

# Collaboration as Scaffolding: Learning Together with Dynamic, Interactive Scientific Visualizations and Computer Models

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**Abstract:** Modern technology not only greatly expands the variety of media available for science learning (e.g., dynamic computer visualizations, interactive simulations, computer-based modeling environments), but also significantly enhances opportunities for supporting collaborative learning. The studies in this symposium examine collaboration as a scaffolding strategy in science classrooms that use technology-enhanced visualizations to aid student learning. Together, they consider various forms of collaboration, including co-construction, critique, discussion forums, knowledge distribution, and peer instruction in technology-enhanced learning environments. This interactive poster session will engage presenters and participants in a conversation that explores the following questions: What opportunities exist for different forms of collaboration in science learning environments that employ interactive visualizations? How can we best design technology-enhanced science visualizations to foster collaborative learning? How can we harness the power of interactive visualizations to enhance the effectiveness of collaborative learning? What are the affordances and constraints of different forms of technology-enhanced collaboration for students trying to understand complex scientific topics?

## Introduction

This interactive poster symposium explores science learning at the intersection of visualization and collaboration. Scientific visualizations are not only essential to the work of scientists; using dynamic, interactive computer-based visualizations offers many advantages to support students' learning of science as well. Abstract science concepts are made visible through multi-media representations (Ainsworth, 1999; Linn, Clark, & Slotta, 2003); correlations among multiple variables in a complex system can be simulated through computer models (Wilensky, 2008; Wu, 2010); nuanced, dynamic science processes can be carefully examined through manipulative features (Wieman, Adams, & Perkins, 2008), and the interactivity of computer visualizations scaffolds student-directed learning (Quintana, Zhang, & Krajcik, 2005).

However, the open-endedness that computer visualizations afford, as well as the complex dynamics between learner-computer, learner-learner, and learner-teacher interactions, introduce challenges to educators and designers of technology-enhanced science visualizations. One challenge is to understand the *role of collaboration* in learning environments equipped with dynamic visualizations and computer models. Collaboration has become a standard practice in frontier scientific research and development (Rhoten & Parker, 2004). Incorporating scientific visualizations into innovative learning environments offers opportunities for various forms of collaboration, which can also be viewed as scaffolds to help students take advantage of complex visualizations. For instance, students can work together to control the pace and direction of a visualization, or to set parameters that influence what will appear on the display (Betrancourt, 2005; Hegarty, 2005; Tversky et al., 2002).

## Purpose and Objectives

This symposium is organized to provide a platform for participants to discuss how collaboration as a scaffolding mechanism can strengthen the use of computerized visualizations to promote students' inquiry in science learning. Although collaborative learning has become a popular element in technology-enhanced learning environments in science education, many questions remain unanswered as to how various forms of collaboration can be best combined with the learning opportunities offered by dynamic science visualizations (Lei & Shen, this symposium). Therefore, this interactive symposium invites presenters and the audience to engage in a dialogue that addresses the following questions: How have various forms of collaboration been designed and enacted in science learning environments that employ interactive visualizations? What are the affordances and

constraints of different forms of technology-enhanced collaboration for students trying to understand complex scientific visualizations? How can we best design technology-enhanced science visualizations to foster collaborative learning? How can we harness the power of interactive visualizations to enhance the effectiveness of collaborative learning?

To initiate an response to these questions, this symposium gathers studies that employ different forms of collaboration as scaffolding to support students in learning with interactive dynamic visualizations, including co-construction, critique, discussion forums, knowledge distribution, and peer instruction. Students may co-construct computer models to explore scientific phenomena or solve complex problems (Wu, 2010; Zhang, et al., this symposium; Xie, this symposium), critique each other's work to establish criteria for evaluating visualizations (Hsieh & Chang, this symposium; Schwendimann, this symposium; Shen, 2010), contribute to online discussions with their classmates on evidence related to a particular visualization (Clark, D'Angelo, & Menekse, 2009), and work in pairs or small groups to solve everyday relevant problems while developing inquiry and metacognitive skills (Chiu, this symposium; Linn, 2006; Matuk & King Chen, this symposium). These various collaborative opportunities in visualization-rich learning environments have been designed to help students to develop the skills and mindsets necessary to succeed in today's technology-enhanced world.

In sum, this symposium will provide opportunities for the CSSL community to further our understanding of collaboration as a scaffolding strategy to enhance students' learning through visualizations in science.

## Session Structure and Participating Presentations

The session is planned as an interactive poster session, chaired by Dr. Marcia Linn from the University of California, Berkeley. The session will proceed as follows. Dr. Linn will briefly introduce the session (~5m). Presenters from each study will then summarize their own research in one minute (~10m). Attendees will then circulate and interact with individual presenters (~50m). When applicable, presenters will bring computer-based demonstrations of the technologies used in their research. After the interaction between the presenters (as panelists) and the attendees, the discussant, Dr. Hsin-Kai Wu from the National Taiwan Normal University, will comment on the presentations (~10m) and moderate a conversation that allows presenters and attendees to share their insights (~15m). The following section summarizes the individual presentations for this symposium. The first six posters are based on empirical studies and the last two combined posters report results of comprehensive synthesis reviews.

### Poster1: Student Collaboration to Generate Scientific Principles during Online Peer Critique Versus Direct Feedback Activities

Fang-Pei Hsieh and Hsin-Yi Chang, National Kaohsiung Normal University, Taiwan

We used a week-long Web-based Inquiry Science Environment [WISE] (Linn, 2006) curriculum, *Thermodynamics: Probing Your Surroundings* (Clark & Sampson, 2007) to engage 71 7th grade students in Taiwan in learning heat and temperature. We incorporated an *online peer critique* activity at the end of the *Thermodynamics* curriculum to promote students to collaboratively generate scientific principles of heat and temperature phenomena from their learning with computer visualizations in the curriculum that depict the observable phenomena and underlying mechanism of thermal conductivity and equilibrium. In another version of the *Thermodynamics* curriculum we replaced the *online peer critique* activity with an *online direct feedback* activity in which students were guided to respond to conceptual questions and receive direct feedback from the computer on their responses in light of the correctness. The conceptual questions targeted students' concepts of heat and temperature necessary for students to generate the scientific principle. The design of the *online direct feedback* activity is based on conventional instruction practices in which teachers formatively assess students' content knowledge and provide feedback on the correctness when students show alternative conceptions. In comparison, the use of *online peer critique* activity is based on research calling for collaborative learning in science classrooms (NRC, 2007) and on empirical studies showing the benefits of critique or reflective activities for promoting integrated understanding (Chang, Quintana and Krajcik, 2010; Linn, Chang, Chiu, Zhang & McElhaney, 2010; White and Frederiksen, 1998).

Two classes of 7th-grade students taught by the same science teacher at a public junior high school in South Taiwan were randomly assigned to either the online peer critique or direct feedback condition. In both conditions each dyad of students worked collaboratively in front of a desktop computer. In the online critique condition student dyads were guided to critique scientific principles of thermal conductivity and equilibrium made and posted by other dyads through the online discussion forum in the curriculum. In the direct feedback condition, after generating their scientific principle, student dyads were guided to respond to multiple-choice questions on related concepts and receive feedback. After either the critique or feedback activity the curriculum in both conditions guided students to revisit and revise their scientific principles. Data collected include pre-post tests, video recordings of student actions and discussions, and students' digital critiques or responses. We

analyzed and compared collaboration promoted by the online critique versus direct feedback activities. Initial results indicated that students in both conditions performed equally well on the pre-post tests. Moreover, results from process videos indicated different dynamics, scales and uses of resources during student collaboration within and across the online critique and direct feedback activities. The collaboration in the *online peer critique* group involved larger scales of participants and resources but also more confusions and uncertainties than the collaboration in the *online direct feedback* group.

## **Poster2: The WISE Idea Manager: A Tool to Scaffold the Collaborative Construction of Evidence-Based Explanations from Dynamic Scientific Visualizations**

Camillia Matuk and Jennifer King Chen, University of California, Berkeley

Collaboratively constructed explanations not only help students connect claims with evidence; they can also promote productive argumentation in scientific inquiry (Bell, 2004; Suthers & Hundhausen, 2001). However, this can be challenging with topics that require learners to select, manage, and integrate multiple pieces of evidence from various sources. In this poster, we present the Idea Manager, an innovative tool to help students construct coherent explanations of complex scientific phenomena. In particular, we illustrate its use in Investigating Planetary Motion and Seasons, an online curriculum that guides students' inquiry into the causes of the seasons.

Individuals of all ages struggle to correctly explain why seasons occur (e.g., Baxter, 1989; Schneps & Sadler, 1994; Atwood & Atwood, 1996). Most mistakenly attribute seasonal variations in temperature to changes in the distance between the Earth and the Sun (e.g., Bakas & Mikropoulos, 2003). This is not surprising, since the correct explanation for the seasons – that the Earth's tilt causes changes in the intensity of sunlight – is not immediately apparent from students' personal experiences. Moreover, negotiating a coherent, shared explanation requires students to coordinate various direct and indirect observations from multiple sources, and to critically evaluate and use these as scientific evidence.

Investigating Planetary Motion and Seasons, a technology-enhanced high school curriculum unit designed with the WISE platform (Slotta & Linn, 2009), addresses these issues by: (1) Providing interactive visualizations for students to investigate seasons through inquiry and experimentation, and (2) Scaffolding students' learning from these visualizations with the Idea Manager. The latter provides a space in which student partners can record their developing ideas; and tools to promote their critical selection of evidence, strategic organization of information, and construction of coherent, evidence-based explanations. Customizable annotation, tagging, and flagging features prompt students to justify their interactions with the visualizations, to articulate their interpretations of the outcomes, and to make explicit connections between the evidence gathered and different possible explanations for the seasons. Finally, activities with the Idea Manager are designed such that students must negotiate all decisions with partners. Thus, they provide multiple opportunities for students to collaboratively build upon their own and others' ideas toward more normative understandings.

By elaborating on the principles behind the design and integration of the Idea Manager into an online science inquiry unit on the seasons, we consider how the design of technological tools can support students' collaborative sense-making of complex phenomena, and ultimately impact their learning.

## **Poster3: Investigating the Role of Collaboration on Monitoring Understanding with Dynamic Visualizations**

Jennifer Chiu, University of Virginia

This study explores how collaboration can help learners monitor their understanding of dynamic visualizations. Although research demonstrates the overall benefit of dynamic visualizations on learning (Hoffler & Leutner, 2007) various studies with animations or dynamic visualizations compared to static representations produce mixed results. In particular, dynamic visualizations that enable learners to control information delivery, manipulate parameters or content, or rotate objects in a screen can facilitate complex understanding and reasoning (Stieff & Wilensky, 2003). However, this kind of interactivity can also present challenges to learners. Learners need to have appropriate self-monitoring skills to know when to stop, restart, or manipulate variables to remedy gaps in understanding (Zahn, Barquero & Schwan, 2004). Learners can be distracted by perceptually salient aspects of visualizations, fail to focus on conceptually relevant aspects, or neglect to investigate the visualization as a whole (Lowe, 2004). Research suggests that training learners in self-monitoring strategies can improve conceptual understanding in hypermedia environments (Azevedo & Cromley, 2004). However, most existing studies use individual subjects and there is very little research focusing on the role of collaborative learning with dynamic visualizations, especially regarding monitoring (Ainsworth, 2008).

This poster explores how collaboration can benefit learning with dynamic visualizations by encouraging learners to collectively monitor their understanding. This poster explores how high school students collaboratively monitor their understanding using dynamic molecular visualizations of chemical reactions.

Students worked in pairs on a week-long computer-based inquiry chemistry unit that featured dynamic visualizations embedded within instruction that encouraged knowledge integration (Linn & Eylon, 2006). Analysis of videotapes and embedded data from the computer-based environment revealed that students working in pairs helped each other notice and focus upon different parts of visualizations, encouraged each other to revisit the visualization to either confirm or rectify misunderstandings, encouraged each other to explain concepts to one another, and spurred each other to interact with the visualizations by changing different parameters or content. This poster offers insights into how collaboration can help students use dynamic visualizations more effectively.

#### **Poster4: Learning Evolution through Collaborative Critique-focused Concept Mapping**

Beat A. Schwendimann, University of California, Berkeley, Beat.schwendimann@gmail.com

The theory of evolution is a unifying theory of modern biology, and notoriously difficult for students to understand (Alters & Nelson, 2002; Bishop & Anderson, 1990). Many students continue to use 'need' instead of 'mutation' to explain evolutionary change, even after years of instruction (Shtulman, 2006; Southerland, Abrams, Cummins & Anzelmo, 2001). This study hypothesizes that the continued use of the concept 'need' is sustained by a disconnection between phenotype-level and genotype-level concepts. The relationships between phenotype and genotype concepts are fundamental to the understanding of heredity and development of organisms (Mayr, 1988). Making these connections visually explicit may help students build a more coherent understanding of evolution. A week-long technology-enhanced curriculum on human lactose tolerance, *Gene Pool Explorer*, was developed and implemented in four 9<sup>th</sup> grade biology high school classes (n=96). The project includes scaffolded inquiry-based dynamic population genetics visualizations and two collaborative concept-mapping activities to explore the connections between genotype and phenotype concepts.

This study investigates how student dyads learn from an inquiry-based evolution curriculum by either co-constructing concept maps or co-critiquing concept maps. Traditionally, students generate concept maps from scratch, which can be time-consuming and challenging, especially for students with low prior knowledge (Schwendimann, 2008). As an alternative, students receive pre-made concept maps that include commonly found alternative ideas. Concept maps in both treatment groups (*generation* and *critique*) consisted of the same concepts and had a drawing area divided into the domain-specific areas of genotype and phenotype to make connections within and across areas explicit. Students had to generate their own criteria to critique the maps and negotiate with their partner on how to revise the map. Pretest and posttest essay items were scored using a five-level knowledge integration rubric (Linn, Lee, Tinker, Husic & Chiu, 2006). Concept maps were scored on a propositional level using the knowledge integration concept map rubric (Schwendimann, 2008) and on a network level.

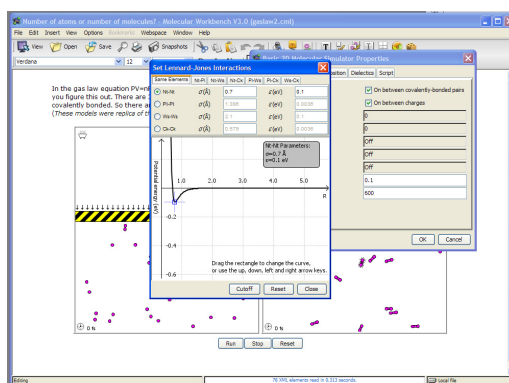
Students in both treatment groups gained significantly from pretest to posttest. Students in the critique group used the alternative idea 'need' significantly fewer times in their posttest answers than the generation group. Students with low and medium pretest knowledge in the critique group improved their overall posttest concept map score more than students in the generation group. Students in both treatment groups created significantly more cross-connections between phenotype and genotype concepts in the posttest map. Students in both groups created significantly more links to the concept 'mutation' in the posttest concept map than in the pretest map, with the critique group showing larger gains. Findings indicate that the curriculum *Gene Pool Explorer* helped students make connections between genotype and phenotype concepts explicit. The concept 'mutation' became more connected, while the alternative idea 'need' was used fewer times. Findings suggest that collaborative concept map critique activities can be a beneficial alternative to generating concept maps, in particular for students with low pretest knowledge. The findings from this study can be valuable for informing the design of effective collaborative learning environments to support a more integrated understanding of evolutionary biology.

#### **Poster5: Collaborative Problem-solving with the Molecular Workbench**

Charles Xie, Concord Consortium

Learning can be enhanced when students are challenged to collaboratively design simulations that answer a question or solve a problem. We conducted a pilot study that addresses collaborative learning in conjunction with problem-based (Dochy, Segers, Van den Bossche, & Gijbels, 2003; Hmelo-Silver, 2004), challenge-based (Apple, 2008), or project-based learning (Krajcik & Blumenfeld, 2006; Polman, 2000). We have built a number of supporting mechanisms into our Molecular Workbench software (<http://mw.concord.org>), a cyberlearning tool used to teach a wide variety of science concepts using interactive simulations. These mechanisms include 1) a web service that allows students to work on the same activity side by side and create a joint report for the teacher; 2) a web service that allows students in a class to see one another's creations; 3) an easy way to download and revise any public simulations; 4) an easy way to publish students' own simulations.

Our pilot studies show that students can come up with surprisingly creative solutions to complex problems. The collaborative mechanisms played an important role in students' intellectual processes. For example, one student specifically commented: “ [the Molecular Workbench] allowed me to explore in a way unimaginable before when I built a fuel cell simulation step by step myself. I could let my curiosity flow by exploring how each editing tool affected my creation. I could also see other simulations built by students from around the world. Thus, I was able to learn in two ways—by attempting my own experiment and by analyzing other simulations.”



**Figure 1.** Screenshot of Molecular Workbench: High School and College Students Can Design Virtual Experiments about Gas Laws and Share Them with Others and Collaboratively Evolve Their Ideas.

It is important to note that while students shared their work with others and were inspired by others' work, we found no evidence that they would just copy one another's simulation or duplicate an existing simulation from the Internet. While collaborating on constructing simulations, students worked together to iterate through many steps of trial-and-error. Our pilot study suggests a pedagogical model that can be broadly useful in developing effective instructional strategies involving interactive, visual simulations. Our future work is to identify more specifically the cognitive mechanisms involved in collaborative modeling, such as the collective intelligence factor (Woolley et al., 2010).

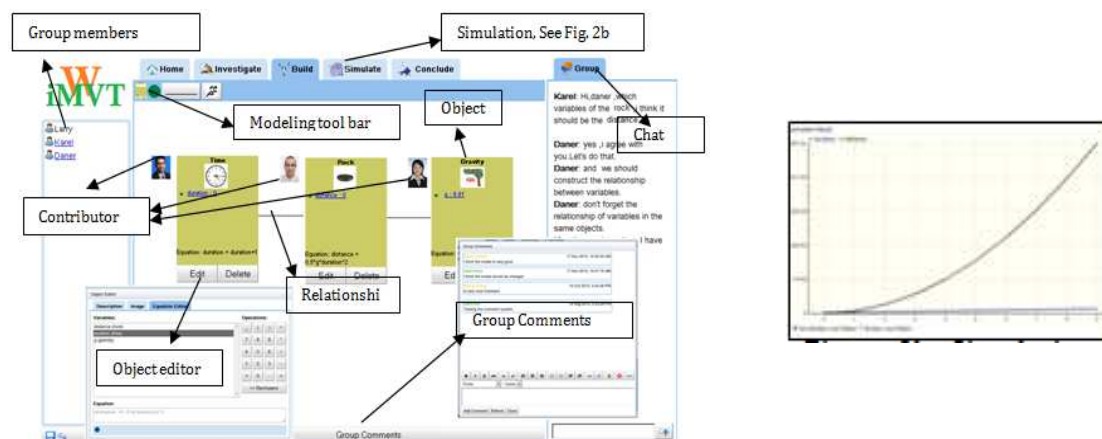
## Poster6: Developing A Web-based Modeling and Visualization Technology Integrated Inquiry-based Science Learning (WiMVT) Environment for CSDL

Baohui Zhang, Daner Sun, Karel Mous, and Quee Boon Koh, Learning Sciences Lab, National Institute of Education, Nanyang Technological University, Singapore

It has been challenging to allow K-12 students to be engaged in authentic scientific practices such as modeling, visualization, and collaborative inquiry to facilitate meaningful learning. Over about five years of intensive school-based studies following a design research tradition, a group of researchers in Singapore have distilled their intervention in their pedagogical design as an iMVT (**Modeling and Visualization Technology Integrated inquiry-based Science Learning** approach) that applies to science learning in general (Zhang, Ye, Foong, & Chia, 2010). The pedagogy was substantiated by a series of curriculum features when integrating inquiry skills, such as asking questions, designing investigations, collecting data, analyzing data and making conclusions, in modeling and visualization practices. In order to sustain and scale up the innovation, we are developing a web-based iMVT system called WiMVT to integrate useful curriculum features systematically.

Innovative learning environments need to support individual as well as collaborative learning (Kreijns, Kirschner, & Jochems, 2003; Stahl, Koschmann, & Suthers, 2006). In addition to features that support iMVT practices (e.g., *simulate*, *validate*), the WiMVT system also includes social technologies such as the *synchronized chat* function and *real time collaborative modeling* feature. The *real time collaborative modeling* feature is a unique component through concurrent interactions among group members and can be reviewed by teachers and group members publicly (Figure 2a,b). The iMVT framework, user-centered, and simultaneous construction of models as CSCL are among a series of design principles. This real time collaboration environment is realized through shared workspace which is a commonly used means for synchronous collaboration (Gutwin & Greenberg, 2002). Other concurrent communicative tools such as a *chat* dialog and *group comment* box are provided for students to exchange ideas and learn together through examining different points of view in their modeling process (Marttunen & Laurinen, 2007). Meanwhile students get quick feedback from their group members or teachers through these tools. To accommodate more students with varied cognitive abilities, progressive modeling approach is integrated for students to master the gradual transition from qualitative modeling to quantitative modeling. The features of collaborative modeling provides students with

different cognitive abilities and flexibility to co-construct a model that allows the elaboration and negotiation of diverged thinking to converge and approximate that of experts (Wu, 2010; Zhang, et al., 2006).



**Figure 2 (a).** The Collaborative Modeling Core Feature of the WiMVT System; (b) Simulation Interface.

The WiMVT system is currently capable of concept visualization through collaborative quantitative modeling. The remaining learning management features that further facilitate collaborative inquiry are still under development. The current system still allows inquiry to be done by using the simplified inquiry process “investigate, build, simulate and conclude” and supplementary curriculum materials. Usability tests have been done when pairs of volunteers co-construct quantitative models. The research report of usability tests is based on process videos, surveys, and participants’ debriefing interviews. The tests help to improve the existing design and show direction on the development.

### **Poster7&8: Collaboration in Technology-enhanced, Modeling-based Instruction (TMBI) Environments in Science Education**

Jing Lei, Heng Luo, Sunghye Lee, Syracuse University [Part I]

Ji Shen, Bahadir Namdar, Rutchelle Enriquez, University of Georgia [Part II]

Well-designed technology-enhanced, modeling-based instruction (TMBI) environments can help students not only learn science knowledge, but also develop modeling skills and metacognitive habits of mind (Stratford, Krajcik, & Soloway, 1998; White, 1993). TMBI helps amplify the power of traditional model by providing new representational system (Dimitracopoulou & Komins, 2005). Many computer-based modeling environments for K-12 science instruction have been developed over the last two decades (Linn & Hsi, 2000; Stratford, 1997; Wieman, Adams, & Perkins, 2008), such as *Model-it*, *MolecularWorkbench*, *NetLogo*, *PhET*, and *Wise*. These TMBI environments often support peer collaboration and interactive computer visualization (e.g., Linn, Clark, & Slotta, 2003).

Collaboration is critical in MBI because students need to be engaged in socially mediated construction of science knowledge, and social interactions can help students develop, negotiate, and revise their models about science concepts (Komis, Ergazaki & Zogza, 2007, Penner, 2001). In practice, students often work in various collaborative formats in these innovative learning environments to share resources or strengthen modeling practices (Barnea & Dori, 1999; Linn et al., 2006). However, although collaboration is often embedded in TMBI environments, little research has been conducted to examine how collaboration occurs during the modeling process and how it can be facilitated by computer technology. Moreover, the role of collaboration in a TMBI environment in terms of individual student learning outcome is contested: e.g., students may see collaboration as an opportunity to reduce workload (Barab et al., 2000); students get less opportunity to manipulate the technology (Metcalf & Tinker, 2004). We address these questions in two related literature synthesis studies. With different foci, both studies review and synthesize empirical studies on TMBI in K-12 science education that were published during 1980 to 2010.

#### **Part 1—Collaboration and Technology Design**

This synthesis study aims to examine what and how technology can facilitate student collaboration during model development. Specifically, we focus on three research questions: (1) What technology tools are effective in supporting collaboration in MBI learning environments? What are their key design features? (2) What types of collaboration are supported by computer technologies? And (3) What are the instructional strategies to facilitate technology-supported collaboration in MBI? Our preliminary findings suggest:

- Most technology tools used in MBI science learning environments are software-based applications that enable science model construction through simulation or programming, and Internet is often integrated to support student's modeling activities and collaboration. The key design features that support collaboration include: allowing students to simultaneously work on the same task, making thinking process visible for peers and instructors, emphasizing norms of discourse to facilitate discussion, providing immediate feedback to construct coherent conversation, and creating a low-stress environment for collaboration.
- Collaboration in classroom settings among small groups is the most common type supported by computer technologies. Tele-collaboration is also supported by web technology to engage students in communicating and collaborating with peers at distance on science modeling building. Major collaborative learning activities include: students with different expertise work as a team and teach each other; students discuss or debate over complex phenomena or confront misconceptions; students share, evaluate or critique each others' ideas or models.
- The effective strategies to facilitate technology-supported collaboration in MBI include: use technology to engage students in authentic project-based or inquiry-based learning so that students are more likely to work together in or outside class; direct students to specialize in different topics so that they can teach each other and develop explaining skills; highlight differences in models' behavior (between different groups, between exhibited and desired, or between different sites) and encourage students to confront such discrepancy through discussion and debate.

## **Part 2—Collaboration and Student Learning**

This synthesis study examines the role of collaborative learning on students' learning outcome in TMBI. We describe how different types of collaboration in a TMBI environment can help students learn science concepts more effectively. We provide taxonomy of collaborative formats and modeling skills based on existing literature about collaboration, use of technology in the science classrooms, and modeling opportunities for students. We present affordances and constraints of such collaborative formats. The major findings, among others, include:

- Classroom collaboration has different levels. Individual, local, and public spaces are often intertwined when students discuss and negotiate how to build the best model (Barab et al., 2000).
- Co-constructed model can be a "reified object" of which students generate collaborative discussion to further their learning (Penner, 2001; Hogan & Thomas, 2001). Comparing to a physical object, typically, a computerized model has several advantages in enhancing students' learning (e.g., portability, interactivity, and transformability).
- Argumentation in these collaborative settings can help students come up with better models and in-depth understanding (Ergazaki et al., 2005; Fazio et al., 2008; Sins et al., 2005).
- When modeling complex phenomena with multiple variables, students working in pairs or small groups may help each other to start to make sense of the interconnected variables (Hogan & Thomas, 2001; Wu, 2010;).
- Benefits notwithstanding, collaboration rarely enters the equation of outcome measurement. This may be because there is no well-defined measure of collaborative ability.

We call for innovative ways for researchers to consider new lenses to look through in examining how to measure the increase of understanding of students within or outside collaborative opportunities in TMBI.

## **Concluding Remarks**

The empirical studies in this symposium explore different forms of collaboration in innovative environments that employ dynamic visualizations to support students' understanding of abstract science concepts. Meanwhile, the review studies examine the role of collaboration in TMBI environments, in which computer visualization is a central component. Together, they suggest insights into the roles of collaboration and visualization. Collaboration may enhance the benefits of visualizations by supporting students in integrating science knowledge, explaining scientific phenomena, solving complex problems, and monitoring their understanding. It is of great value to further understand the affordances and constraints associated with different collaborative forms and methods (e.g. co-construction vs. co-critique for students with different prior knowledge) in order to make collaborative learning through visualizations more successful. Furthermore, collaboration that blends local and public levels (e.g., a group of students may evaluate a visualization generated by another group) presents both opportunities as well as challenges in designing visualization-rich learning environments.

This symposium will generate meaningful dialogue and lively interaction among presenters and audience members. It will also be a chance to initiate future research collaborations. Contributions from the audience's multiple perspectives will help further our collective understanding of the roles and mechanisms of collaboration in innovative learning environments and how to best facilitate successful collaboration to help students take advantages of learning with visualizations.

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