

## **Teaching with Visualizations: A Comparison Study**

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### **Abstract**

Previous research suggests the value of technology-enhanced materials that guide learners to use dynamic, interactive visualizations of science phenomena. The power of these visualizations to improve student understanding depends on the teacher. In this chapter we contrast two professional development programs focused on teaching with visualizations. The programs differ in intensity but follow the same basic philosophy. We show that the more intense professional development approach results in more effective teacher implementation of visualizations and greater student learning gains. We identify specific strategies that other educators can use to improve student knowledge integration with interactive visualizations.

## **BACKGROUND**

### **Introduction**

It is the last period of the day in the 6<sup>th</sup> grade classroom in Jefferson Middle School.

Instead of daydreaming about the end-of-the-day bell or chatting with friends about lunchtime gossip, students are engrossed in exploration of the greenhouse effect.

*Student 1: Okay, Go. Make it [albedo] really high?*

*Student 2: How about sunrays? Click on that*

*Student 1: Want to put a cloud? What do you think is going to happen now when we put CO<sub>2</sub>?*

*Student 2: [Reading text on computer] The CO<sub>2</sub> plus thinning air is going to help the clouds bounce off the sunrays. Do you see how they're going to do that?*

*Student 1: See! watch that one [sunray] right there.*

*Student 2: [Reading] Do you see how they're bouncing? The sunrays are bouncing off of the clouds. And they're bouncing off of the CO<sub>2</sub> too. So...*

*Student 1: Let's see how long it takes before [the sunray] leaves. Oh, that one's going....oh, no...that one's going back in [the earth].*

*Student 2: The CO<sub>2</sub> helped the clouds even though the CO<sub>2</sub> is bad. It reflected the sunlight.*

*Student 1: Because that's what, that's what's in the air right now on earth and... But, here [in the visualization], we can just like, magically take it away and we see what happens...*

Students in the above example try out multiple conjectures about global climate change, a highly relevant science topic that is rarely taught due to its complexity. Students “magically” add and take away different variables like cloud cover and carbon dioxide and observe their role in earth’s temperature. This interaction sharply contrasts with how students typically experience science in a secondary classroom. Most science instruction follows an absorption model of teaching and learning (Linn & Eylon, 2011). Teachers tend to focus on adding ideas through lectures, rather than on helping students refine their thinking by supporting them to integrate these new ideas with the repertoire of their existing ideas. Students work individually on drills and exercises that often fail to engage their curiosity, and that leave little room for them to articulate their understanding. Moreover, when classes reach up to 40 students, teachers find

themselves limited to monitoring students' progress through end-of-unit tests. This makes it difficult for teachers to provide useful, individualized feedback, and students become frustrated and disengaged as their only indication of success or failure comes from a single test.

Inquiry activities featuring visualizations of science concepts move away from this absorption model of instruction. We define visualizations as computer based, interactive models, simulations, animations, graphs, data tables, drawing and diagramming tools. Visualizations give students the opportunity to direct their own learning as they explore the variables involved in complex science phenomena, such as cell division, global climate change, chemical reactions and evolution. Visualizations require scaffolding in order to improve students' scientific understanding. Students, as shown in the example above, often change the visualizations conditions rapidly - "*make albedo really high...how about sunrays, click on that...want to put a cloud...what about CO<sub>2</sub>*" - and seemingly at random. Students are engaged. But they do not necessarily link evidence from the visualization to scientific ideas.

Research indicates that visualizations can be "deceptively clear" (Chiu & Linn, in press). That is, they can leave students with a feeling of deep understanding when that understanding might in fact be superficial or erroneous. Students often point out salient features of visualizations but need support to gather and use evidence from visualizations to formulate scientific explanations and arguments; systematically experiment with a visualization by controlling variables and documenting outcomes; sort out ideas gathered from different visualizations of related processes within the same scientific phenomena; identify limitations of a visualization, work effectively with a partner to reconcile visualization interpretations and articulate views, and identify gaps in their understanding (Chiu, 2009; Dunbar, 1993; McEleheny & Linn, 2011; Zhang & Linn, in press).

The Web-Based Inquiry Science Environment (WISE, <http://wise4.berkeley.edu>), the focus of this chapter, places visualizations in an inquiry oriented scaffolding, assessment and classroom management environment. Visualizations in WISE include but are not limited to interactive molecular level simulations, Flash and Java animations, graphs generated by students or displaying data collected by sensors, data tables, diagramming, drawing and animation tools, idea managers, and video. Schools are likely to have more success with WISE to support student inquiry learning, in comparison to stand-alone visualization tools because of these features. Studies on professional development for stand-alone visualization tools have documented the substantial challenges teachers face when trying to design lessons to incorporate stand-alone visualizations to both support inquiry and address science curriculum standards (Gerard, Varma, Corliss & Linn, 2011).

Extensive research on demonstrates significantly greater student knowledge integration in target science concepts when students use WISE, than when using the traditional textbook instruction (Linn, Lee, Tinker, Husic, & Chiu, 2006; Lee, Linn, Varma, & Liu, 2010). These student learning outcomes are significantly, positively impacted by teacher participation in professional development focused on teaching with visualizations (Liu, Lee & Linn, 2011). In this chapter we illustrate effective teaching practices with visualizations resulting from professional development. We provide two examples of professional development programs that had positive results on teaching with visualizations and students' science learning outcomes, though the programs differ substantially in how far reaching their impact is and their overall cost. We begin by describing the knowledge integration framework guiding the design of the WISE learning environment and professional development programs. Next, we detail the comparative impacts of two professional development programs on teachers' use of WISE visualizations and

their students' developing understanding of abstract science concepts. We end with recommendations for schools as they consider integrating visualizations into their science program.

### ***Knowledge Integration***

We use the knowledge integration (KI) framework to guide the design of professional development, curriculum and assessments with respect to visualizations in WISE. The KI framework is a constructivist view that emphasizes building on the repertoire of ideas held by learners and helping them incorporate new practices. The framework is based on extensive research, which suggests that simply adding new ideas about teaching practices or the target science discipline is not sufficient for inducing behavioral change. Learners, including teachers and students, have a repertoire of ideas about instruction and learning, science and technology, based on their observations, experiences, and education. The KI perspective emphasizes asking learners to articulate their ideas about the target phenomena, adding ideas to learners' repertoire in ways that make the new information accessible, enabling learners to use evidence to sort out and distinguish among these new ideas and their existing views, and encouraging learners to engage in an ongoing process of reflecting on and integrating the ideas, which most appropriately explain the science content, teaching and/or learning phenomena (Linn & Eylon, 2011).

### ***Web-Based Inquiry Science Environment***

The Web-Based Inquiry Science Environment is an exemplary, web-based learning environment that embeds varied visualizations in inquiry activities to guide student investigation of a target phenomenon (Linn et al., 2004). Each WISE project typically takes 5 to 7 class periods (50 minutes each) to complete. WISE projects target topic areas that are aligned with

state (CA) and national science standards, and that research suggests are difficult to teach, because they are hard if not impossible to see in a school laboratory experiment or a regular textbook (Linn & Hsi, 2000).

The WISE projects engage students in collaborative activities with visualizations such as investigating hypotheses, designing solutions to problems, critiquing scientific claims, and building scientific models. Assessments are embedded throughout the WISE projects to help students and teachers monitor student understanding and progress as they interact with visualizations. The embedded assessments ask students to make predictions about the visualizations, sort out evidence, and link ideas together to explain concepts and processes observed. The embedded assessment notes open in a pop-up window that students can place where they prefer on the screen (See Figure 1). This allows students to work with an embedded note while they explore a visualization tool. Pop-up hints are also available on demand, by clicking on the Panda icon (see top left of Figure 1). Hints open in a pop-up window that students can place where they prefer on the screen. These assessments support students' in monitoring their ideas to determine how new ideas relate to previous ideas, which facilitates KI.

For example, in the *Mitosis* project, students investigate one big question throughout the project: how can plants help to stop cancer? The project *elicits' ideas* about cell division by asking students to explain what cancer is to a friend, and then predict what would happen to body parts if cells started dividing out of control. Students are supported to *add ideas* by viewing and manipulating dynamic visualizations of normal cell division, and cell division when treated by three different plant medicines (See Figure 1). The *Mitosis* project helps students *distinguish ideas*, by guiding students to collect and use evidence from the visualizations. Students manipulate the visualizations to identify phases of mitosis in normal cell division, and in cell

division when treated by three different plant medicines. Finally, the students *make connections among ideas* as they use the evidence from the visualizations of cell division to recommend one of the plants to a doctor as a medicine for cancer.

## **EXEMPLARS**

Approximately 200 teachers and over 40,000 students have partnered with the WISE research team over the last 5 years to refine curricular and instructional support for student learning with WISE visualizations. Teachers and their students participated in one of our two professional development research programs focused on teaching with visualizations: Mentored and Online Development of Educational Leaders in Science (MODELS) or Technology-Enhanced Learning in Science (TELS).

The professional development differed between MODELS and TELS, with respect to the depth of interactions with teachers. The MODELS project focused on supporting teachers in two local school districts to integrate technology-enhanced inquiry science materials into their instruction. Each MODELS teacher participated in a 1-week summer institute for 5 consecutive years. The TELS center focused on scaling teacher use of the same technology-enhanced inquiry science materials. It supported over 175 teachers in seven states to implement the materials in their classrooms. Teachers received support as needed in the classroom and participated in optional, 1-day workshops.

We analyzed the data from seven of the teachers and their students who: (a) participated in either the MODELS or TELS professional development program for 2 consecutive years, (b) implemented the WISE *Mitosis*, and or *Simple Inheritance* project for 2 consecutive years, and (c) administered a student knowledge integration baseline test, and delayed posttests for 2 consecutive years. All teachers were similar in that they had at least 5 years of experience as a

science teacher, worked in schools with a diverse student body, and had multiple colleagues also using the WISE curriculum in their school. In the next sections, we describe how a MODELS teacher and a TELS teacher improved their teaching practices with Mitosis visualizations over 2 years of professional development. Then, we illustrate the comparative impacts of the professional development programs on the 7 teachers' teaching practices and students' science learning outcomes.

### ***Exemplar 1: Teaching with Visualizations in MODELS Professional Development***

Ms. Cramer in the classroom (Year 1): Ms. Cramer initially selected the 7-10 day WISE *Mitosis* project because she strives to help her 7<sup>th</sup> graders realize the relevance of biology to real-world problems and was disappointed that her textbook-based lessons did not interest her students. Ms. Cramer was impressed with the relevant scientific issues addressed in *Mitosis* and the varied visualizations of cell division.

In the first year using Mitosis, Ms. Cramer was challenged by primarily technical and classroom management issues. She had little time to focus on student learning with visualizations. Rather, registering students in the WISE environment, viewing student work in the grading tool, managing a classroom of students working in pairs on a computer, and troubleshooting a slow school Internet connection, were primary concerns.

Ms. Cramer participated in a summer professional development workshop after her first year teaching with WISE. This provided Ms. Cramer extended time to reflect on her students' thinking in relation to the Mitosis visualizations. Ms. Cramer and her 7<sup>th</sup> grade colleagues who also taught Mitosis identified specific embedded notes that called for their students to use evidence from the visualizations to explain mitosis. The teachers reviewed their students' explanations, sorting responses according to how students linked their ideas using evidence. Ms.

Cramer found that her students reported a wide range of normative and non-normative ideas about the relationship between cell division and cancer. Ms. Cramer and her colleagues refined knowledge integration rubrics to categorize and assess their students' ideas on these notes, and planned whole-class discussions to prompt for deeper understanding. Ms. Cramer felt excited and well prepared to implement *Mitosis* in the upcoming school year.

Ms. Cramer in the classroom (Year 2): Ms. Cramer begins with a brief review of some key concepts and then guides her students to complete Activity 1. After the introduction to the role of mitosis and its relationship to cancer in the human body, students begin to distinguish the phases of mitosis and explore the possibility of using plants to cure cancer. Over the next 2 days, they analyze interactive visualizations of cell division coupled with informational text and diagrams.

Ms. Cramer brings her students together for a whole class discussion about strategies for experimenting with a mitosis visualization. She uses an LCD to project the visualization on the wall. *“Let the model run through completely the first time but know that you’re going to look at again to see how you would divide the process into different phases...Then, run the model again, stopping and starting it to figure out what would be an important phase, what makes this part of the mitosis process different from another?”* Ms Cramer recounts, *“Then I let students use the model on their own and I walk around the classroom looking at what they picked up from our discussion, where they stop the model for each phase.”* Anja and Paulo start and stop the visualization at different points, and record in their Student Journal the key characteristics from their perspective of each mitosis phase. Next the two students read how professional scientists divided mitosis into phases and gave each a special name.

At the start of class the next day, Anja and Paulo begin to compare dynamic visualizations of mitosis occurring in 3 unique, rainforest plants, to the dynamic visualization of normal mitosis in a human cell. The two students gather and evaluate evidence from the visualizations, and weigh the benefits against the potential side-effects of the plants for treating cancer. They continue to add to and refine their argument concerning which plant would be the best treatment for cancer in their WISE Journal.

Ms. Cramer listens to the student discussions and observes that multiple pairs are challenged to relate the visualizations of abnormal mitosis to cancer treatment. She feels that this is an important time to review students' work. That night, Ms. Cramer reads the student-pair responses to one note about the visualization of mitosis in Plant A, "*What are your recommendations for Plant A as a possible medicine to treat cancer?*" She finds that students are challenged to sort out the evidence from the plant visualization to formulate a recommendation for cancer treatment. "*Students are really torn about whether they actually want to stop mitosis or not. With each of the plant models, they're like, 'well, I don't want to choose any of these plants because if you stop mitosis you won't have any cells.'*" Ms. Cramer notices a particularly interesting explanation written by Anja and Paulo, which utilizes evidence from the visualization of Plant A and the description of the boy with cancer. With a tool in her Teacher Dashboard, Ms. Cramer flags Anja and Paulo's response, along with a few other students' responses for comparison. In class the next day, she projects the flagged responses (clicking a button to anonymize each flagged example) and guides a lively whole-class discussion. "*We talk about each model, weighing the different side effects of each plant treatment in relation to effects of cancer.*" This helped students to sort out their ideas about the

relationships among the plant mitosis visualizations, effects on the human body, and tradeoffs of different cancer treatments.

In a culminating activity within the *Mitosis* project, Anja and Paulo participate in a structured online debate with their peers about the benefits and drawbacks of each plant as an effective cancer treatment. The principal stops in to observe students work in the WISE project. Ms. Cramer monitors the debate by circling the classroom to read what students are writing, and to give suggestions as needed. She remarks to Paulo and Anja, *“Tell your peers about all 3 plants. What did each one do? Why did you like/not like each one? Why did you pick that one?”* Anja and Paulo revisit the visualizations of Plant A, B and C, and then substantiate their ideas with further evidence. *“We would recommend plant B because mitosis is stopped and the cell affected by cancer will simply just die without a nucleus and with its chromosomes floating around the cell, because during metaphase, when the spindle fibers were coming out, the plant caused the spindle fibers to retract... We recommended plant B instead of plant C because though they ended up with the same results, the cell affected by plant B never divided in the first place and was affected by the plant sooner. Plant A caused the chromosomes on the right side of the cell to disappear during anaphase making it so that the cell on the right will not be able to divide again. However, the cell on the left can continue dividing out of control, which is why we did not recommend this plant.”* The principal reads Anja and Paulo’s response over their shoulder, and is impressed by their use of evidence.

On the last day, Ms. Cramer leads a class discussion on the current state of scientific inquiry into cancer treatment. She recognizes that the mitosis visualizations illustrate not only how cancer treatments can work, but also the substantial limitations of cancer treatment. *“I know several different kids who have somebody in their family struggling with cancer so I want them*

*to finish the project with a bit of hope.*” Some students who completed the project early presented research posters on the benefits and side effects of different treatments used today.

Ms. Cramer in the classroom (Summer Workshop): During the 1-week summer professional development workshop Ms. Cramer works with her colleagues and the WISE researchers to analyze her students’ responses to key assessments using the KI rubrics. She uses her Teacher Dashboard to share the *Mitosis* project run with her other 7<sup>th</sup> grade colleagues so they can see her students’ work in context. Based on their collaborative analysis of student data, Ms. Cramer and her colleagues negotiate customizations to the project and their teaching strategies in order to further scaffold students’ use of the visualizations (See Table 1).

[Insert Table 1]

They also refine their premade comment list for the *Mitosis* note regarding Plant A.

### ***Exemplar 2: Teaching with Visualizations in TELS Professional Development***

Ms. Lewis in the classroom (Year 1): Ms. Lewis decided to use the *Mitosis* project in Year 1 because she liked how it connected cell division to the issue of curing cancer. Prior to running the project, a TELS professional development mentor met with Ms. Lewis and showed her how to register students in the WISE environment, manage student pairs, and assess student work.

Ms. Lewis was excited by the *Mitosis* visualizations. “*The visualizations really brought mitosis to life. It made it concrete for the students.*” She was challenged however to integrate the project with her existing curriculum and efficiently assess student work. Ms. Lewis’ decided to implement the *Mitosis* project after teaching the textbook unit on cell division with the hope that the visualizations would provide greater detail than the text. Students found this sequence frustrating. As Ms. Lewis introduced the WISE project to the class, several students remarked,

“*Didn’t we already do mitosis - why are we doing it again!!*” Technology challenges also arose as Ms. Lewis figured out how to locate students’ forgotten WISE passwords, arrange students into pairs, and access students’ work. A professional development mentor came to the classroom several days during the project implementation to assist Ms. Lewis.

Ms. Lewis’ biggest challenge in Year 1 was assessment. She was eager to grade all of her students’ work in Mitosis to be sure they linked appropriate evidence from the mitosis visualizations to cancer treatment. To prepare, Ms. Lewis “*went through the whole project as if [she] was a student and jotted down possible answers that students might put for each question.*” Generating criteria to grade students’ responses to the embedded notes was particularly challenging however. She suggested the curriculum developers provide a key for the teachers that would give the correct answer to each question and a range of sample student responses. In addition, Ms. Lewis found that reading, grading and commenting on every single student response was exhausting. She decided to give most students a numerical score for each response, but wrote only 2 comments.

Ms. Lewis in the classroom (Year 2): Ms. Lewis redesigned her curriculum in Year 2 to “*do the Mitosis project in conjunction with a little bit of notes that they read in the textbook and the related workbook pages.*” Joseph and Sara were excited to work together on Mitosis. They watched a visualization illustrating the different rates of cells division in muscle, liver, nerve and skin cells. Sara hypothesized “*Different kinds cells divide at different rates because they need to be replenished at different speeds. For example, muscle cells divide more often than nerve cells because they are damaged more often.*” Joseph linked the rates of cell division to what he and Sara read as the definition of cancer, a term for diseases in which abnormal cells divide without control. Joseph commented, “*I think cancer cells would divide as fast as skin cells, because they*

*divide frequently and will be able to recover as quickly as other cells would.*” Ms. Lewis observed Joseph and Sara’s discussion. She decided to grade students responses that night to help students sort out their ideas about rates of cell division and cancerous cells. Ms. Lewis used a more efficient approach to grading this year. *“The biggest difference for me from last year is the grading. I used to grade by group and now I grade by step. I can go really fast. This helps me help the children more quickly.”* She wrote to Joseph and Sarah, *“Healing of a cut actually begins in a few hours. Do you think cancer is that fast?”*

When Joseph and Sara returned to class the next day they read Ms. Lewis’ comment and eagerly moved ahead in the project to learn more about cancer and cell division. They began to investigate the visualization of normal mitosis, starting and stopping the model to distinguish patterns between phases. *“We stopped the model when the chromosomes started lining up in the middle of the cell with the spindle fibers attached.”* While the students worked, Ms. Lewis sat at her desk and read students answers in the grading tool. *“I can grade as they are doing it, you know I can look up their answer and I know right away if they understand it or not.”* She called up a few student pairs to her desk when she saw their responses off track. *“I pull them up very frequently to talk one-on-one. I quiz them, asking them why did they say that?”*

For the next 2 days Joseph and Sara and their peers worked hard to compare the effects of Plants A, B and C on cell division. Ms. Lewis noticed that *“some students got confused about what to do with the visualization of the Plants A, B and C. I could see there are a lot of incorrect answers to the question, like 3 or 4 pairs having trouble, so we stopped and discussed.”* Ms. Lewis reminded the students of what to look for in the visualizations of cell division. What cell structure is affected? How does this impact the whole mitosis process? *“I found that if I get the same question it does not take long to get them back on track through a class discussion.”*

Ms. Lewis decided to grade student again after school and send comments after school since she had observed how challenging it was for students to analyze the mitosis process in the visualizations. The professional development mentor stayed to help Ms. Lewis reflect on students' work. She read Joseph and Sarah's response "*We think that Arias chromagonia is a possible cure because even though it doesn't stop the cell from dividing it stops the chromosomes from reaching the other cell*". Ms. Lewis and the mentor wrote back, "*Go back to the model. What phase of mitosis did the plant effect? Why is this important for curing cancer?*" During the grading process, Ms. Lewis told the mentor her continued difficulty with grading. "*We are not all experts in these areas. I've taught life science a long time but this is difficult.*"

Students returned to class the next day and read through Ms. Lewis' comments. Sara and Joseph went back and watched the visualization of Plant A and of normal mitosis carefully. They added to their response "*The phase of mitosis that was affected by arias chromagonia was Anaphase.*" The principal popped in to observe but Ms. Lewis "*barely noticed because I am so engaged.*" Ms. Lewis continued to monitor and observe students carefully. The professional development mentor modeled how to circle the room, kneeling down to talk with student pairs at their computers as they engaged with the visualizations. Ms. Lewis remarked to the mentor "*My interactions with my students are different when I am teaching a WISE unit than regular teaching. It is more like one-on-two. There are a lot of students I don't have to help so they can move ahead and work with the visualizations without my assistance. They feel good about themselves.*" As students completed the project, Ms. Lewis was pleased. "*I enjoyed doing Mitosis myself, the models helped me in supporting inquiry*". She "*extended the project one week so students could go back, and continue to redo their notes one time and come ask if they have questions*".

Ms. Lewis in the Classroom (Professional Development Mentor). At the end of the project, Ms. Lewis sat down with the WISE professional development mentor to reflect on her student work. Together, they looked over students' pretest/posttest data and identified areas of difficulty. Ms. Lewis noted that students did well at identifying how the Plants affected mitosis, but few linked this back to the overarching issue of how to use the Plants to treat cancer. Ms. Lewis planned to restructure her whole class discussions about the Plant visualizations to help students use the evidence to describe cancer treatment.

***Exemplar 3: Comparative Impacts of Professional Development on Teaching and Student Learning with Visualizations***

Ms. Cramer and Ms. Lewis illustrate the trajectory of teachers who participated in WISE related professional development for more than 2 years. Consistent with the data from the other 5 teachers in our longitudinal study, the seven teachers reported that the biggest change they made in their instruction to support student learning with visualizations, from Year 1 to Year 2, related to assessment and whole class discussions.

Each of the teachers reported that they examined students' responses to embedded assessments about the visualizations more frequently and/or more efficiently in Year 2. As a result, teachers in both MODELS and TELS increased the amount of comments they gave to each student during a WISE project from Year 1 to Year 2. The TELS teachers gave an average of 2 comments to each student during a WISE project enactment in Year 1, and 7 comments in Year 2. The MODELS teachers gave an average of 6 comments to each student during a WISE project enactment in Year 1, and 10 comments in Year 2. The MODELS teachers felt better prepared to evaluate student work than the TELS teachers, having spent time in the summer workshops collaboratively analyzing and scoring students' responses to embedded notes. All

teachers in Year 2 encouraged their students to revise their work in the WISE project after they received comments from their teacher. This often meant revisiting the visualization to gather specific pieces of evidence to further substantiate their claims, or to distinguish among normative and non-normative ideas.

We have conducted further research on role of teacher comments in learning. Our work has found that teachers' use of specific comments, which build on student ideas about a particular visualization, (e.g. "What happened to the spindle fibers in the visualization of Plant A?") are more likely to result in student revision and high quality revisions than general comments (e.g. "Revisit the visualization and add evidence to your claim") (Sato, 2011).

A common, successful strategy illustrated by Ms. Cramer was to identify a key embedded note about a visualization, send students feedback on their responses to this note at night, and then lead a whole class discussion, or "Opener", at the start of class the next day to clarify and build on students' ideas. Some teachers projected the visualization on the wall during the discussion, as we saw Ms. Cramer do. Teachers reported that this approach helped their class to distinguish key features or limitations of a visualization. Students then went back to review their individual comments from the teacher, revise their work, and continue in the project. TELS teachers led fewer whole-class discussions during the week of implementation likely due to less time in summer workshops to plan such discussions.

We have since conducted research on how teachers Openers about students' interpretations of WISE visualizations affect learning. Findings suggest that when teachers led a class discussion about the visualization, their students demonstrated a more robust understanding of the visualization and more frequent revision of their explanation of the visualization, than their students who did not have a class discussion. More specifically, class discussions that

engaged students in each of the knowledge integration processes resulted in greater student learning than class discussions in which the teacher presented information shown in a visualization (Zertuche, Gerard & Linn, NSF Annual Report).

Teachers' improved strategies for teaching with visualizations had a significant effect on their students' understanding of complex Life Science topics like mitosis and inheritance principles. We used pretests – delayed posttest comparisons to evaluate annual student learning gains in the two professional development programs.

[Insert Table 2]

Teachers who participated in both professional development programs significantly improved student understanding of mitosis and genetics from Baseline to Year 2. By the end of the second year, students in all participating teachers' classes made significant achievement gains from the baseline Year 0 test, to the Year 2 delayed posttest on targeted mitosis and genetics KI assessment items.

The MODELS teachers were more effective, helping their students to make more significant gains in the first year and the second year. In order to show the magnitude of the performance differences, we also presented the effect size in Cohen's  $d$  (Figure 2). An effect size larger than .80 is considered large, .50 to .80 medium, .20 to .50 small (Cohen, 1988). This shows further support for intensive professional development on teaching with visualizations.

[Insert Figure 2]

## **NEXT STEPS**

### ***Evaluating Visualization Technologies***

The data presented in this chapter highlight the key role professional development plays in teaching practices and student science learning with visualizations. The teacher provided

essential guidance to help students make predictions about the science phenomena in the visualization, gather evidence from the visualization to distinguish among their many ideas about the phenomena, and integrate their ideas to explain scientific processes. This stands in contrast to a majority of visualization-tools available to educators today. Many of the visualization tools are stand-alone, rather than embedded within curriculum projects involving scaffolding for inquiry, and coupled with intensive teacher professional development. These visualization tools are less likely to result in significant science learning as teachers have little if any guidance on how to effectively incorporate the visualization into standards-aligned inquiry activities. Without aligned assessments teachers have no record of student thinking to guide the design and refinement of instruction. Without sustained professional development teachers have no time or access to curriculum design and domain experts to help teachers cultivate, test and refine strategies for guiding student learning with visualizations (Gerard et al., 2011). In short, our research suggests that when purchasing technologies for a school(s), one should identify materials that embed visualizations into tested inquiry activities, provide assessment tools, and have extensive high-quality professional development opportunities for teachers.

### ***Developing Strategies for Teaching with Visualizations***

The data from our WISE programs suggests that visualizations can significantly improve science teaching and learning when the professional development, curriculum and assessments are aligned with the knowledge integration framework. Alignment allows researchers to document the effects of professional development on student learning. Further, it supports the notion of teaching as an evolving process in which practitioners become proficient by adjusting practice according to collaborative reflection on student work and instructional practices, not merely by repeating routines. The availability of the assessment data, detailing student learning

in relation to instruction is essential. Investing resources in intensive professional development that supports teachers to analyze student work, reflect on teaching and assessment strategies, and collaborate with colleagues, can improve students' learning outcomes faster, and most importantly, to a greater degree. The alternative and less costly option is to support teachers as needed in the classroom to navigate the technologies and reflect on student work as they implement new visualization tools in their classroom.

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## TABLES

Table 1. Sample Teachers' Customization Plan for Mitosis Project

Evidence	Changes to the Mitosis Project	Changes to In-Class Teaching Strategies
Students demonstrated misunderstanding as to what was expected when asked to give a name to phases shown in the model in act2 step5	Rewording of the prompt along with some more specific directions. Instead of "give each phase a name" I will write, "click on the edit button and make up a name for each phase".	I believe a whole class discussion on the benefits of classifying portions of a dynamic process will be valuable prior to this step. Use of analogies might be helpful, i.e. why we classify people as babies, children, adolescents, and adults even though there is no way to say exactly when one "phase" changes to another.
Students don't pay attention to the particular parts of the cell affected by the plant in the model in act 4 and 5	Reword the question to illicit more detail in the cell mitosis.	The students will review the model projected. Together we will watch movement of the mitosis processes. Verbalize the process reinforcing/interjecting vocabulary.
Kids had trouble making multiple links and justifications of using certain plants for the control of cancer control. No growth in the #5 answers from Year 1 to Year 2.	Insert a step prior to this with a pro and con for each of the plants. Concept mapper that allows the students to state the qualities of the plants. This may also help them to recognize the parts of the cells and be more specific.	A class discussion including a chart where students list the qualities of each plant.
Students are not naming the specific parts of the cells.	Question should be more specific to name and describe the part of the cell affected by the plant during mitosis.	Review of the model showing the plant effects on mitosis. Verbal discussion
Students understand that uncontrolled mitosis is the cancer but are not making the connections with jobs that the plants do.	Ask the students to make the connections between the changes that occur in the cell and how the plant is affecting the mitosis process.	Whole class discussion. Student derived charts giving the pros and cons of each plant for stopping cancer.

Table 2. Descriptive Statistics, t-test and Effect Sizes

Teacher	Baseline Test			Year 1			Year 2			$t_{b,1}$	$t_{b,2}$	$d_{b,1}$	$d_{b,2}$
	N	Mean	SD	N	Mean	SD	N	Mean	SD				
<b>MODELS</b>													
Rachel	48	-.06	.21	48	.08	.21	48	.15	.24	3.27***	4.56***	.54	.74
Danielle	50	-.07	.20	65	.18	.38	50	.38	.42	4.55***	6.84***	.62	1.02
Cathy	68	-.09	.24	68	.10	.32	88	.33	.48	3.92***	7.13***	.52	.82
Penny	78	-.02	.19	78	.10	.28	76	.28	.29	3.13***	7.57***	.39	.94
<b>TELS</b>													
Barbara	129	-.08	.24	186	.06	.39	198	.13	.37	3.85***	6.14***	.32	.51
Sarah	119	-.09	.41	169	-.04	.26	130	.13	.59	1.08	3.42***	.12	.33
Gary	133	-.09	.49	176	-.07	.33	169	.02	.29	0.41	2.31**	.04	.25

Note: \*\*\*  $p < .001$ ; \*\*  $p < .005$

The numbers under ‘mean’ are the mean ability estimate for students taught by each teacher. As described in the data analysis section, these estimates are put onto a logit scale from -3 to 3. The higher the estimate, the more able the student is.  $t_{b,1}$  stands for the  $t$ -test value between the baseline and Year 1 data. Similarly for  $t_{b,2}$   
 $d$  = effect size, calculated by the dividing the mean difference between the baseline and post tests by pooled standard deviation.  $d_{b,1}$  stands for the effect size of the difference between the baseline and Year 1 data. Similarly for  $d_{b,2}$

## FIGURES

Figure 1. A Step in the WISE Mitosis Project

The screenshot displays the WISE Mitosis Project interface. On the left, an 'Inquiry Map' shows a vertical sequence of steps: 'Make a Selection', 'See the Eff...', 'Our Findings', 'Make a Selection', and 'Go to Next Activ...'. The main content area is titled 'Investigating Plant A' and contains the text: 'The cell below was treated with *Plant A*. Watch the animation of mitosis carefully and see if you can figure out how this plant affected cell division.' Below this text are two diagrams: 'Mitosis Affected by Plant A' (Current Frame: 189) and 'Normal Mitosis' (Current Frame: 236). The 'Normal Mitosis' diagram shows spindle fibers connecting centromeres. Below the diagrams are two 'Embedded Note' boxes. The first note asks: 'Describe what changes occurred during mitosis when Plant A was used?' with a 'Save Note' button. The second note asks: 'What parts of the cell and Mitosis processes were affected by this plant?' with a 'Save Note' button. At the bottom right, a 'Hint 1 of 1' box features a panda icon and the text: 'Do you think there are ways of interfering with mitosis but not stopping cell division?'. At the bottom, four blue arrows point to these elements: 'Inquiry Map' (pointing to the left sidebar), 'Embedded Note' (pointing to the first note box), 'Visualization' (pointing to the mitosis diagrams), and 'Hint' (pointing to the hint box).

Figure 2. Effect Size of Baseline to Year 1 and Baseline to Year 2 Performance

