DISCUSSION-BASED STRATEGIES FOR USE OF SIMULATIONS AND ANIMATIONS IN MIDDLE AND HIGH SCHOOL SCIENCE CLASSROOMS

Computer simulations have immense potential for use in science classrooms to help promote conceptual change. As of yet, however, there is little research on how to best utilize these tools to support student learning. This paper describes the process of creating a manual for teachers on strategies that can be used during simulation-based lessons. Strategies included in the manual were identified during observations of middle and high-school science lessons over the course of a three and a half year study. We discuss the process by which strategies were identified, compiled, and organized into a functional manual that teachers can use to strengthen simulation-based lessons and scaffold student learning. We highlight the important role of teacher feedback in shaping the final product. Finally, we describe eleven core strategies that can be used to promote student engagement and support conceptual change.

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Computer simulations are increasing in popularity as powerful tools teachers can use to scaffold student understanding of complex and abstract science concepts. While there have been a large number of studies conducted on the use of simulations in science classes (Russell and Kozma, 2005; Williams, et al. 2004; Jones et al., 2001; Linn, 2003; Buckley 2000) very few focus on the strategies teachers can employ to use them most effectively (Adams et al, 2008; Price et al., 2010). Two other papers in this volume report on teaching strategies identified by our group during a teacher self study and the analysis of selected videotaped lessons which took place as part of a larger three-and-a-half-year study on the use of simulations in middle and high school classes. These other studies are more typical research studies addressing particular research questions, but in this report our goal is to describe a process for making newly observed strategies available to teachers. During this time, we observed eight teachers using simulations in lessons across nine different topics. During the 3 ½ year study, our group has amassed a large dataset of strategies. This paper describes the process by which these strategies were gathered and how they are being organized using teacher feedback to create a teacher manual. We will also describe eleven core strategies that can be used to scaffold conceptual change.

Methodology

Strategy Identification:

During the first three years of this project, eight teachers were observed and often videotaped as they led simulation-based lessons. The classes observed ranged from seventh to twelfth grade and included both whole class and small group formats. During most lessons, there was at least one member of the research team present during the lesson; often there were two, with one person responsible for filming while the other took notes. On a few rare occasions, when there was more than one lesson occurring at a time, a camera was set up in the back of the room and left to run through the course of the lesson.

In the field notes, we indicated sections of the lessons that seemed successful, sections that did not appear to work as well, interesting teacher moves, and notable student questions, comments and reactions. We later transferred our notes to a more structured lesson analysis form, where we expanded upon some of our observations. The form was designed to stimulate thinking about the lesson and its implementation. Certain questions targeted the identification of strategies used during the lesson. These questions included:

1. *What were teacher's strategies for interacting with tool?*
2. *What were some strengths of the lesson and interaction (around the animation)?*
3. *What candidates for teaching-principle hypotheses or pitfalls to be wary of can you suggest from your thinking about this lesson?*
4. *What were other teacher moves you observed, not general enough to be principles but still interesting?*

After each lesson or at the end of a given topic, the teachers were interviewed using the same analysis form. We later reviewed the information provided on the lesson analysis forms and combined all the strategies described into one large database.

A second round of strategies were identified during the post-hoc analysis that occurred in the second, third, and fourth year of the study. All of the videos taken during these lessons were uploaded and transcribed and many of them were coded and analyzed for different studies. The research conducted with this data set covered a number of different topics including whole class vs. small group instructional strategies, gender differences, discussion strategies, and model-based learning (see Stephens et al., 2010; Stephens et al., 2009; Price et al., 2010; Vasu et al., 2010). As a result, a significant number of additional strategies were identified in this round of videotape analysis and added to the database to form a large list of strategies.

Strategy Organization:

After compiling the original set of strategies, we began the process of shaping them into a manual for teacher use. We organized and honed the list in multiple ways, exploring its potential use to teachers. This phase of the process was guided by a number of different goals; we wanted to 1) highlight the many affordances of a simulation, 2) identify strategies that strengthen simulation-based lessons and scaffold student learning, 3) present the information in a way that is both functional for teachers and accessible to teachers who may not be as familiar with the medium.

To help us meet these goals, we sought feedback from three different teachers at multiple points during the design of the manual. We selected teachers that worked in high school and middle school and represented a range of experience using simulations in the classroom. In the first round of feedback we asked for general information about the way they thought about simulations in the classroom and what they would want to see in a manual on strategies for using simulations. We asked:

1. *What is the main purpose you see for using a simulation in the classroom? As a presentation tool or a probe for student thinking? How do you use simulations?*
2. *How would a teacher be apt to use a manual on strategies around simulation use? What organization or grouping of the strategies do you think would make sense to the most teachers and why?*

By asking these questions we were hoping to get a sense of how teachers might approach a manual of strategies for simulation use.

We spent a few months designing a number of alternative models for organizing and presenting the strategies. When we had narrowed the potential models to three, we presented them to two of the teachers for feedback. They both identified the same one as the one they found most helpful. We selected this model and asked them to analyze it further, responding to the following questions:

1. *Does this organization make sense to you? If not, what changes would you make to how the strategies are organized?*
2. *Which strategies seem most promising?*
3. *Which strategies seem least promising? Most difficult? Would any actually*

discourage the use of simulations?

We used the teacher feedback to inform a major revision of the strategy organization. We narrowed the list from over seventy-five strategies to eleven core strategies and an additional thirty strategies. The core strategies are those we perceive to be most easily generalized across lessons and most powerful in scaffolding student conceptual change. The additional strategies are more specific. We organized the additional strategies by function for teacher use, linking each to one or more categories in an appendix. These are not intended to be disjoint categories but to provide different means of access for teachers. A few examples include: *strategies for whole class use, strategies for small groups, model-based strategies, strategies to scaffold middle school students,* and *strategies to scaffold high school students.* Thus, one strategy might be linked to a number of different categories in the appendix.

Using this core structure, we continued the process of revision for a number of months, submitting each successive version to teachers for feedback. At the time of this paper, we are using the teachers' feedback to shape the list of strategies into a final organizational structure. We are also exploring different ways of presenting the strategies so they are easy to understand and teachers are able to apply them in their lessons. We plan to use screen shots, diagrams, transcripts, and narratives in the hard copy version of the manual and are working on an online option that will include video clips. The framework meets our goal of providing teachers with guidance on how to create and implement effective simulation-based lessons designed to scaffold student conceptual learning of difficult or abstract material.

Results: Core Strategies Identified

In the process of identifying teacher strategies around using the simulations, we were informed by previous research on increasing viewer comprehension of visual displays, engaging students in active reasoning, and promoting conceptual change in science classes. We were interested in identifying the way in which strategies uncovered in these areas of research might be adapted for use in simulation-based lessons. We also wanted to identify topics or lessons for which a simulation would be especially effective at supporting student learning. Finally, we were looking for strategies that organically developed around the simulation during these lessons. In this process, we identified eleven strategies we believe to be especially useful to supporting student learning in simulation-based lessons. For the purposes of this paper, we organized them into three categories, although some strategies can fit into more than one category.

Category One: Strategies to help students understand important features and assumptions in visual displays

Previous research suggests that it is critical that teachers highlight important characteristics of the simulation because, without support, students and novice viewers are not always able to correctly interpret what they are viewing in a simulation or relate it to previous knowledge (Tversky, Bauer-Morrisson, & Betrancourt, 2002; Adams et al., 2008). To scaffold conceptual change, it is critical that students observe and accurately interpret relevant features of the simulation (Jones et al., 2001). This can be done through a directed independent or small group activity or by scaffolding students in a whole-class setting.

In his work on visual models, Mayer (1989) suggests that **highlighting the most relevant aspects of a visual model** is a powerful strategy to use with visual displays; it can help individuals attend to relevant information and increases the likelihood that they will internalize and retain the target concept. One strategy we observed teachers using was to **run a simulation at different speeds** in order to draw student attention to different features important to understanding the model depicted. For example, during a lesson sequence on diffusion, the teachers used the *Atomic Microscope (*Stark Design, 2005) simulation to show particle motion to their classes. During a lesson designed to highlight the model element *particles move randomly*, one of the teachers ran the simulation slowly and directed his students' attention to the motion of individual particles. Later in the lesson sequence, when the he wanted to highlight the model element *particles move from areas of high concentration to areas of low concentration,* he sped it up so they would attend to the overall trend of particle motion. This helped direct student attention to either micro or macro trends in the simulation.

Teachers also **used questions to effectively direct student attention to key elements of the simulations.** In a high school physics lesson on projectile motion, the teachers used a series of related animations to help students understand the vertical and horizontal components of velocity overtime. The animations show a ball moving in an arc with no wind resistance along an XY axis. The animation tracks the ball's path at equal intervals of one second. There are three variations of the animation designed to show the horizontal component, vertical component, and vectors associated with projectile motion. In this example, the teacher presented *Lines Animation II* (Stephens et al., 2010) in which the constant spacing between lines indicates that the horizontal velocity component is constant (See Figure 1). As she played the animation, the teacher asked the students, "What's the first thing you notice about those vertical lines?" By asking the students to reason about the line spacing, the teacher was simultaneously drawing their attention to an important feature of the simulation and encouraging them to actively engage with the material.

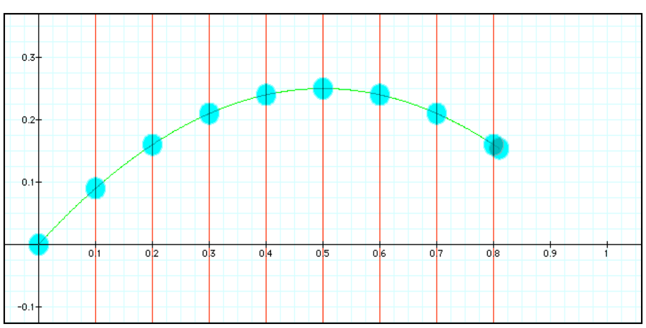

Figure 1. Lines Animation II (Stephens et al., 2010)

Another important strategy teachers used to make the simulation more comprehensible to their students was to **highlight the assumptions of the simulation**.

One example of this strategy took place during the same unit on projectile motion, in a different class. In this lesson, the teacher used the *Galileo* simulation (Fowler, 1998). In this simulation a ball is launched into the air and its path is tracked; the simulation provides information on the distance it travel, the height it reaches, and the amount of time between being launched and when it lands. The viewer is able to manipulate different variables including the mass of the ball, launch angle, and launch velocity (see Figure 2).

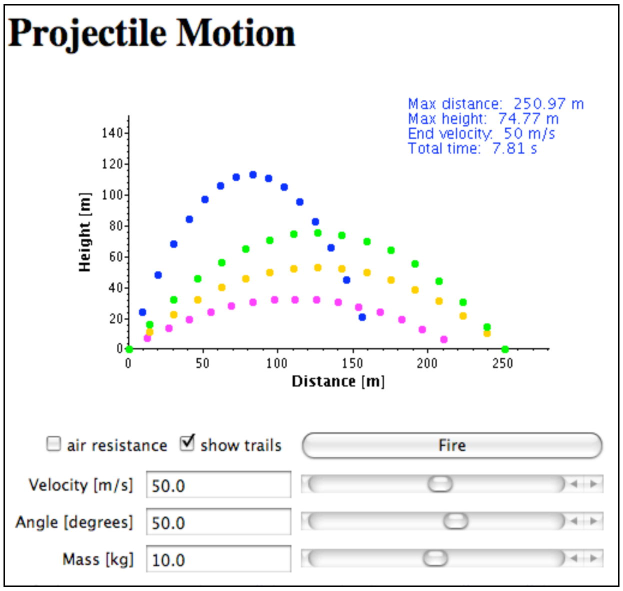

Figure 2. Projectile Motion (Fowler, 1998)

In this segment of the lesson, the teacher asked students to predict how changes to the mass of the ball, while keeping all other variables constant, would change the range of the projectile. The students made a number of different predictions, which the teacher had them share, before he tested their hypotheses by launching a 5 kg and then 10 kg ball. The students observed, while the teacher noted aloud, that the change in mass had no effect on the range. After watching the teacher launch more balls with even greater masses, a student noted that he did not understand how the path could remain the same. Other students also expressed confusion and one of them rooted his disbelief in the fact that it would take more force to launch a heavier ball.

The teacher acknowledged the student's concerns and clarified a number of assumptions implicit in the simulation in order to help them "believe" what the simulation was showing them. First, he conceded that in real life it would take more effort to throw a heavier ball than to throw a lighter ball with the same speed. But he encouraged them not to dwell on the force needed, as the simulation was designed so one could make the assumption that it would be possible to launch a 1000kg ball with the exact same launch speed as a 5 kg ball. Force is not a factor in this model. Second, he addressed the other variable that would affect what it would be like to throw two balls in real life- air resistance. He underscored the assumption that air resistance was "turned off" and therefore would not affect the ball's trajectory Thus, in this lesson, although the assumptions of the simulation seemed clear, the teacher had to address and clarify them in order to help his students comprehend the what they were observing (see Transcript Segment 1).

Transcript Segment 1

T: Here it is with the five kilograms of mass. It gives us a trace like that. Now, let's double it up to ten kilograms of mass. And, somehow it ended up the same. Let's kind of just make sure that's really right and go all the way up to a hundred kilograms of mass, and of course, it does the same thing. How about if I went all the way up to a thousand kilograms of mass? Yeah, it takes a lot more-

S: I don't really get that though.

S2: Yeah.

T: Yeah, you don't get it. I hear you.

S: Yeah I don't-

S3: It takes a lot more force to do it-

T: Yeah, what's the difference? This one's a lot, it's harder to get it going; this one is really easy. But if I were to get them going with an equal amount of push, somehow- excuse me, an equal speed leaving my hand- it's not an equal push, I've got to push this one a lot harder because of all that extra inertia. I've got to push it harder to get it up to that speed...*(picks up a heavy and light ball to demonstrate with)...*And I'll try to ensure that they're the same speed by keeping them stuck together, and just...(*throws the balls).* They basically follow the same path. They're very different masses. Now, would that work if I went outside with these two balls and threw them as hard as I-and threw them at equal speeds, but much bigger than what I just did?

S: Let's do it- let's throw them out the window.

S2: There is air resistance so...

T: Yeah, because this thing [*indicating the lighter ball*] is basically like a balloon, right, and it's windy out there... A real ball like this would be very affected by the weight. If we assume that air resistance really is negligible, then we should get the result that mass does not matter, that's what we saw up here.

In some lessons, the teachers also found it important to **clarify the limitations of the simulation** they were using. In the unit on diffusion, for example, three teachers used the *Atomic Microscope* to represent a semi- permeable membrane. They placed a number of molecules of varying sizes on the screen and erected a wall down the middle. The wall had a hole in it that was large enough to allow some of the molecules through but not others. Unfortunately, the simulation only allowed the user to leave one gap in the wall, rather than the multiple gaps that would more accurately represent a semi-permeable membrane (see Figure 3). In some classes the teacher addressed this limitation directly, while in other classes the teacher asked students a question to help them identify it. In one class the teacher acknowledged the limitation and then expanded on the idea that most models are approximations by saying, “[the simulation] is a model and models aren’t perfect. Its a simplification of reality.”

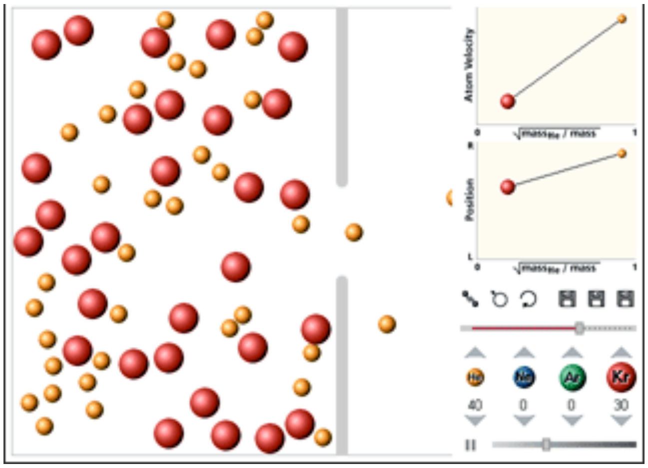

Figure 3. Atomic Microscope (Stark Design, 2005)

Category Two: Strategies to engage students in active reasoning about a visual display

During this project, we observed teachers using a number of creative strategies to engage students in active reasoning during simulation-based lessons. These strategies are particularly important given the fear some educators have about students slipping into “couch potato mode” as passive observers of the simulations. Many of the teachers used questions to promote active reasoning, a strategy research suggests can be an effective way to elicit student participation and encourage students to engage in complex reasoning and abstract thinking in class (Chinn, 2006, Van Zee and Minstrel, 1997, Williams and Clement, 2007).

We observed a number of teachers **asking students prediction questions** during lessons with simulations. Prediction questions can be used for a number of different purposes. In some classes, teachers introduced the simulations frozen and asked for predictions on what the class thought would happen when they pressed play. Asking a prediction question at the beginning of a lesson can serve as a formative assessment. It can also prime the student to create a mental model of what they expect to occur. Other teachers periodically froze the simulations, changed one or more variables, and asked the students to predict what would happen when they ran it again. Using prediction questions in this way can encourage visualization and model based reasoning. By showing students a frozen image of a dynamic model and asking what will happen next, they are encouraged to “run” the model in their mind in order to make a prediction. This strategy is advocated by a number of authors who have advocated model based reasoning as a central strategy for accomplishing conceptual change (Narayanan & Hegarty, 2002; Hegarty, Kriz, & Cate, 2003; Clement, 2008).

In many classes, teachers also called on multiple students to share and defend their predictions to the class. Asking students to share and explain their predictions is another important strategy. By doing this, teachers are encouraging them to attend to *"differences of opinion*," a tactic that Hogan and Pressley (1997) suggest can effectively stimulate student thought.

Finally, prediction questions can be used towards the end of a lesson to assess conceptual understanding by **asking students to apply their model to a novel situation.** In an interesting variation of this strategy, one middle school teacher asked students to apply their model of molecular motion to a new situation. He asked them to draw a phase diagram of what the air would look like on a molecular level at three different points in time; right after opening a bottle of ammonia, a few minutes later and after one hour had passed (see Figure 4). In this move, the teacher is pairing asking prediction questions with an additional strategy of **eliciting drawings and gestures around the simulation.** In doing this, the teacher is both encouraging students to engage in model based thinking while also "stimulating multi-modal thinking," by asking questions that demand verbal, written and drawn answers. The latter is a strategy Chin (2006) suggests helps students understand concepts from multiple perspectives.

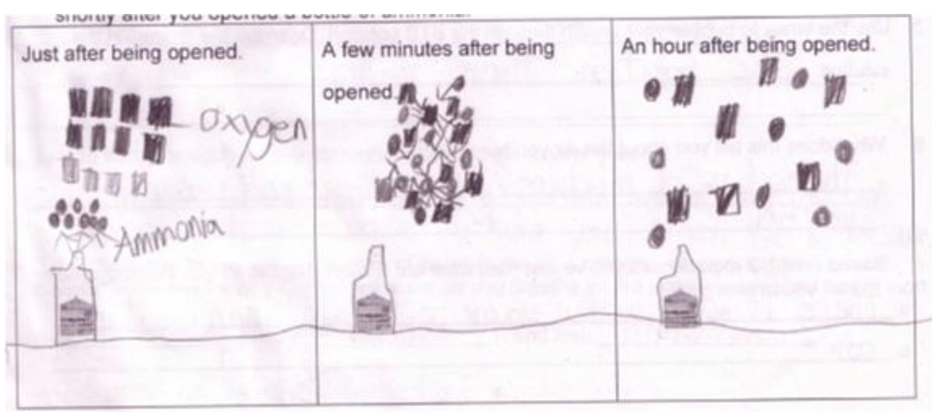

Figure 4. Phase Diagram

Another type of question teachers used to encourage active reasoning is known as a **reflective toss** (Van Zee and Minstrell, 1997). The reflective toss place responsibility for interpreting the simulation and reasoning about the concepts it was designed to illustrate on the students. When a teacher engages in a reflective toss, he or she repeats a question made by a student back to the student or the class (Chinn, 2006). One example of this strategy occurred in a high school physics lesson on projectile motion. A student asked*: (Does it have) equal acceleration?* To which the teacher responded: *Does it have equal acceleration? What do you think?* This forced the student to think about the answer rather than just relying on the teacher's response. This is an important strategy because it gives students the responsibility for reasoning more fully about the material (Engle and Contant, 2002)

Other strategies that fell into this category encouraged students to **engage kinesthetically with the simulations**. Research suggests that the opportunity to engage with concepts kinesthetically can be important to scientific thinking (Clement, 1994;

Clement, Zietsman, & Monaghan, 2005; Reiner and Gilbert, 2000; Gooding, 1992). We observed teachers using kinesthetic imagery as a strategy to promote active engagement and increase conceptual understanding. One example of this strategy occurred during a high school class physics lesson on energy. The teacher was using a simulation developed by PhET (Reid, et al. 2009) called Energy Skate Park, which depicts a character on a skateboard and shows changes to his kinetic and potential energy as he moves from the top to the bottom of a skate park ramp. To help her students engage with the concepts of energy and work, she encouraged them to imagine themselves in the scenario. At one point, she said "If you were at that point on the skateboard track, you'd be pumping with your knees." By placing them in the scenario, not only did she engage them kinesthetically but may also have increased their interest in the lesson as previous research suggests that relating a simulation to real-world problems can increase student motivation (Adams et al., 2008).

Category Three: Strategies to increase conceptual understanding

During this project, we identified places in the curriculum for which simulations were uniquely helpful in scaffolding conceptual change. In the two examples described below, the teachers took advantage of the unique affordances of a simulation to show things that would otherwise be unobservable. Both took place as part of middle school lessons designed to support student understanding of molecular motion.

Previous research suggests that middle school students experience difficulty understanding kinetic molecular theory (Brooks, Briggs and Driver, 1984; Gabel, Samuel & Hunn, 1987; Hibbard & Novak, 1975; Westbrook and Marek, 1991). In developing their Matter and Molecules curriculum, Lee et al. (1993) found that student misconceptions were multitudinous and pervasive, with students clinging to their scientifically inaccurate conceptions even after exposure to different curricula. Specifically, they found that the middle school students they studied had difficulty separating the microscopic attributes of molecules from the macroscopic properties of the substances they made up. Thus, the students perceived molecules of ice to be "frozen" and molecules of wood to be "hard." Students also experienced difficulty with the idea that molecules were constantly in motion and that changes we observe on a macroscopic level result from changes in the arrangement and/or motion of molecules. These misconceptions were deeply ingrained and the authors found that some students had retained inaccurate conceptions even while demonstrating a grasp of the vocabulary associated with canonical molecular theory. The authors point to these findings as evidence for the need to implement strategies designed to promote conceptual change rather than just teach rote facts and vocabulary (Lee et al., 1993).

Model-based teaching is one approach that can be used to promote conceptual understanding and support student reasoning (Narayanan & Hegarty, 2002; Hegarty, Kriz, & Cate, 2003; Nunez-Oviedo, 2005; Williams & Clement, 2007 & Ramirez et al. 2008). In her research on scientific reasoning among students, Mary Hegarty argues that once an individual has constructed a dynamic mental model, they can manipulate it to reason about different cases (Narayanan and Hegarty, 2002; Hegarty, Kriz, & Cate, 2003). Research that expert scientists use model construction and mental simulation when reasoning through novel cases underscores the importance of teaching these skills (Clement, 2008, Trickett & Trafton, 2002).

There are a number of studies that identify teacher moves that can be used during model-based instruction. Clement (2008) describes one approach called co-construction. During model based co-constructed lessons, students and the teacher share responsibility for producing and analyzing ideas as they work together to build a consensus model of the target concept of interest. In both of the lessons described in this section, the teachers engaged in model based lessons that were at least partially co-constructed.

Allowing students to conduct experiments and observe the outcomes is one strategy that supports model based co-construction, as it provides students with the opportunity to test different hypotheses and modify their mental models based on the results (Williams and Clement, 2007). As molecules exist on a microscopic level and are therefore unobservable, simulations can provide a unique platform for students to observe them as they construct a model of molecular motion. In the two strategies described below, teachers creatively utilize this opportunity to show students a microscopic phenomenon to promote model construction and scaffold conceptual change.

The first strategy, which we have labeled **the overlay strategy,** took place as part of a unit on diffusion. On Day 1 of this lesson sequence, the teacher brought out a beaker of perfume. He then asked the students to close their eyes. He placed the perfume on a burner and heated it up and had them indicate when they began to smell the perfume. The strategy described here took place on Day 2. At the start of the lesson, he had the class review what had occurred the day before and asked the students what they thought “made the perfume spread.” The students came up with a number of different hypotheses; they proposed that the perfume was spread by the air current created by the air conditioner, the perfume spread because it was in the smoke and traveled when the smoke traveled, the perfume spread because it was moving away from the heat, and/or the perfume spread because air particles bounced into perfume particles. Thus, the students had many misconceptions and partially correct conceptions about how the perfume “spread.”

To provide students with the opportunity to observe molecular motion, the teacher introduced the Atomic Microscope simulation He drew a box on the whiteboard and projected a simulation of colliding oxygen and nitrogen molecules, onto it. He told the students that the box represented the classroom and asked them to describe what they saw. During this discussion, he made sure to highlight student observations that the molecules were constantly in motion and that they moved randomly, key model elements to building a deeper conceptual understanding of molecular motion.

The teacher then paused the simulation and added a stack of red molecules, all bunched together in one corner to represent the perfume in the beaker. To map what was occurring on the microscopic level to what had happened at the macroscopic level, he told the students that he was going to draw their noses on the whiteboard to represent where they were around the classroom when he had started to heat up the perfume. He drew the noses of the students that were sitting closest to the front of the room nearest to the bunch of red molecules and the ones that had been in the back of the room, farthest away. He then ran the simulation and the students were able to watch what had happened on a molecular level when the perfume had spread around the room. Thus the more general simulation was overlaid on top of a more specific context drawn by the teacher.

Using the simulation, the teacher provided students with the opportunity to observe what was happening on a microscopic level and build their mental model of molecular motion. By adding the overlay, he was also able to tie what they were viewing to the macroscopic phenomenon they had already observed. In this way, the overlay strategy scaffolds conceptual change around molecular motion more generally and addresses the difficulty students often have bridging macroscopic phenomena to their microscopic explanations. The teachers liked this strategy and used it again in subsequent years. We have included a screenshot from a lesson conducted the following year on how the scent of baking cookies spread in order to illustrate how this strategy might be used (see Figure 5).

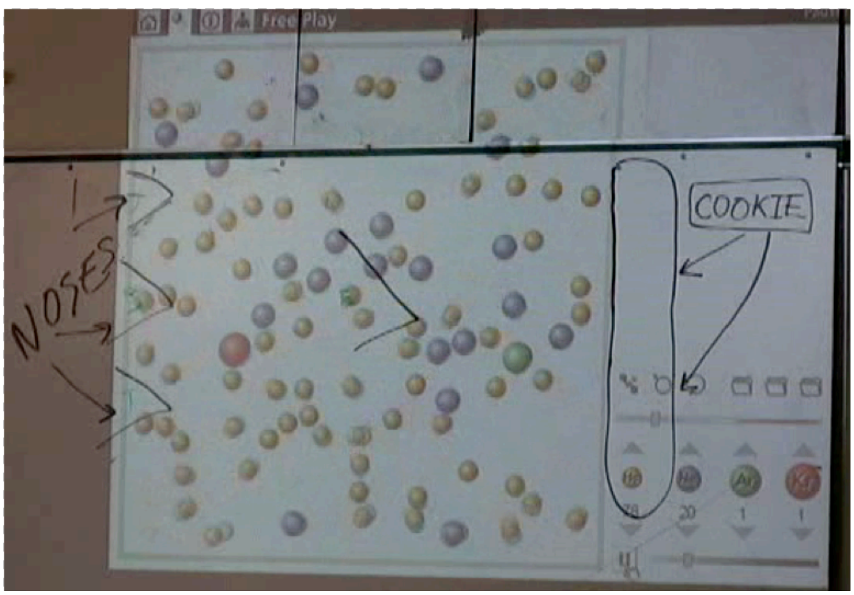

Figure 5. A screen shot of the overlay strategy being used in a very similar class on molecular motion the following year. In this lesson, the overlay represented the scent of a baking cookie spreading through the room (rather than perfume)

The lesson described above took place at the beginning if a lesson sequence designed to support middle school students in the construction of an increasingly sophisticated model of diffusion. The second strategy took place later in the sequence when a different teacher introduced the model element of a *semi-permeable membrane.* To illustrate this concept, the students had just finished an experiment in which they had submerged an egg into vinegar and then into corn syrup and gathered data on how much the weight changed each time. They discussed that the change in weight was caused by diffusion, molecules passing in and out of the egg. To help them understand the concept of permeability, the teacher again projected the *Atomic Microscope* (Stark Design) simulation onto the whiteboard. He divided the simulation into two parts with a barrier (as shown in Figure 5) running down the middle of the display. The teacher first presented the simulation with the barrier completely closed so that it formed a solid wall down the center of the display. He overlaid an outline of the egg over one side of the simulation so that one half represented the egg and the other represented the vinegar; the barrier represented the egg's skin. He then introduced "egg particles" to one side of the barrier and "vinegar particles" to the other (as distinguished by their color). The barrier served as an impermeable membrane and the particles each stayed on their own side. To introduce the idea of a semi-permeable membrane, the teacher asked students to explain what was wrong with the model he presented model (see Transcript Segment 2)..

In this case, the teacher shows students what an impermeable membrane would look like as a dissonance-producing move. Here, the term dissonance is used according to the definition described by Clement and Rea-Ramirez (1998); "an internal sense of disparity between an existing conception and some other entity." By **showing students an inaccurate model** the teacher was able to give them the opportunity to modify it so that it was correct. In this class the students were able to help generate the idea that there needed to be holes in the membrane for it to be a more accurate. Presumably, in modifying the simulated model, the students also modified their own internal model of a permeable membrane. This strategy of creating an extreme case takes advantage of the unique affordance that simulations offer to show things that we would normally be unable to observe.

Transcript Segment 2:

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T: Here's the egg here's the vinegar. Does everyone see that
that's the modeling going on here?
. . .
T: There's the membrane right here. So if the membrane were like
this, what would happen to our egg? Who can tell me? If the
membrane of the egg were like this who can tell me, what would
happen in the egg?
S1: I think the vinegar would just bounce off of it.
T: Nice. If the vinegar bounced off what would have happened to
the egg?
S2:It would have stayed the same.
T: It would have stayed the same. So lets see if this happens.
Lets run this.
S3: That's not cool-its supposed to break through.
T: Yeah, now it's supposed to break through but in this model we
are showing the membrane, it cannot be broken through.
. . .
T:. Now if I poked a million holes in this then it would be like
a strainer and that would be permeable right. What I'd like you
to draw here, we know that the egg is- Is the egg membrane
permeable or impermeable?
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S4: permeable
T: It's got to be permeable because we saw the egg get bigger. So
here I want you to draw a picture of what the egg membrane must
look like…I want you to draw me a picture of the cell or the egg
if it were permeable. What would that look like?
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Conclusion

Over the course of this three-year project, we observed teachers demonstrating a number of different strategies during simulation-based lessons. Some of these strategies already have support in previous research on effective teaching strategies but we were able to observe how they were adapted in the special context of working from a visual display. Others seemed to emerge organically from the unique demands of these lessons. Out of the forty strategies we identified, we have selected eleven that appeared to observers to be especially effective in simulation-based lessons. All eleven of these core strategies can be used in simulation-based lessons to promote student engagement and support conceptual change.

Category One: Strategies to help students understand important features and assumptions in visual displays

1. Highlight the most relevant aspects of the visual model presented within the simulation (as by running the simulation at different speeds to draw attention to different relationships within the simulation)
2. Use questions to direct student attention to key elements of the simulation
3. Highlight the assumptions of the simulation
4. Clarify the limitations of the simulation

Category Two: Strategies to engage students in active reasoning

5. Ask students prediction questions
6. Have the students apply the model to a new situation when the simulation is not on
7. Elicit drawings and gestures around the simulation
8. Use reflective toss to place ownership of the material on the students
9. Provide students with the opportunity to engage kinesthetically with the simulations

Category Three: Strategies to increase conceptual understanding

10. Project an abstract simulation onto a whiteboard and overlay it onto a drawing of the object it is designed to represent.

11. Use the simulation to create extreme or ideal scenarios that would otherwise be unobservable.

How to organize a manual of strategies for teachers is an interesting problem. Our current plan is to include all forty strategies in a manual, but to introduce the manual with the eleven strategies above as a more manageable introductory set.

References

Adams, W. K., Reid, S., LeMaster, R., McKagan, S. B., Perkins, K. K., Dubson, M., & Wieman, C. E. (2008). A study of educational simulations Part I - Engagement and learning. *Journal of Interactive Learning Research, 19*(3), 397-419.

Atomic Microscope, 3-D Plus. Computer software. Stark Design, 2005. Windows network

Buckley, B. C. (2000). Interactive multimedia and model-based learning in biology. International Journal of Science Education, 22(9), 895– 935.

Chin, C. (2006). Classroom interaction in science: Teacher questioning and feedback to students' responses. *International Journal of Science Education, 28(11)*, 1315.

Clement, J. & Rea-Ramirez, M. (1998). The role of dissonance in conceptual change, Proceedings of ational Association for Research in Science Teaching.

Clement, J. (2008). Student/Teacher Co-construction of Visualizable Models in Large Group Discussion. In J. Clement & M.A. Rea-Ramirez (Eds.), *Model based learning and instruction in science (pp11-22).* Dordrecht: Springer.

Engle, R.A. and Conant, F.R. (2002). Guiding Principles for Fostering Productive Disciplinary Engagement: Explaining an Emergent Argument in a Community of Learners Classroom. *Cognition and Instruction, 20(4),* 399-483.

Fowler, M. (1998). *Projectile Motion,* applet. Galileo and Einstein Physics, University of Virginia.
http://galileoandeinstein.physics.virginia.edu/more_stuff/Applets/ProjectileMotion/jarapplet.html

Hegarty, M., Kriz, S. & Cate, C. (2003). The roles of mental animations and external animations in understanding mechanical systems. *Cognition & Instruction*, 21, 325-360

Hegarty, M. Narayanan, N. H. & Freitas, P. (2002). Understanding Machines from Multimedia and Hypermedia Presentations. In J. Otero, A. C. Graesser & J. Leon (Eds.). *The Psychology of Science Text Comprehension*. Lawrence Erlbaum Associates.

Hogan, K. and Pressley, M. (1997). Scaffolding Scientific Competencies within

Classroom Communities of Inquiry. In Hogan and Pressley (Eds.), *Scaffolding Student Learning: Instructional Approaches and Issues,* (74-107). Cambridge: Brookline.

Jones, L., Jordan, K., & Stillings, N. (2001). Molecular visualization in science education (2001). *Report from the Molecular Visualization in Science Education Workshop*, NCSA Access Center, Arlington, VA, January 12-14.

Lee, O. Eichinger, D.C., Anderson, C.W., Berkheimer, G.D&Blakeslee, T.D. (1993). Changing middle school students' conceptions of matter and molecules. *Journal of Research in Science Teaching, 30 (3)*, 249-270.

Linn, M. (2003). Technology and science education: Starting points, research programs, and trends. International Journal of Science Education, 25(6), 727–758.

Mayer, R. E. (1989). Models for Understanding. *Review of Educational Research, 59* (1), 43-64.

Narayanan, N. H., & Hegarty, M. (2002). Multimedia design for communication of dynamic information. *International Journal of Human–Computer Studies, 57*, 279–315.

Nunez-Oviedo, M. (2005). Proceedings from AERA 05: *Examining the use of drawings to promote model based learning during group discussions.* Montreal, Canada.

Price, N., Leibovitch, A. & Clement, J. (2010). Proceedings of the NARST 2010: *Case Study of Teaching Strategies Before, During and After a Simulation to Scaffold the Development of a Visualizable Microscopic Mental Model.* Philadelphia, PA.

Ramirez, M. A., Clement, J. and Nunez-Oviedo, M.C.(2008). An Instructional Model Derived from model Construction and Criticism theory. In J. Clement & M.A. Rea-Ramirez (Eds.), *Model based learning and instruction in science (pp23-44).* Dordrecht: Springer.

Reid, S., Adams, W., Dubson, M., Loeblein, T., Perkins, K., & Wieman, C. (2009). E*nergy Skate Park v2.05.* PhET Interactive Simulations, University of Colorado. http://phet.colorado.edu/index.php

Russell, J. & Kozma, R. (2005). Assessing learning from the use of multimedia chemical visualization software. In J. K. Gilbert (Ed.) *Vizualization in science education*. Dordrecht, The Netherlands: Springer.

Trickett, S. B., & Trafton, J. G. (2002). The instantiation and use of conceptual simulations in evaluating hypotheses: movies in the mind in scientific reasoning. *Proceedings of the 24th Annual Conference of the Cognitive Science Society.* Mahwah, NJ: Erlbaum.

Tversky, B., Bauer-Morrisson, J., Betrancourt, M. (2002). Animation: Can it facilitate? *International Journal of Human-Computer Studies. 57*(4), 247-262.

van Zee, E. and Minstrell, J. (1997). Using questioning to guide student thinking. *The Journal of the Learning Sciences*, 6(2), pp. 227-269

Williams, M., Linn, C., Ammon, P., & Gearhart, M. (2004). Learning to teach inquiry science in a technology-based environment: A case study. Journal of Science Education and Technology, 13(2), 189-206.

Williams, E.G. & Clement, J. (2007). Proceedings from NARST 07: *Identifying model-based teaching strategies: A case study of two high school physics teachers.* New Orleans, LA.