientific reasoning skills following a model based instruction experience.

In this work, 190 middle school students use an interactive model of the greenhouse effect. Pre-post tests measure content learning prior to and following the instruction experience. A subset of the items was designed to measure scientific reasoning. Additionally, log data documents how students' reasoning strategies change over time. Students engage in "simulated discovery tasks" (Zimmerman, 2000) as they use the model to conduct multiple experiments. They investigate the roles of solar energy, infrared energy, greenhouse gases, clouds, and Albedo in the greenhouse effect. Students are instructed to change only one variable at a time so that their experiments can provide valid information about the variable they are investigating. Supporting students to engage in this type of model-based instruction is an effective instructional strategy (Penner, Lehrer, & Schauble, 1998). Overall, students' understanding of the scientific content improves (t (189)=8.66, p < .001). The log data show that they use multiple reasoning strategies. Some closely follow the instruction to engage in the control of variables strategy and use it consistently in their experiments with the model. Some use the strategy after initial random exploration of the model. Others systematically manipulate two variables at a time to make comparisons. Ongoing analyses are looking at the range of reasoning strategies involved in experimentation and evaluating correlations between students' scientific reasoning and changes in their content knowledge. This work informs researchers interested in using model-based instruction that combines content learning and scientific reasoning. A more detailed presentation of the findings will extend the discussion of the complexity of supporting both of these learning goals.

Abstraction and Re-representation in Visualizations: Understanding Where the Learning Occurs

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Graphic representations (i.e., visualizations) have a long history as a tool to promote learning in science. Historically, a "craft-based" approach has been the primary strategy used to design and evaluate visualizations for use in instruction (e.g., Tufte, 1983). That is, heuristics based on practice are used to create representations that communicated, in the designer's eyes, the necessary information for student learning. More recently, a number of frameworks based on current understandings in the learning sciences have been applied to better guide visualization design and to understand why some designs are more effective than others. This paper will present an approach developed from semiotic theory (Hartshorne & Weiss, 1960) and the knowledge integration framework (Linn, 2006) for science meaning-making to develop strategies for visualization development and use in classrooms. Focusing on the knowledge-integration's component of making scientific phenomena visible, the presented work will look at the interplay of phenomena visible in the natural world with unaided senses with the conceptual and phenomenological elements of science learning that live in invisible, abstract layers. Semiotics is used to understand re-representations that move between the same level of abstraction and new representations that move toward or away from abstraction.

Student work in elementary science (Grades 2-5) was used as data source for validating this new approach to understanding student meaning-making through visualizations. A stratified sample of notebooks (M=7) were taken from 7 classrooms (4 Grade 2 and 3 Grade 5) for a total of 45 notebooks. From these notebooks, student entries for all activities relating to two science kits (EDC, 2004; FOSS, 2008), one per grade, were analyzed—a total of 1195 pages. Student entries were coded based on dimensions related to the context of the work (science learning goal, phase of inquiry), and the type of entry (text, graphic, mixed). For the graphic entries, the level of abstraction, how the abstraction was represented in the graphic, and the relationship of the graphic to complimentary text were coded in order to chart the moves in relation the meaning-making goals, as defined by the curriculum. This analysis will provide insight for the design of future, computer-based systems and how they may differ from those currently being designed for later school grades. Better understanding these moves and their role in learning provides new approaches to the creation of computer-based visualizations specifically designed for elementary science contexts.

Exploring Drawing and Critique to Enhance Learning from Visualizations

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Many chemistry students struggle to make sense of chemical phenomena at the molecular level (Johnstone, 1993). They have difficulty visualizing a chemical equation (e.g., $2H_2+O_2 \rightarrow 2H_2O$) as a chemical reaction that involves atom rearrangement and bond breaking and formation (Krajcik, 1991). As a result, they cannot form deep understanding of chemical concepts by linking ideas at the molecular, symbolic, and observable levels. Dynamic visualizations have potential to meet this challenge by demonstrating changes at the molecular level. Nevertheless, many visualizations are confusing (Tversky, Morrison, & Betrancourt, 2002), and often students are beguiled by their deceptive clarity (Chiu & Linn, in press). They need support to add ideas at the molecular level and connect with ideas at other levels. My previous research (Zhang & Linn, 2008) has suggested that creating drawings is an effective approach to promote student learning. Yet it requires more instructional time and may not be efficient. Critique may be another candidate to effectively support students' learning. In this study we explore this two ways.

This study reports student learning with a dynamic visualization embedded in an inquiry-based WISE curriculum unit entitled *Hydrogen Fuel Cell Cars* (Linn & Hsi, 2000). In the project, students first learned chemical reactions by interacting with the visualization showing molecular interactions during hydrogen combustion. They then drew four pictures to represent intermediate phases of the reaction (drawing condition), or critiqued two sets of pre-made drawings aiming to demonstrate the same information (critique condition). The drawings to be critiqued were designed to capture various ideas held by students from previous studies (Zhang, 2007). At the end of the project, students need to use integrated ideas about atomic reactions, cars, and fuel economy to analyze the advantage and disadvantage of hydrogen fuel cell cars.

High school chemistry students (N=73) participated in this study (critique condition: n=48; drawing condition: n=25). Both groups of students gained significantly [drawing group: $p<.001$, effect size=2.17; critique group: $p<.001$, effect size=1.73] after the project. Students were able to integrate ideas such as bond breaking and formation with prior knowledge and use these ideas to explain observable phenomena and other chemical reactions. There was no significant difference in the two groups of students' posttest scores after controlling for pretest scores [$t(70)=.17$, $p=.87$]. Further analysis of students' embedded assessments and log files of interaction with the visualization suggests that drawing supports learning by enabling students to distinguish among ideas and recognize gaps in their knowledge. Students are prompted to revisit the visualization for nuanced information. Critique, in contrast, requires students to distinguish their own ideas from the ideas they critique. Students also revisit the visualization to solve conflicts between ideas.

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