Student and Teacher Regulation of Learning in Technology-enhanced Science Instruction

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Abstract: This study investigates student and teacher regulation of learning during a 7-day technology-enhanced inquiry unit on the topic of global warming, and changes in students' strategies for learning science after interacting with the curriculum. Results reveal that students engage in some productive learning strategies promoted in the design of the project, such as learning with visualizations and collaborating with others. Students reported the visualizations to be the most helpful to their learning. The teacher provided the most guidance to students in the form of high-level questions that prompted students to make connections and to monitor their comprehension during days when the students interacted with the visualizations. After completion of the project, students reported engaging in more active and productive strategies for learning and monitoring their understanding of new science material. Implications and plans for further research are discussed.

Inquiry-based science learning and teaching can be enhanced by the use of technology in the classroom (Bransford, Brown, & Cocking, 1999; Linn, Davis, & Bell, 2004). However, integration of inquiry-based science curricula and technology integration can be difficult for teachers and students. Given the more student-directed versus teacher-delivered aspects of both inquiry and technology-enhanced learning, learners must be skilled at regulating their own learning and teachers must be prepared to manage a variety of learners who are progressing at different rates.

Many students lack the self-regulated learning strategies needed to be successful in these types of learning activities (Azevedo, Cromley, Winters, Moos, & Greene, 2005; Quintana, Zhang, Krajcik, 2005; White & Frederikson, 2005). Specifically, students need to know what to learn, how to learn it, how to monitor their understanding of the topic, how to monitor the effectiveness of their learning strategies, and how to revise their strategy use and understanding of the topic if needed (Azevedo et. al, 2005; Jonassen & Reeves, 1996). Azevedo and colleagues have found specific aspects of self-regulated learning to be associated with increased understanding of complex science topics in hypermedia learning environments (Azevedo et. al, 2005, Green & Azevedo, 2007) and developmental differences of self-regulated learning strategy use. Younger students were much less likely to use effective self-regulated learning strategies than high school and college students. This suggests that younger students need more guidance when learning complex science concepts with technology-enhanced curricula.

Guidance for students in technology-enhanced inquiry learning environments often comes from the teacher or from various types of cognitive tools and scaffolds built into the technology. This scaffolding has potential to increase students' understanding by making aspects of metacogniton more explicit, (Lajoie, 1993; Quintana, Zhang, Krajcik, 2005; White & Frederikson, 2005) prompting reflection, (Davis, 2003) and making students' thinking visible (Linn, Clark, & Slotta, 2001). Quintana and colleagues (2004) offer suggestions in their scaffolding design framework for ways to support students' sense making, process management, and articulation and reflection in technology-enhanced learning environments in science. Linn and Eylon (2006) discuss patterns of instructional design and how these patterns influence the process of students' knowledge integration, which involves students monitoring their ideas to determine how new ideas relate to previous ideas. Adaptive scaffolding from human tutors, peers, and teachers can also support students' metacognitive monitoring and understanding during technology-enhanced learning situations (Chi, Siler, & Jeong, 2004). This research demonstrates the importance of metacogniton and self-regulated learning in students' ability to be successful in technology-enhanced inquiry curricula.

In this study we investigate students preferences for learning new science material both before and after their interaction with technology enhanced inquiry curriculum. We also examine student and teacher regulation of learning during a 7-day technology-enhanced inquiry unit on the topic of global warming. The teacher involved in the study is participating in a 5-year NSF grant funded professional development project, MODELS (Mentored and Online Development of Educational Leaders for Science). The program is designed to enable schools to implement technology-enhanced inquiry instruction by supporting teachers as they plan, implement, and reflect on their experiences using the technology in the classroom. The teacher has participated in the project for 3 years and has attended a summer professional development workshop each year focused on teaching and assessment strategies to help students learn with the technology-enhanced curricular projects.

The purpose of this study is to answer the following questions: (1) What self-regulated learning processes do students engage in during the technology-enhanced inquiry curricular project? (2) How does the teacher use questioning strategies to regulate and scaffold students' learning? and (3) How do students' preferences for learning science material change after interacting with the curriculum? This study serves as a first step to investigate how students learn with technology-enhanced curricula and how teachers scaffold student learning, which will inform the design of technology-enhanced inquiry learning environments, professional development, and instructional strategies for teachers to better support student learning within these environments.

Methods

Participants

Participants were 141 mixed-ability sixth grade science students from an ethnically and economically diverse school in the San Francisco Bay Area. All students were enrolled in a science class taught by the same teacher. The teacher has 33 years teaching experience. He has taught science for 20 of the 33 years, and has been using WISE curricular projects for 3 years.

Learning Environment

Students completed a computer-based unit on the topic of the Greenhouse Effect and global warming using the Web-based Inquiry Science Environment (WISE; http//wise.berkeley.edu). Students conduct experiments with a greenhouse effect visualization by manipulating levels of solar energy, atmospheric carbon dioxide, Albedo, sunlight, and cloud cover. Following their investigations, students draw conclusions about the role of the different factors involved in the greenhouse effect (Varma, 2006). The project engages students in various collaborative activities, such as designing solutions to problems, investigating hypotheses, and critiquing scientific claims.

Procedure

Participants individually completed pre and post-tests measuring their preferences for learning new science content, comprehension monitoring strategies, and content knowledge of the greenhouse effect. Students spent 7 days working in pairs through the Global Warming Project during their science class time. After completion of the project, students completed a questionnaire about their learning behaviors when working with the WISE project.

Data Sources

Pre/Post Tests

The pre/post tests consisted of 6 likert-scale items about students' preferences for learning new science material. Students were given the prompt, "When learning new science material I prefer to …" and then circled either always, sometimes, or never for six common strategies for learning science (e.g., be told what is correct by the teacher, do experiments and try to figure things out, discuss material with classmates). Additionally students responded to two items, one multiple choice and the other free response, about their strategies for monitoring their understanding of new science material. Students also answered 4 free response questions about the greenhouse effect and global warming.

Classroom observations

A University researcher observed both teachers and students during 4 of the 7 days of the project for approximately 1.5 classes each day. Observations of the teacher's actions were recorded on an observation form containing specific categories: general interactions, working with visualizations, and small group interactions. Additionally, all questions the teacher asked to either the entire class or to groups of students were recorded.

Learning Strategies Questionnaire

The questionnaire consisted of 11 likert-scale items about students' self-regulated learning behaviors when working through the WISE Global Warming project. Students were given the prompt, "When working on the Global Warming project, I …" and then asked to circle either a lot, some, a little, or none for 11 common strategies when learning with WISE projects (e.g., went back to previous steps in the project to help me understand something better, checked to make sure that I truly understood the material presented in the project, discussed ideas and questions with my partner while I was working) Students also responded to three free response items asking them to explain the strategies they used for monitoring their understanding, how the models/visualizations helped them learn, and what helped them learn the most about global warming.

Results

Student learning strategies during inquiry unit

Students responded how frequently (none, a little, some, a lot) they engaged in 11 strategies when learning with the Global Warming Project. Items were coded: none = 1, a little = 2, some = 3, and a lot = 4. Frequencies of each response and averages were calculated for each of the 11 strategies. Students reported using the models and visualizations most often when working through the Global Warming project, followed by thinking about the learning goals of the project and discussing ideas with their partners. Students reported revising their work, asking the teacher for help, and using Amanda (online hint tool) least frequently. The project was designed to enable students to manipulate a complex visualization to facilitate their learning and to allow students to work together, so it is encouraging that students reported engaging in these strategies frequently when learning about global warming. However, it is unfortunate that students did not take advantage of some of the scaffolds provided within the program more frequently, such as the online discussion tool and hint tool, or use the opportunity to revise their work within the program more often. See Table 1.

Table 1: Student learning strategies in the Global Warming Project

Strategies	Response Percentage (n)				n	Mean
	None	A little	Some	A lot		
Used the visualizations	2.36% (3)	4.72% (6)	25.98% (33)	66.93% (85)	127	3.57
Thought about learning goals	2.31% (3)	5.38% (7)	37.69% (49)	54.62% (71)	130	3.45
Discussed ideas and questions with partner	1.59% (2)	10.32% (13)	35.71% (45)	52.38% (66)	126	3.39
Went back to previous steps to understand something better	1.54% (2)	16.92% (22)	37.69% (49)	43.85% (57)	130	3.24
Thought about prior knowledge	3.08% (4)	18.46% (24)	43.85% (57)	34.62% (45)	130	3.10
Checked understanding	3.10% (4)	25.58% (33)	33.33% (43)	37.98% (49)	129	3.06
Read online discussion posts	6.30% (8)	22.05% (28)	33.86% (43)	37.80% (48)	127	3.03
Posted to online discussion	8.73% (11)	26.98% (34)	38.10% (48)	26.19% (33)	126	2.82
Revised work after learning something new	9.52% (12)	29.37% (37)	43.65% (55)	17.46% (22)	126	2.69
Asked teacher for help	7.14% (9)	38.10% (48)	38.89% (49)	15.87% (20)	126	2.63
Used Amanda (hint tool) when extra help was needed	33.07% (42)	36.22% (46)	24.41% (31)	6.30% (8)	127	2.04

Students responses to the open-ended question, "What helped you learn the most about global warming?" are consistent with the results of the previous questions regarding the learning strategies students reported engaging in. Responses were coded into categories. Categories were not mutually exclusive because some students listed more than one thing that was helpful to their learning. The visualizations were overwhelmingly the most reported response, at 67%. The teacher, hint tool, and the online discussions were mentioned least frequently. See Table 2.

Table 2. Students' responses to what was most helpful in their learning.

Reported to facilitate student learning	% of student responses
Visualizations	67%
Explanation and note steps	7%
Reading/studying	6%
Partner	5%
All of it	5%
Teacher	2%
Online discussion	1%
Amanda (online hint tool)	1%

Students were then asked to elaborate on how the visualizations helped them to learn about global warming. Student responses were coded into categories. The categories were not mutually exclusive because some students listed more than one way the visualizations helped them to learn. The most frequently stated response was that the visualizations showed scientific processes or effects of various variables (e.g. carbon dioxide, albedo, cloud cover) on global warming. This was followed by a more general answer; 20% of students stated that the visualizations made it easier to "see" or "visualize" or that it was easier to look at the visualization than to read the information. See Table 3.

Table 3. Students' responses to how the visualizations helped their learning.

Ways visualizations facilitated student learning	**% of student responses**
Showed processes/effects of variables	30%
Helped to visualize/easier than readying	20%
Showed an example	11%
Allowed for experimentation to determine effects	10%
Helped to understand the problem and answer the questions	10%
It didn't help	2%
Allowed to see or do things you can not in real world	2%

Results of a paired t-test revealed significant learning gains in students' knowledge of the greenhouse effect and global warming (t (*125)* = -11.04, p<.001). Mean composite scores on the content items increased from 4.71 on the pre-test to 7.14 on the post-test. There was no correlation between students' reported use of self-regulated learning strategies when working through the project and learning outcomes.

Teacher questioning strategies

During 4 days of classroom observations, a total of 67 questions that the teacher asked to students were recorded; 58% were directed to the entire class and 42% were asked to pairs of students working together through the project. Questions were coded in two ways, level of knowledge integration the question promoted and purpose of the question. The Knowledge Integration (KI) Framework views learning as building important bridges among pre-existing ideas as well as making links between existing ideas and new ideas (Linn & Hsi, 2000). We used this framework to code questions into low, medium, or high level questions, based on the type of knowledge integration it promoted. Of the 67 questions, 42% were low-level questions, 34% were medium-level questions, and 24% were high-level questions. See Table 4.

Table 4. Teacher questions to support students' knowledge integration.

Level of KI	**Questions support students to:**	**Examples**	**Percentage**
Low	Define a term or element of the model	What is IR? What is a greenhouse made of?	42%
Medium	Make one connection	Why is a greenhouse made of glass? What happens when IR hits the atmosphere?	34%
High	Reflect and make many connections	What is the role of albedo in the greenhouse effect? Why are we worried about global warming?	24%

When questions were broken down by day, more questions were asked on days 4 and 5 than days 2 and 7, and the majority of the questions asked on days 4 and 5 were medium to high-level questions. During these days the students were primarily interacting with the visualizations, manipulating variables to determine their effects on global temperature. See Figure 1.

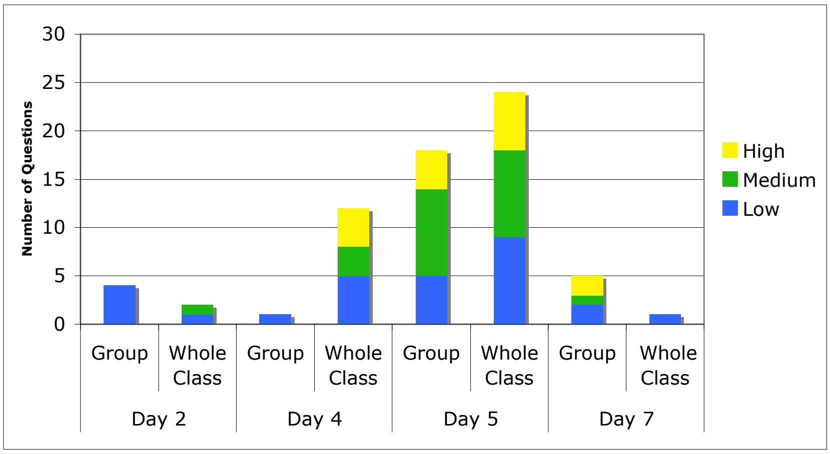

Figure 1. Teacher questions during classroom observations

Questions were also coded into 5 emergent categories based on the purpose of the questions. These categories were not mutually exclusive because some questions were multi-purpose. Questions to monitor the students' comprehension of the material were asked most frequently, 58% of the questions, followed by questions to prompt students to make connections, 46%. Other questions activated students' prior knowledge, checked their progress within the project, and cleared up student misconceptions. See Table 5.

Table 5. Purpose of teacher questions

Purpose of question	Example	Percentage
Monitor comprehension	What do clouds do to global warming?	58%
Prompt connection	Why are we worried about global warming?	46%
Activate prior knowledge	How does the experiment we did last week relate to what we are studying now?	13%
Plan/check progress	Who is on Activity 6?	6%
Clear up misconceptions	Can sunlight actually slow down?	3%

When looking at the purpose of the teachers' questions across days, results showed that questions to plan and check student progress were spread evenly across days. The teacher started out each class period asking students how far along they were in the project. All questions to clear up student misconceptions were asked on day 5. On day 4 the teacher noticed that many students were misinterpreting the visualization, so he started class on day 5 with discussion questions to clear up any misunderstandings. Questions to monitor students' comprehension were asked on all days, and questions to prompt connections and activate prior knowledge were asked on days 4, 5, and 7. See Figure 2.

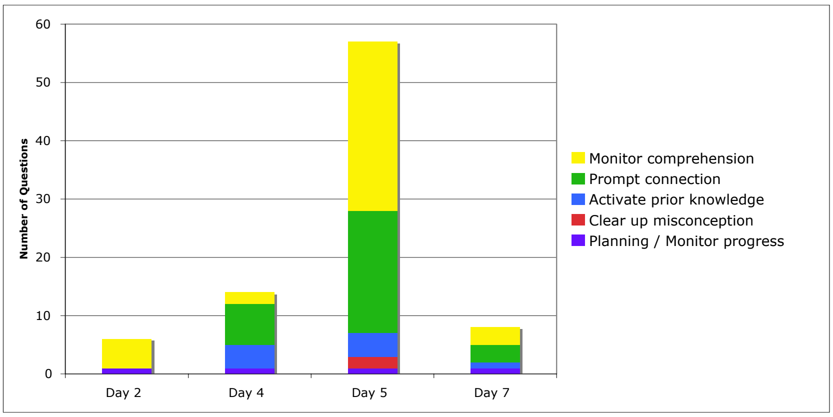

Figure 2. Purpose of teacher questions during classroom observations.

Students' strategies for learning science

On the pre-test and post-test, students read 6 common strategies for learning science material and responded how frequently (always, sometimes, or never) they engaged in each strategy when learning science. Items were coded: Never = 1, Sometimes = 2, Always = 3. Averages were calculated for each of the 6 strategies.

Pre-test data revealed that the strategy students prefer to use most often when learning new science material is doing experiments to try and figure things out followed by using what they already know to understand new material. Interestingly, using visualizations to help them understand new material and discussing material with classmates were the two strategies students reported to use least often.

On the post-test which was given at the end of the semester after students had engaged in WISE curricular projects, students' reported learning preferences changed. Results of an ANOVA reveal students reported they prefer to use visualizations to help them learn about science more frequently on the post-test than on the pre-test ($F_{(1, 261)} = 19.45$, $p < .001$). Students also reported they prefer to discuss material with their classmates significantly more frequently on the post-test than on the pre-test ($F_{(1, 257)} = 3.92$, $p < .05$). Students also reported that they preferred to be told what is correct by the teacher and to do experiments to figure things out least frequently on the post-test than on the pre-test. WISE projects are designed to present students with interactive visualizations to facilitate learning of complex science topics and to take advantage of collaborative learning. Students took more of an active role in their learning when interacting with the inquiry project, and it is encouraging that students reported preferring to use these more active strategies when learning new science material. It is surprising that students rated doing experiments least frequently on the post-test. Perhaps, students did not realize that they were experimenting with the greenhouse effect visualization within the computer-based project, since it is different from the classroom-based lab experiments they are accustomed to. Figure 3 and Table 6.

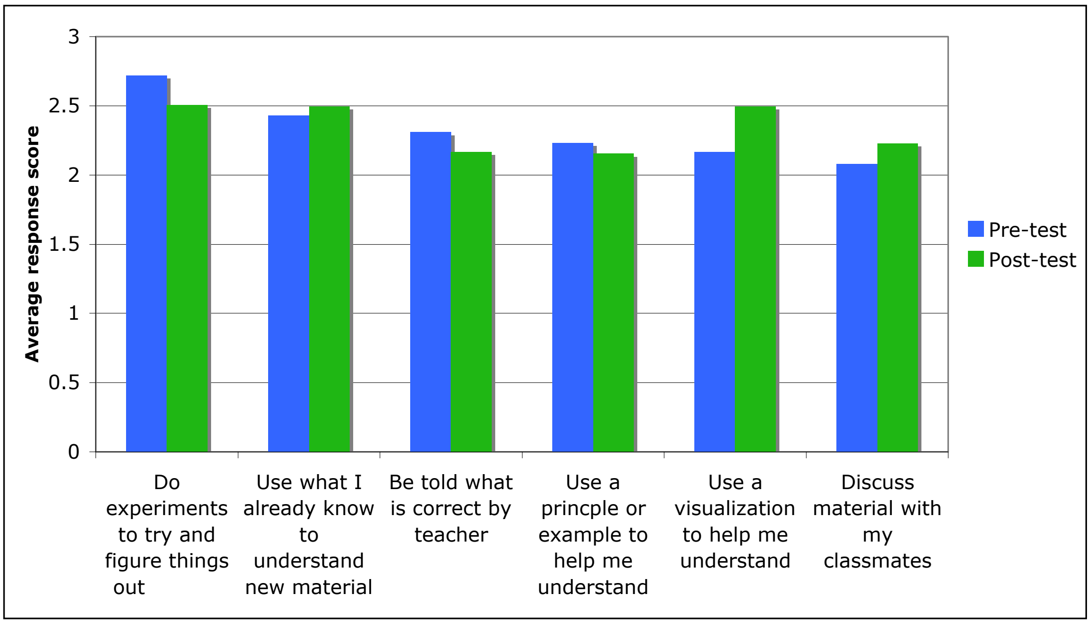

Figure 3. Students preferred strategies for learning science.

Table 6. Changes in students preferred strategies for learning science

Learning Strategy	Pre-test Mean	Post-test Mean	F	p
Doing experiments	**2.72**	**2.50**	11.67	**p < .001**
Using prior knowledge	2.43	2.50	0.98	p = .32
Being told by teacher	**2.31**	**2.17**	4.20	**p < .05**
Using principles or examples	2.23	2.25	1.00	p = .32
Using visualizations	**2.17**	**2.50**	19.45	**p < .001**
Collaborative learning	**2.08**	**2.23**	3.92	**p < .05**

Pre-test data also revealed that students do not always use productive strategies to monitor their comprehension of new science material. Students were asked how they know they understand new science material, and selected from five common strategies the one that best describes them. The most frequently reported answer was "when I can get an A on the test" and the least frequently reported answer was "I've finished the assignment". This suggests that students do not monitor their comprehension during learning. They can finish an assignment and still not know if they understand the material, and often use test grades to inform them of their understanding. Since tests are usually given at the end of a unit, this suggests that students do not monitor their comprehension while they are in the process of learning the material, which gives little opportunity to clear up any misconceptions.

On the post-test students' reported using more productive comprehension monitoring strategies. The most frequently selected strategy for knowing when they understand new science material was "when I can explain it to someone else". This increased from 30% of the responses on the pre-test to 52% of the responses on the post-test. Students also reported using other non-productive strategies least frequently on the post-test, such as "getting a A on a test" and "the teacher explaining it". This suggests students were using more active comprehension monitoring strategies while they were working, rather than relying on summative feedback such as a test score or passively learning from the teacher.

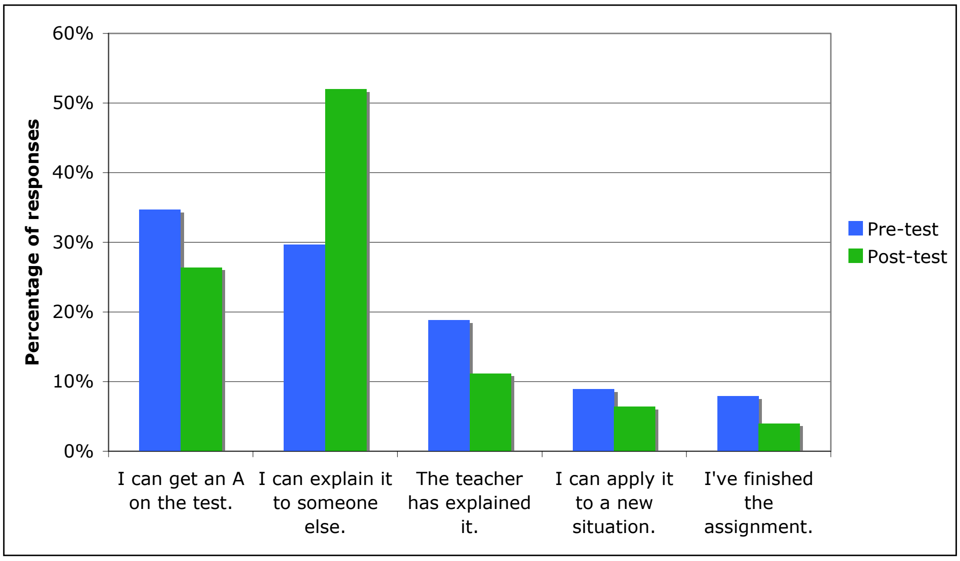

Figure 4. Students Comprehension Monitoring Strategies.

Conclusions

Results revealed some interesting findings of how students and the teacher regulated learning within the Global Warming Project. Is seems that the project facilitated students' engagement in certain productive learning strategies, such as learning with visualizations and discussing ideas with others, even though the pre-test data revealed that using visualizations and discussing ideas with others were not their preferred way to learn science material. It is encouraging that students took advantage of these design elements in the project. However, students did not report engaging in many other productive learning strategies that are also promoted within the project, such as using an online discussion tool, using an online hint tool, asking the teacher for help, and revising their work after learning something new. Further work will examine if scaffolding the use of these strategies leads to better student learning.

The most interesting finding is that students reported the visualizations to be the most helpful in their learning about global warming, and the teacher provided the most support to the students during their interactions with the visualizations. The teacher asked more questions overall, and higher-level questions meant to prompt students to make connections and to monitor their comprehension on days when students were interacting with the visualizations. It seems that the students did not realize their teacher was providing them with so much guidance because they did not report asking their teacher for help frequently or that the teacher was very helpful to their learning. This is also consistent with the fact that the students may not use effective comprehension monitoring strategies, as revealed on the pre-test. It may have been the teachers' guidance or the prompting questions within the Global Warming Project that facilitated the students' learning with the visualizations rather than simply interacting with the visualizations alone, yet the students are not aware of this. This is consistent with other research that reveals students often over-estimate their understanding of complex visualizations in science learning (Chui & Linn, 2007).

Results also revealed that students' preferred strategies for learning and monitoring their understanding of new science material changed after their interaction with the inquiry project. Students' reported using more productive comprehension monitoring strategies, such as explaining material to someone else, and more active learning strategies, such as discussing with classmates and interacting with complex visualizations, on the post-test. The design of the project encourages students' to take a more active role in their learning. As students practice these strategies perhaps they will be more likely to engage in them again in future science learning opportunities.

Next Steps

An empirical study will be conducted to determine if embedded technology scaffolds to support self-regulated learning strategies (planning, monitoring, revising) lead to better understanding of the complex science topics. In future studies log data gathered by the technology will be analyzed to determine how students progress through the program. This data is a more accurate measure of student behavior and can provide additional insight into what students are thinking at various times within the project.

Teacher data will be analyzed across years and projects to determine if the level of guidance provided to the students has changed over time. A focus of the professional development summer workshops the past two years has been on strategies for helping students to make better connections when learning with visualizations, so we will determine if there have been changes in teacher practice and increased student learning over the past two years.

This descriptive study is a first step in investigating how students learn with technology-enhanced science curricula and how teachers scaffold student learning. Results from this study and future studies will inform the design of technology-enhanced inquiry learning environments, the design of professional development, and the design of instructional strategies for teachers to better support student learning within these environments.

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