COMPARATIVE CASE STUDIES OF DISCUSSION STRATEGIES USED IN DYNAMIC COMPUTER SIMULATION AND STATIC IMAGE-BASED LESSONS

Norman Price and John J. Clement

University of Massachusetts – Amherst

Author's Note

Norman T Price and John J. Clement, School of Education and Scientific Reasoning Research Institute, University of Massachusetts-Amherst.

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Correspondence should be addressed to Norman Price, 428 Lederle GRT, 710 N. Pleasant St., Amherst, MA 01003-9305. Email: nprice@educ.umass.edu or normprice@gmail.com

ABSTRACT

A central question for teachers and researchers is how to engage active student reasoning, be responsive to student ideas, and still efficiently meet content goals. The availability and sophistication of visual displays or external images for use in science classrooms has increased exponentially and offers teachers new opportunities to elicit and respond to student ideas. However, it can be difficult for teachers to use these images to encourage and engage active student thinking. There is a need to describe flexible discussion strategies that use images to engage active thinking. Other researchers have identified teaching strategies for large group discussions, but few if any have focused on special strategies to use with discussions of visual media such as overheads, animations and simulations. This study analyzes teacher behavior in a lesson using visual media about the particulate nature of matter that was taught by two experienced middle school teachers. Each teacher taught a lesson to one half of his students using static overheads, and taught the other half of his students using a dynamic simulation. The two types of lessons had similar content goals, lab activities, and handouts but differed in the type of image mode used during large group discussion. Video and transcripts of large group discussions were analyzed to identify a set of image based discussion strategies. Results suggest that the simulation mode offered greater affordances than the overhead mode for planning and enacting discussions. Differences in teacher use of discussion modes such as presentation, IRE, and IRF suggest that teacher preferences for discussion modes may have interacted with the simulation or overhead condition.

INTRODUCTION

Background

Projected static overheads and computer simulations are common tools for developing student understanding of scientific concepts, yet it can be challenging for teachers to move beyond "show and tell" uses of these images and, instead, strategically employ them in large group discussions to promote active reasoning and scaffold the construction of dynamic visualizable models. The purpose of this study is to examine, describe, and compare student learning and teacher large group discussion practices used in computer simulation and static overhead based lessons.

Previous psychological studies have indicated that words and pictures together are more effective instructional messages than either words or pictures alone (Mayer & Moreno, 2002), and that students need help interpreting complex visuals (Lowe, 2003). Our long term interest is pursuing this line of research in a classroom setting where projected images can function like pictures, and the class discussion can function like the words or narration used in these studies. We want to explore how students' internal imagery of scientific models may be improved by the use of external images of models, and what strategies teachers can employ during large group discussion to integrate images and engage students in reasoning about models. Static and dynamic images appear to offer different advantages and disadvantages to teachers when leading whole class discussions, but these affordances need to be described and strategies developed for teachers to be able to employ different image modes to reach the thinking and knowledge goals of a lesson. We will use the term 'image' broadly to refer to both internal images, such as mental simulations, and external images, such as drawings or projected computer animations.   Usually the intent will be clear from the context, but when it is unclear we will specify 'internal image' or 'external image.'

In this study, we will attempt to explore the affordance of static and dynamic images for use in large group discussion and find new descriptors for certain strategies teachers use to help them exploit these affordances. We hope that with further refinements, such descriptors will help teachers communicate about strategies for using images to build conceptual understanding, as well as help teachers learn new strategies.

Whole Class Discussion

The importance and complexity of discussions has been cited by many other authors interested in science instruction (van Zee & Minstrell, 1997, McNeill & Krajcik, 2008, Lump & Staver, 1995, Price, 2007, and Shulman, 2000 among others). Some studies have described general strategies teachers can use to encourage active student participation. Engle and Contant (2002), for example, describe how teachers can encourage discussions by fostering "productive disciplinary engagement" in the classroom. In classes that encourage productive disciplinary engagement, students are expected to "problematize" the concepts they are learning - to ask questions, test out hypotheses and generally grapple with the material they are learning - rather than serve as passive recipients of knowledge. In these classes, the students are taught that their contributions are a valid and important part of the process of learning. Similarly, in their paper on questioning in the classroom, van Zee and Minstrell (1997) note that in "inquiry teaching," teachers must be prepared to shift their agenda and ask different questions in response to student contributions throughout the lesson. During these lessons, the authors note, teachers can also shift the role of evaluating student responses to the class as a whole. Managing class discussions in which students are asked to evaluate other students is a complex task that requires teachers to develop new skills (Price, 2007).

While these studies provide an important framework for how to encourage student participation in science classes more generally, they often do not explicitly address how to use cognitive strategies in discussions to reach content goals. We have found two perspectives in the literature which do attempt to address explicitly how to reach content goals using whole class discussion and which can help to explore the complexity of a discussion which develops around a complex dynamic visual, like a simulation.

Theoretical Frameworks

We used the frameworks of model co-construction (Clement, Clement, J., & Rea-Ramirez, M. A., 2008) and the communicative approach (Scott, Mortimer, and Aguiar, 2006) to analyze how the discussion strategies can foster active engagement and scaffold the evolution of student mental models. The model co-construction literature offers a framework for setting an agenda to navigate the complex discussions that unfold when teachers attempt to explore and respond to complex student ideas in co-constructed lessons. The communicative approach describes the importance of alternating between teacher and student points of view, and exploring student generated ideas and sense-making during a discussion

The Communicative Approach Perspective

Scott, Mortimer, and Aguiar (2006) analyze classroom discourse along two axes: authoritative/dialogic and interactive/non-interactive (see Figure 1). Authoritative communicative discourse, they argue, takes place when teachers are interested in communicating one concept or perspective to their students (typically the "expert" perspective). Dialogic communicative discourse, in contrast, occurs when the teacher encourages or is open to a variety of different perspectives or ideas. Scott, Mortimer, and Aguiar (2006) contend that many teachers rely too heavily on authoritative approaches, since students can most effectively explore scientific ideas through a dialogic, highly interanimated, interactive approach. Interanimation refers to the degree to which a class is encouraged to engage with these different perspectives, comparing and contrasting different ideas to further explore the targeted scientific concept. The authors argue that having "open" periods of discussion, when students are encouraged to interact with each other around the material without being evaluated against the expert model, is critical to making meaningful conceptual gains.

Figure 1. The two dimensions of classroom discourse (Scott, Mortimer, and Aguiar, 2006)

	Interactive	**Non-interactive**
Dialogic	Interactive /Dialogic	Non-interactive /Dialogic
Authoritative	Interactive /Authoritative	Non-interactive /Authoritative

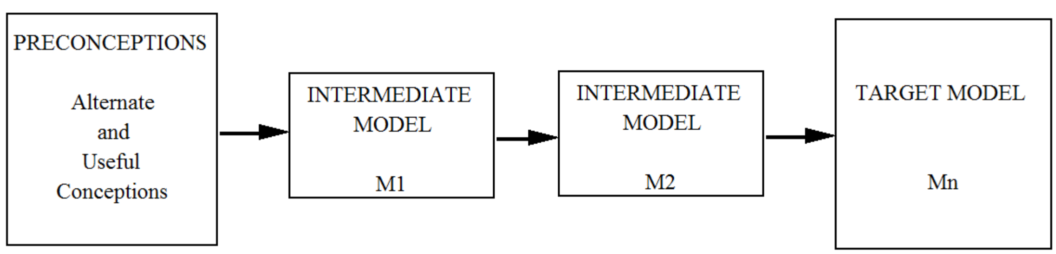
Importantly, however, Scott, Mortimer, and Aguiar (2006) do not believe that teachers need to use a dialogic, highly interanimated, interactive approach at all times during their lessons. Rather, they argue that "any sequence of science lessons, which has as its learning goal the meaningful understanding of scientific conceptual knowledge, must entail both authoritative and dialogic passages of interaction (pp.606)." Thus, over the course of a lesson, the teacher can constantly be moving the discourse up and down the axes of these two dimensions depending on "the teaching purpose," or the learning goals, for that part of the lesson.

Model Based Co-construction

In his work on model evolution via co-construction, Clement (2008) offers a framework for how to use student ideas to reach content goals. Model based learning refers to the process by which people acquire and assimilate knowledge into explanatory mental models. Research shows that expert scientists use mental models to reason through scientific problems and make predictions in novel cases (Clement 2003, 2004). Studies conducted on science classes have shown that supporting students in the construction of mental models can also enhance their understanding of difficult scientific concepts (Nunez-Oviedo, 2005; Williams & Clement, 2007, White & Frederiksen, 2000; Reiser et al., 2003; Johnson & Stewart, 1990; Krajcik et al., 2006). In her research on scientific reasoning among students, Mary Hegarty argues that once students have constructed a dynamic mental model, they can manipulate it to reason about different cases (Narayanan & Hegarty, 2002; Hegarty, Kriz, & Cate, 2003).

During model based co-constructed lessons, both students and teacher share responsibility for producing and analyzing ideas as they work together to build a consensus model of the target concept. Clement (2008) notes that in a co-constructed lesson, it is important that the "knowledge developed is largely student generated but at the same time, the agenda is largely teacher directed (pp.27)." Importantly, students are not expected to understand the model right away. Rather, over the course of the lesson, the teacher scaffolds the students learning process as the students build an increasingly sophisticated mental model of the target concept. This often happens in stages, as the teacher presents students with activities, demonstrations, or new information designed to prompt students to evaluate and revise their initial models (Figure 2).

Figure 2. Diagram of the model evolution process in which instruction is directed at helping a student move from model Mn to model Mn+1 and toward a target model. (Clement, 2000)



There are a number of studies that identify teaching strategies that can be used during model-based instruction. Many of these studies highlight cognitive strategies that teachers might use to engage students in reasoning or to encourage visualization. For example, teachers can engage their class in the co-construction of a target model by scaffolding student movement through the different phases of the GEM cycle (Nunez-Oviedo, 2005, Williams and Clement, 2007). A GEM cycle is the process of "generation, evaluation and modification" that scientists use to construct conceptual models (Clement, 1989). Hegarty et al. (2002) found that asking students to make predictions or answer "what if" questions can encourage them to engage in mental animations. This can also serve to support model generation. Other studies have identified dissonance-producing strategies that teachers can use to inspire independent student evaluation of model components (Clement and Rea-Ramirez, 1998). For example, opportunities for model competition, and presenting students with discrepant events, are dissonance creating strategies (Nunez-Oviedo, 2005, Thompson, 1989 as cited in Rea-Ramirez and Nunez-Oviedo, 2008, Clement & Rea-Ramirez, 1998).

Combining Theoretical Frameworks

These two theoretical frameworks taken together provide a way to explore how whole-class discussions can be used by teachers to engage active student thinking while efficiently meeting content goals. The communicative approach describes the importance of alternating between teacher and student points of view, and exploring student sense-making during a discussion. However, little has been written, from the communicative approach perspective, on how teachers can generate agendas for using the specific student ideas during a lesson to encourage conceptual change. Research on model co-construction provides cognitive strategies for using student ideas to support conceptual change, via model evolution. The model co-construction literature offers a framework for setting an agenda to navigate the complex discussions which unfold when teachers attempt to explore and respond to complex student ideas in co-constructed lessons. Both frameworks offer useful theoretical perspectives for exploring the structure of a simulation based lesson and describing how a teacher attempts to surround a simulation with a productive (content +) and engaging (thinking +) discussion.

Objectives of the Case Study

A goal of this study is to examine how different image modes are used by teachers to teach the same content.

Part One: Difference between image modes

Part one of the paper reports on a comparative case study that examined the ways that the discussion of images was managed in matched sets of a simulation lesson and overhead lesson taught by the two teachers. Part one addresses the questions:

> 1.1) What strategies were observed being used for leading whole class discussion in each image mode?
>
> 1.2) How were lessons with similar lesson plans enacted differently when using different image modes?

Part Two: Difference between teachers

Part two of the paper reports on a comparative case study that examined differences between teachers enacting the same lesson and image mode. This part of the paper will examine patterns of teacher student interactions used by each teacher during the entire lesson. Part two addresses the questions:

> 2.1) Did the teachers use different patterns of interactions (e.g. presentation vs IRF, see Table 18)?
>
> 2.2) If so, did the patterns of interaction used by the teacher impact how the image was used in the lesson?

Part Three: Differences due to teachers and image modes

Part three of the paper reports on a cross comparative study where effects due to teacher differences and image mode are considered. Part three will address the questions:

> 3.1) Was an image discussion strategy linked with particular interaction patterns?
>
> 3.1) Did teacher interaction pattern choices change after an image mode started?

<u>METHODOLOGY</u>

To pursue this research objective, a lesson was selected from an exemplary curriculum on the particulate nature of matter, which uses static images to help students construct explanatory models. This lesson had a particular content goal and student handout, and was designed to run for most of a class period (45-50 minutes). The overhead lesson employed an overhead as described by the curriculum and was taught using the overhead only. The simulation lesson used the same lesson structure and handout but adapted the lesson to replace the overhead part of the lesson with a computer simulation. Each teacher taught a class using an overhead lesson and a class using a simulation lesson. The lesson had the same content goal, student worksheet, and non-image based parts. The teachers collaborated with the researchers to develop the specific overhead and simulation lesson plan.

A primary focus of this study on the large group discussions that occur during this lesson was adapted from *Matter and Molecules* (Lee, Eichinger, Anderson, Berkheimer, & Blakesee, 1993). *Matter and Molecules* was selected because it has been shown to foster meaningful growth in science understanding, and it addressed the content goals relevant to the school's curriculum standards. In developing the curriculum, Lee et al. examined students' ability to learn and demonstrate an understanding of kinetic molecular theory. They found that student misconceptions around molecular theory were multitudinous and pervasive, with students clinging to their scientifically inaccurate conceptions even after exposure to lessons that taught them the expert explanations. These findings support previous studies that have found kinetic molecular theory to be an area of particular difficulty for science students.

The curriculum provides detailed readings, activities, overheads, and worksheets to accompany the lessons, each designed to address a specific misconception or set of misconceptions. However, the authors of the curriculum provide little specific guidance on how to run or manage the classroom discussions that surround the activities and explicate the concepts of the lessons. The curriculum employs complex static overhead images as a key element of the instruction but was developed at a time when computer simulations were not widely available. In this study, a simulation lesson was created by substituting a computer simulation for the overhead provided in the *Matter and Molecule* curriculum.

This study explores an image-based lesson about the particulate nature of matter taught by two experienced middle school teachers. Each teacher taught one half of his students with lessons using static overheads, and taught the other half of his students with lessons using a dynamic simulation. Each simulation/overhead lesson pair had similar content goals, lab activities, and handouts but differed in the type of image mode used during large group discussion.

Participants, Context & Setting

This case study focuses on one lesson that took place during a four-week unit on matter and molecules in an eighth grade classroom at a small, middle-class, public middle school. The lesson took place approximately two weeks into the unit. The lesson was part of a larger section on air, and how air is made up of many different types of molecules. The lesson in this study attempted to help students construct a visualizable particulate model explaining how a gas can push back on a plunger when compressed. The written plan used for this lesson was developed by the teachers in conjunction with researchers at the University of Massachusetts/Amherst.

The two teachers involved with the study taught 4 classes of heterogeneously grouped students. To display the images, each teacher used a single PC computer projected onto white board in front of the class or an overhead projector with transparencies. Each teacher guided a whole class discussion as students worked through the lab activities and handouts provided by the curriculum. The lesson analyzed in this paper was taught by one of the authors of this paper, Norman Price, whom we will refer to as Mr. P, and another teacher, whom we will refer to as Mr. C. The teachers were selected for this study because they have experience teaching this age group (each has between 10 -20 years of middle school teaching experience), they are familiar with this science content, and each teacher has demonstrated interest in participating in the planning and enacting of these complex lessons. The selection of simulations to be used in these lessons was completed jointly by the teachers in consultation with our research group.

Data Collection Methods

Data collected included open observations in class, videotapes, and student work samples. Over the course of the 4 weeks of study in the *Matter and Molecules* unit, approximately 20-25 hours of classroom activity were videotaped and later transcribed and analyzed using Transana video software (Woods & Fassnacht, 2007). The data from this study comes from this data set. In this study we will be examining video data comes from video tape of four lessons, from teacher Mr. C and Mr. P, each using an overhead lesson and a matched simulation lesson. We refer to the latter as the Overhead condition and the former as the Simulation condition.

Qualitative Data Analysis

As an exploratory study in an understudied area, analysis focuses mostly on open coding of video episodes, using constant comparison techniques, in order to differentiate and refine new constructs describing teaching strategies at different levels (Chin, 2006; Glaser and Strauss, 1967). The purpose in general of such an exploratory case study is to provide existence demonstrations of newly observed behavior patterns that promote the generation of hypotheses about effective teaching and learning strategies. The constant comparison method will be used to develop descriptions and categories of teacher discussion practices and strategies that were believed to engage student reasoning and construction of a particulate model of air. This will involve the interpretive analysis cycle of segmenting the data; making observations from each segment; formulating a hypothesized model that can explain the observations; returning to the data to look for more confirming or disconfirming observations; and criticizing and modifying, or extending the interpretation (Clement, 2000a). Since Price is a teacher in the study, he added an inside perspective of teacher thinking that occurs during the lessons. Members of the research team took field notes while video taping the lessons, so their experience and observation of the lesson provided an important outside perspective and source of validity for our analysis of the lessons. We consulted regularly with members of our research team during the analysis to check the plausibility and validity of my findings.

Figure 3. Key features in the Lesson used in the study.

<table>
<tr><td>Title of the lesson</td><td colspan="2">Compression of Air and Water Lesson (4.2) from the Matter and Molecules curriculum (Lee et al., 1993)</td></tr>
<tr><td>Topic of the lesson</td><td colspan="2">How does the particulate model of matter explain the behavior of water or air when attempts are made to compress a liquid or a gas in a closed syringe?</td></tr>
<tr><td>Mode of interaction</td><td colspan="2">The teacher facilitated a large group discussion of the image which was projected in front of the class.

The same handout was used to guide the lesson regardless of image mode used.</td></tr>
<tr><td>Image mode</td><td>The "Overhead" or OV version of the lesson was taught as suggested using two static overheads provided by the curriculum.</td><td>The Simulation or "SIM" version of the lesson was taught as suggested but here PhET computer simulation was used in place of the overheads.</td></tr>
<tr><td rowspan="2">Video data</td><td>50 minutes of Mr. P teaching the OV class</td><td>50 minutes of Mr. P teaching the SIM class</td></tr>
<tr><td>50 minutes of Mr. C teaching the OV class</td><td>50 minutes of Mr. C teaching the SIM class</td></tr>
</table>

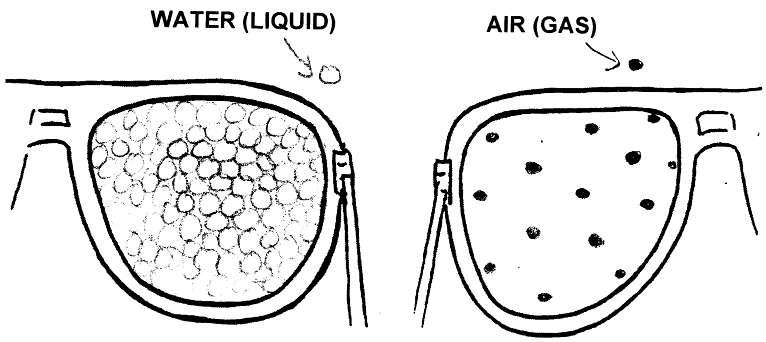
Description of the lesson

In this paper, we examine two teachers as they led their class through a lesson in *Matter and Molecules* (Lee, Eichinger, Anderson, Berkheimer, & Blakesee, 1993). *Matter and Molecules* has received high recognition in the science education community. The American Association for the Advancement of Science identified it as a noteworthy curriculum that fosters meaningful growth in science. In developing the curriculum, Lee et al. (1993) examined students' ability to learn and demonstrate an understanding of kinetic molecular theory and found persistent student misconceptions. Their findings support previous studies that have found kinetic molecular theory to be an area of particular difficulty for science students.

The curriculum provides readings, activities, and worksheets to accompany the lessons, which are each designed to address misconceptions. However, the authors of the curriculum provide little specific guidance about how to run or manage the classroom discussions which surround the activities and explicate the concepts of the lessons. This paper describes and analyzes the large group discussion that occurred in each of the teachers' classes as they enacted a common lesson plan.

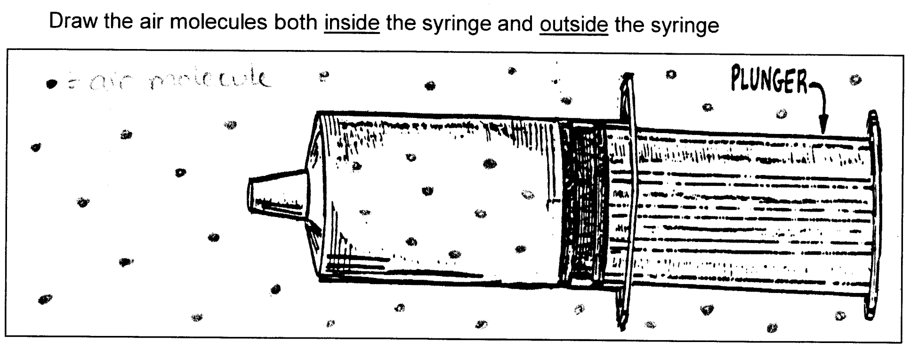
The lesson began with students drawing their model of a liquid and a gas, which had been developed in previous lessons Figure 4, and predict what this model suggested about the compressibility of a liquid and a gas.

Figure 4. Student drawing of particulate models in the “eyeglasses of science” from hand out.



Students were then given a clear 100 ml open syringe filled with air and asked to draw how molecules of air were distributed inside and outside of the syringe (Figure 5).

Figure 5. Student drawing of molecules inside and outside of the syringe.



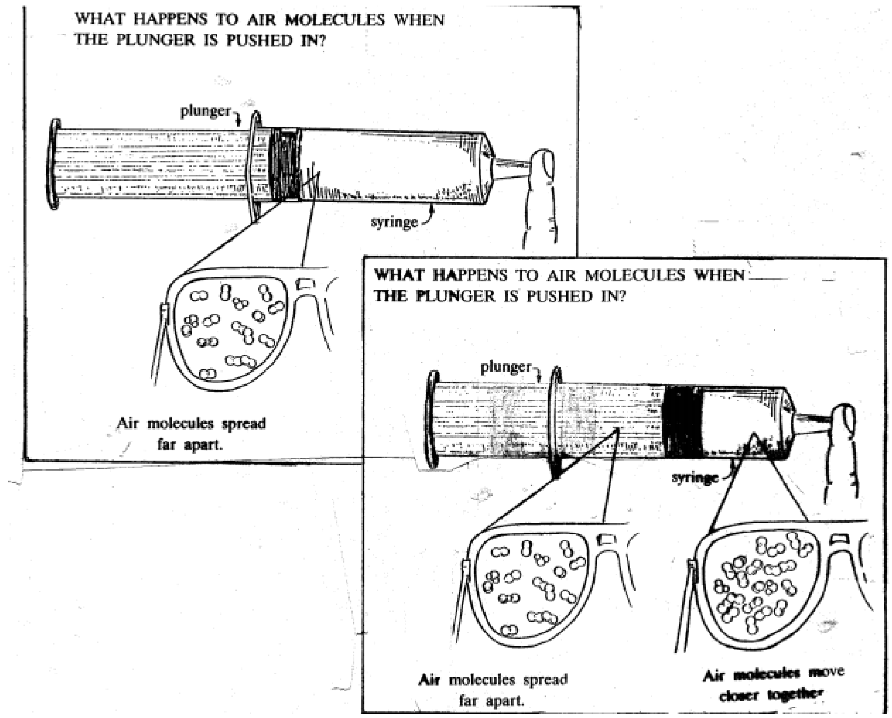
Students then used the syringe to observe the degrees of compressibility found in liquids and gasses. Student filled their syringes with water, put their finger over the end so nothing could escape, and attempted to push the plunger in. They repeated this experiment with air.

After observing the syringe, students were asked to use their molecular model of a liquid and a gas to explain why a water-filled syringe did not compress but an air-filled syringe did. When students pushed on an air-filled syringe, they were able to squeeze about 60 ml of air down to about 15 ml. A series of images were then discussed to encourage students to evaluate and modify their molecular model of a gas to explain their observations. Why did the liquid feel like a solid? How did the gas prevent them from pushing the plunger all the way in? (A few students were surprised when they pushed enough to blow out the side of the syringe!) How can invisible air molecules feel like a solid object?

To explain the behavior of a compressed gas, students needed to understand how molecules in a gas can generate a force which can resist the force of the plunger. The main content goal of the lesson was to have students explain the observable force of resistance as caused by the invisible action of trillions of molecules of gas bouncing against the wall of the plunger. The lesson used the discussion of external images to attempt to develop the internal mental imagery of bouncing molecules and link that imagery to the force produced by a compressed gas.

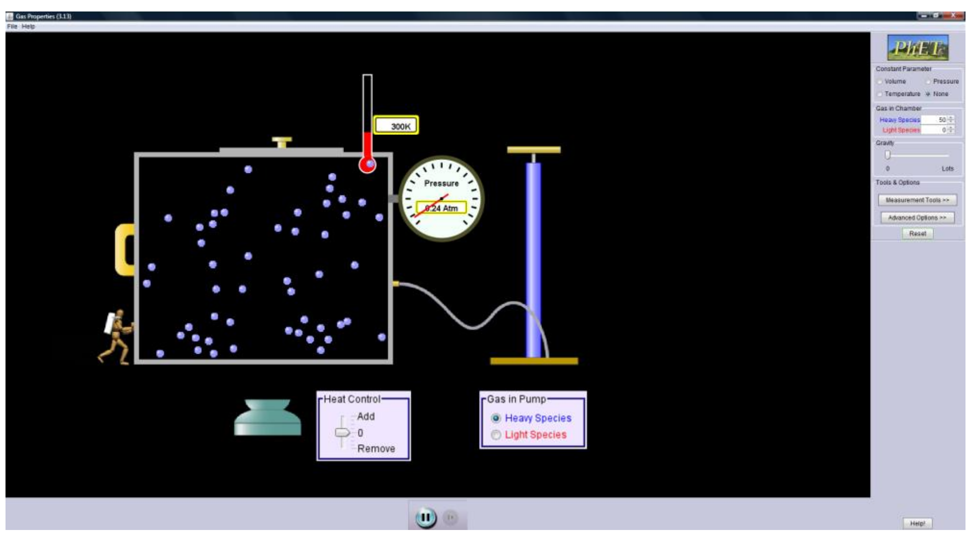
The overhead lesson used paired set of overheads to show the non-compressed and the compressed state of the gas (Figure 6) from Lee, Eichinger, Anderson, Berkheimer, & Blakesee, 1993.

Figure 6: Transparencies used in the overhead lessons.



The simulation lesson replaced this overhead with a computer simulation called Gas Properties (Reid, S., Adams, W., Dubson, M., Loeblein, T., Perkins, K., & Wieman, C., 2009).

Figure 7: Screen shot of the Gas Properties simulation by PhET.



<u>ANALYSIS AND FINDINGS</u>

This case study examines the large group discussion that occurred during this lesson. We will describe how the teacher and students discussed the projected images and how they were used to foster model construction and develop a molecular explanation of a gas. We also describe patterns of teacher-student interaction, specifically how the teacher used presentation, questioning, and follow-up to help students develop and reason with their model.

Part 1: Examining the effects of image mode on discussion.

In this case study, the constant comparison method was used to develop and refine descriptions and coding categories of discussion strategies that helped us describe possible effects of image mode (simulation vs. overhead).

1.1) Description of Image Based Discussion Moves Coding categories

The first level of coding involved looking at the entire lesson and determining when the lesson was focused on 1) managing logistics, as when students were finding papers and homework, 2) carrying out experiments, as when students were using the syringe to make observations, and 3) engaging in discussion, as when the teacher and student were thinking and talking together about the explanatory model and using it to address the questions included in the lesson plan. The data for this level 1 coding is show below in Figure 8.

Figure 8: Time spent on different parts of the lesson.

SIMULATION Lesson		
	Mr. ~~C~~R	Mr. ~~P~~T
Length of Total Lesson	52:25	51:35
Time spent on Logistics	7:40	7:53
Time spent on the Laboratory Activity	9:46	7:43
Length of Discussion Section of the Lesson	34:59	35:59
Length of Non-Simulation Discussion	17:48	30:18
Length of Simulation Discussion (Image based)	17:11	5:41
OVERHEAD Lesson		
	Mr. ~~C~~R	Mr. ~~P~~T
Length of Total Lesson	48:35	48:33
Time spent on Logistics	6:51	1:38
Time spent on the Laboratory Activity	7:43	10:55
Length of Discussion Section of the Lesson	33:43	36:00
Length of Non-Overhead Discussion	31:46	32:34
Length of Overhead Discussion (Image based)	1:57	2:05

The second level of coding focused on the effect of image on the discussion portion of the class. To do this, we identified when the overhead or simulation was used with large group discussion to develop the content goal of the lesson. This "Image-based" discussion code was applied to the portion of the lesson when the teacher focused student attention on the image projected in front of the class and discussed the information it contained. Once these Image-based discussion episodes of class were identified, we attempted to describe and categorize small (5-90 second) time scale teaching strategies that seemed to engage students in observing and reasoning with the image as the class discussed how the particulate model of a gas can be used to explain macroscopic events in the syringe experiments. The coding for this section was based on discussion strategies previously developed by Price, Leibovitch, and Clement (2010) to analyze a simulation based lesson simulation in an earlier *Matter and Molecule* lesson, and as part of a larger study on visualization in science learning.

Strategies that the teacher used to navigate discussion of the images in these lessons were identified and described. In this paper, these small scale lesson strategies are called "image-based teacher discussion moves." These image based discussion strategies, or moves, can be grouped into two sets, moves used frequently and moves used infrequently, Table 9a and 9b. Moves used frequently include: orienting students to what the image represents by mapping the image to the situation under discussion, predicting how the model will look or behave in subsequent states or future situations, highlighting conceptually important parts or actions in the image, and linking cause and effect relationships between parts of the image. Moves used infrequently include: critiquing the limitations of the image as model, situating students in the image by asking them to imagine themselves as part of it, framing the image by discussing the purpose of the image in the lesson, and extending discussion to applications of the image beyond the situation presented in the image. These moves were rare but they seemed be associated with high student engagement with the image such as unsolicited, and often loud, student contributions.

Figure 9a. Image-based Discussion Moves that were used frequently by both teachers

Moves Small time scale Strategies (5-90 second)		**Goal of Move:**
ORIENT What are we looking at?	**O**	Students can see an image but not know what it represents. Identifying structures and mapping them to the situation under discussion can help the image to communicate the model more clearly and reduce student confusion.
PREDICT What will happen if...? Why?	**P**	Predicting how an image will look (structures) or behave (dynamic/function) in subsequent states or future situations can encourage students to reason with their explanatory model. Asking students why they made their predictions provides information about this reasoning process.
HIGHLIGHT What is happening?	**H**	Using words, gestures, or image enhancements (arrows or colors) to focus attention on and describe conceptually important parts or actions in the image can help students to clarify and articulate the function of parts of the model.
LINK What is causing this?	**L**	Describing causal links between elements of a model, such as explaining a visible phenomenon in terms of its underlying molecular model, can help students to connect multiple elements in explanatory models.

Figure 9b. Image-based Discussion Moves that were used infrequently but may be associated with high student engagement

CRITIQUE What is wrong with this image?	**C**	Exposing the limitations of the image as representation of the model reminds student that the image, no matter how complex, is just an approximation of reality and one representation of the model.
SITUATE What if you were in the image?	**S**	Inviting students to imagine themselves in the image or as interacting with parts of it can help student to engage kinesthetic imagery and reasoning.
FRAME Why look at this image?	**F**	Identifying the key question which the image will address before showing the image or composing a wrap up or “take home” before turning off the image can help students connect the image to larger lesson or modeling goals.
EXTEND Where else would I see this?	**E**	Discussing applications of the model beyond the situation represented by the projected image can encourage student to overlay the image of the explanatory model on other experiences of the phenomena in their lives.

1.2) Description of differences between Simulation and Overhead conditions

We found that both teachers spent more time and employed a larger number and variety of discussion moves to integrate the dynamic simulation into the model construction process as compared to a static overhead.

Figure 10. Comparison of image mode showing more time was spent discussing dynamic image than the static image.

Teacher	**Time spent discussing the dynamic image (PhET computer simulation)** (min:sec)	**Time spent discussing the static image (2 static overheads)** (min:sec)
Mr. P	**5:41**	**2:05**
Mr. C	**17:11**	**1:57**

Figure *11*. Comparison of image mode showing that a greater variety of Image Based Discussion Moves was used during the dynamic image

	Teacher	Orient	Predict	Highlight	Link		Critique	Situate	Frame	Extend
Instances of moves in SIM Lesson	Mr. P	5	0	8	4		1	0	1	0
	Mr. C	6	5	11	12		5	1	2	1
Instances of moves in OV Lesson	Mr. P	2	0	1	0		0	0	0	0
	Mr. C	0	0	2	4		0	0	0	0

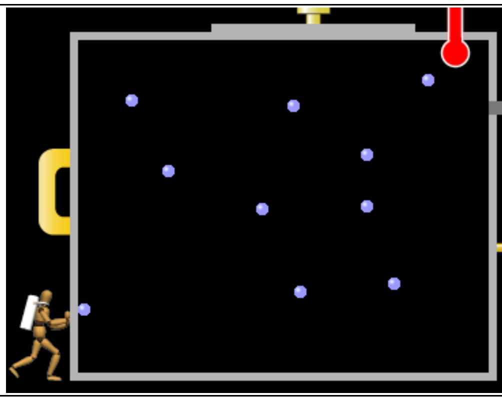
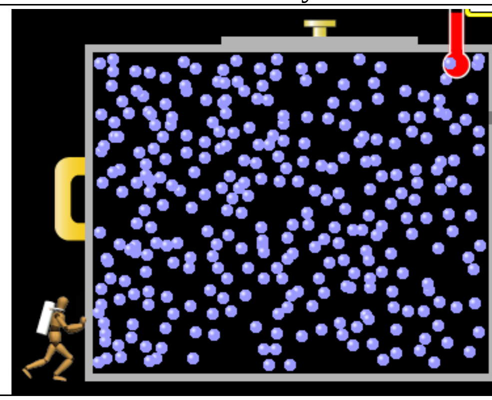
1.3) Possible causes for the difference between the Simulation and Overhead conditions.

When comparing different image modes, we found that some of the differences we observed between conditions (time, variety of moves) could be attributed to the differences in the overhead and simulation lesson plans, and some could be attributed to spontaneous and unplanned actions by the teachers.

1.3.1) Effects on Lesson Plan: The simulation may provide affordances for planning large group discussion.

Our intention in designing this study was to substitute a simulation for the overheads provided by the curriculum. The teachers and researchers in this study planned this lesson jointly. The group chose to use the overheads provided by the *Matter and Molecule* curriculum as directed by the authors of this curriculum since those authors had found these images and lesson plans to be effective at promoting learning as measured by instruments used in their study. (Lee et al., 1993) In the course of considering how to use the simulation, the team felt it natural to use the affordances we could see in the simulation to depict the difficult to comprehend dynamic elements of a model. For example, the simulation allowed the teachers to manipulate the number of gas molecules in the chamber, and this triggered us to set up extreme cases of the syringe, one with only a few molecules and one packed full of molecules (Figure 12).

Figure 12. Simulation modified to represent two extreme cases.

Extreme Case: Few Molecules	Extreme case: Many Molecules
	

Due to the flexibility of the simulation, it was easy to obtain images of different states of the model and each image gave the teacher an opportunity to discuss how the rate at which molecules collide with the plunger affects the forces on the plunger. This analysis suggests that one advantage of the simulation is that it can be easily modified. The simulation lesson plan, in fact, called for the simulation to be modified a total of ten times, whereas the overhead lesson only called for two image changes, one change for each of the two overheads provided by the lesson. Each time the simulation is modified, it provides a new image; in this way the simulation is a reservoir of images (Figure 13).

Figure 13. Number of times the lesson plan requested a change in the image by the simulation and the overhead lesson plans.

	Simulation Lesson Plan	Overhead Lesson Plan
Requested changes to the image	10	2

Each image provided by the simulation afforded the teachers with an opportunity to plan small episodes of the discussion. Though the move codes were not described when we wrote the plans, it is possible to use them to code the lesson plan for request for various moves. The result of coding the lesson plan (Figure 14) reveals that the simulation lesson plan did, in fact, call for a larger number and variety of moves than did the overhead lesson plan.

Figure 14. Number of times a move was requested by Simulation and Overhead lesson plans

Move requested by the lesson plan	Simulation Lesson Plan	Overhead Lesson Plan
Orient	8	2
Predict	4	0
Highlight	5	0
Link	5	2
Extend	0	0
Critique	1	0
Situate	0	0
Frame	1	0
Total Moves	24	4

Part 1 Conclusions

We hypothesize that the greater number of moves was caused, in part, by the ability of the simulation to be modified to present different states of the model. Since each new state was imagistic, it could be imagined by the lesson planner and used to trigger questions and discussion points to be raised during this episode of discussion when this image was to be projected. Lesson planning involves mentally rehearsing the events of a lesson; the mental rehearsal involved with a large group discussion can overwhelm working memory due to its complexity and the multiple paths a discussion can take. Here, the simulation may have allowed the lesson planner to isolate and imagine separate images to be discussed. These images are an efficient way to represent a great deal of information about the model. A list of text about the model, for example, would quickly become too dense to be useful in a lesson plan.

The set of information rich images provided by the simulation may have facilitated the mental rehearsal of small episodes of discussion and triggered prompts for these discussions that could then be written into the lesson plan. This same sort of planning was possible in the overhead lesson plan but since there were fewer images, fewer episodes may have been imagined, rehearsed, and written into the plan. In this way, the simulation seemed to trigger more discussion moves in the simulation lesson plan than in the overhead lesson plan. These scripted moves contributed to the greater time spent and the greater variety of moves seen in the simulation lesson. We hypothesize that the simulation provided a greater affordance for planning a discussion than did the overhead.

1.3.2) Effects on spontaneous and unplanned actions by the teachers: The difference in lesson plan is only part of the story, however. The simulation also appeared to provide an affordance for the spontaneous strategic application of discussion moves. While the lesson plan called for certain modifications of the simulation and suggested a set of discussion moves, neither teacher in the study enacted the lesson exactly as it was written. For example, while Mr. C did all of the steps in the lesson plan, he made twice as many modifications to the simulation and almost twice as many discussion moves than were called for in the simulation lesson plan (Table 15a nd 15 b).

Figure 15a. Comparison of Simulation lesson plan and Simulation lesson enactment by Mr. C.

Mr. C's Simulation Lesson	Planned Actions (PA) suggested by the Simulation Lesson Plan	Teacher Actions (TA) made by Mr. C during the teaching of the Simulation Lesson	Spontaneous Actions (SA= TA - PA): Difference between the enactment and the lesson plan
	Instances	Instances	Instances
Orient	8	6	-2
Predict	4	5	+1
Highlight	5	11	+6
Link	5	12	+7
Extend	0	1	+1
Critique	1	5	+4
Situate	0	1	+1
Frame	1	2	+1
Total Moves	24	43	+19
Modifications to the Simulation	10	22	+12

*Figure 15b.*Comparison of Overhead lesson plan and Overhead lesson enactment by Mr. C.

Mr. C's Overhead Lesson	Planned Actions (PA) suggested by the Overhead Lesson Plan	Teacher Actions (TA) made by Mr. C during the teaching of the Overhead Lesson	Spontaneous Actions (SA= TA - PA): Difference between the enactment and the lesson plan
	Instances	Instances	Instances
Orient	2	0	-2
Predict	0	0	0
Highlight	0	2	+2
Link	2	4	+2
Extend	0	0	0
Critique	0	0	0
Situate	0	0	0
Frame	0	0	0
Total Moves	4	6	+2
Modifications to the Overhead	2	4	+2

Mr. P did not complete all the steps of the simulation lesson plan, but he did six more moves than were suggested by the parts of the lesson plan that he did complete (Table 16).

Figure 16a. Comparison of Simulation lesson plan and Simulation lesson enactment by Mr. P

Mr. P's Simulation Lesson	Planned Actions (PA) suggested by the Simulation Lesson Plan	Teacher Actions (TA) made by Mr. P during the teaching of the Simulation Lesson	Spontaneous Actions (SA= TA- PA): Difference between the lesson plan and the enactment
	instances	instances	instances
Orient	8	5	-3
Predict	2	0	-2
Highlight	2	8	+6
Link	1	4	+3
Extend	0	0	0
Critique	0	1	+1
Situate	0	0	0
Wrap	0	1	+1
Total Moves	13	19	+6
Modifications to the Simulation	7	7	0

*Figure 16b.*Comparison of Overhead lesson plan and Overhead lesson enactment by Mr. P.

Mr. P's Overhead Lesson	Planned Actions (PA) suggested by the Overhead Lesson Plan	Teacher Actions (TA) made by Mr. P during the teaching of the Overhead Lesson	Spontaneous Actions (SA= TA - PA): Difference between the enactment and the lesson plan
	Instances	Instances	Instances
Orient	2	2	0
Predict	0	0	0
Highlight	0	1	+1
Link	2	0	-2
Extend	0	0	0
Critique	0	0	0
Situate	0	0	0
Frame	0	0	0
Total Moves	4	3	-1
Modifications to the Overhead	2	2	0

This data provides evidence that teachers generated more spontaneous moves during the discussions of the simulation than they did during the discussion of the overhead. The lesson plan can serve as a guide for the lesson but it is not simple, nor always desirable, for a teacher to follow a lesson exactly. Often opportunities for encouraging student reasoning develop in the moment, and these opportunities are difficult to anticipate in the lesson planning process. Teachers improvise responses to the thinking needs of the students and the flow of ideas that unfolds in a large group discussion. A simulation can be manipulated in response to student questions and comments and provide clear and accurate images of the model. This capability may allow the simulation to support teachers as they improvise the orchestration of discussion.

For example, this lesson plan did not call for any situating or extending, yet Mr. C was observed using these moves in response to student comments. In addition, both Mr. C. and Mr. P did more highlighting and linking moves than were suggested by the simulation lesson plan (shown in yellow on Figure 15a and 16a). Since highlighting and linking focus student attention on the dynamic elements of the model, both teachers may have noticed more opportunities or needs than anticipated by the lesson plan and used the simulation to explicate theses dynamic elements.

In this way, the simulation condition appeared to foster a variety of unscripted discussion moves. These unscripted, spontaneous moves contributed to the time spent discussing the simulation. We hypothesize that the simulation provided a greater affordance for managing a discussion than did the overhead.

Part 2 Examining differences in the behavior of the two teachers.

This part of the paper reports on a comparative case study that examined differences between teachers enacting the same lesson and image mode. This part of the paper will examine patterns of teacher student interactions used by each teacher during the entire lesson and will address the question: 1) Did teachers use different patterns of interactions? 2) If so, did the patterns of interaction used by the teachers impact how the image was used in the lesson. In this case study, prior descriptions of interaction modes in the literature (Nassaji and Wells, 2000), along with the constant comparison method, were used to refine descriptions and coding categories of interaction patterns that helped us describe different patterns of teacher behaviors during discussion.

2.1) Description of interaction patterns and coding categories

This analysis makes use of the first level of coding described above to isolate the section of the lessons devoted to discussion. Here we will examine patterns of interactions which occurred during the discussion.

Figure 17a. Times spent on discussion in the simulation lesson.

Simulation Lesson Discussion Times (in minutes: seconds)		
	Mr. C	Mr. P
Length of Discussion Section of the Lesson	34:59	35:59
Length of Non-Simulation Discussion	17:48	30:18
Length of Simulation Discussion(Image based)	17:11	5:41

Figure 17b. Times spent on discussion in the overhead lesson.

Overhead Lesson Discussion Times (in minutes: seconds)		
	Mr. C	Mr. P
Length of Discussion Section of the Lesson	33:43	36:00
Length of Non-Overhead Discussion	31:46	33:55
Length of Overhead Discussion (Image based)	1:57	2:05

This data reveals that a major difference in teacher behavior was the difference between the time teachers spent discussing the simulation: Mr C spent 17:11 minutes, Mr P, 5:41 minutes. Note that 'Non-Simulation' in Figure 17a does not refer to the Overhead Condition but rather to the portion of the Simulation Condition classes that were spent in discussion without the simulation displayed.

2.2) The effect of interaction patterns on the use of the simulation.

Since the major teacher effect was seen in the Simulation condition, the analysis in this section will focus only on data from the simulation lesson. To better understand how the difference in teachers may have affected discussion, we coded for four patterns of interaction: presentation, IRE, IRF, and other (Figure 18).

Figure 18. Table explaining the interaction pattern codes

Interaction patterns observed during the image based and non image based discussion		
P	Present	The teacher describes or states the school science perspective of the model or concept
IRE	Initiation Response Evaluation	The teacher asks a question and then evaluates student responses.
IRF	Initiation Response Follow up question	Teacher asks a question and then probes students answer with a series of follow up questions.
O	Other	This category included times when the teacher was manipulating the simulation, reading from the handout, or the students were working in small groups.

We then counted instances and tallied the time each teacher spent involved with each interaction pattern (Figures 19a and 19b) *Note that in the remainder of the paper, 'interaction pattern' does not refer to a statistical interaction between variables, but rather to one of the modes in Table 18.*

Figure 19a Mr. C count and time of interaction pattern in the Simulation condition

Mr. C's Simulation Lesson		P		IRE		IRF		OTHER
	Time	count	time	count	time	count	time	Time
Non -Sim discussion	17:48	16	6:22	6	1:56	0	0:00	9:30
Simulation Discussion	17:11	25	6:40	4	1:41	6	4:30	4:20
Total Discussion	34:59	41	13:02	10	3:37	6	4:30	13:50

Figure19b Mr. P count and time of interaction pattern in the Simulation condition

Mr. P's Simulation Lesson		P		IRE		IRF		OTHER
	Time	count	time	count	time	count	time	Time
Non-sim discussion	30:18	9	10:18	4	1:47	10	12:07	6:06
Simulation discussion	5:41	9	2:27	7	1:58	2	1:04	0:12
Total discussion	35:59	18	12:45	11	3:45	12	13:11	6:18

This data reveals that Mr. C was observed presenting the school science point of view more than twice as often as Mr. P. (41 times compared to 18 times) in the simulation condition classes. Mr. P spent more time engaging in IRF interactions then Mr. C (13:01 minutes compared to 4:30 minutes). Pursuing and clarifying student meanings through follow up questions takes more time than directly presenting the model.

Part 2 Conclusions

This data leads us to hypothesize a possible cause for the teacher difference in simulation use seen in Figure 17a. Mr. P tended to ask students to generate the model and used discussion time to pursue divergent student thinking. The time spent by Mr. P engaging in IRF interactions before the simulation left less time for Mr. P to discuss the simulation. Less time to discuss the simulation could also result in a smaller number and variety of image based discussion moves as seen in Figure 11. Mr. C tended to present the target model and thus converge on the model without leaving much room for students to articulate their model. By presenting clear statements of the model, Mr. C was able to move quickly through the lesson and was able to spend more time discussing the simulation.

An interview with Mr. C revealed that his preferences for convergent discussions sprang from his concern that pursuing divergent student thinking could introduce too much "noise in the signal," or introduce misconceptions that would compete with a clear statement of the target model. In his opinion, a clear statement of the target model and a clear evaluation of student answers promoted the best learning of the target concept. Mr. P worried that presenting the model too quickly would leave students' misconceptions hidden and that this would interfere with learning. He believed that probing both convergent and divergent student ideas engaged student reasoning and provided him with information about the state of student thinking that he could then use to co-construct the target model using student ideas. His preference was pursuing student ideas even if it took longer than expected. He acknowledges that the pursuit of the student points of view did uncover misconceptions that were challenging to address, and that addressing these misconceptions resulted in longer and more divergent episodes of discussion. These longer divergent episodes made it difficult to efficiently converge on the target model and reach the content goal of the lesson.

These sorts of teacher beliefs seem to influence the number and type of questions the teachers asked. When IRF and IRE instances are combined, they provide one measure of the amount of questioning done by each teacher. We converted the time spent on each interaction pattern into percentages. For example, in the third row of Table 20a, Mr. C used presentation mode for 6 minutes and 40 seconds during the time the simulation was up and being discussed, which is 39% of the time he spent discussing the simulation (6:40/17:11 = 39%). Tables 20a and 20b show that Mr. C used about 23% of the total discussion time asking questions compared to 47% of time spent on questions by Mr. P.

Table 20a. Percent of discussion time spent on each interaction pattern by Mr. C in the Simulation condition.

Mr. C's Simulation Lesson	Time	Presentation (P)	IRE	IRF	OTHER
Non-sim discussion	17:48	36%	11%	0%	53%
Simulation discussion	17:11	39%	10%	26%	25%
Total discussion	34:59	37%	10%	13%	40%

Table 20b. Percent of discussion time pent on each interaction pattern by Mr. P in the Simulation condition

Mr. P's Simulation Lesson	Time	Presentation (P)	IRE	IRF	OTHER
Non-Sim discussion	30:18	34%	6%	40%	20%
Simulation discussion	5:41	43%	35%	19%	3%
Total discussion	35:59	35%	10%	37%	18%

Teacher preferences for asking questions may be related to their beliefs about how to manage the tensions between divergence and convergence which occur in a discussion. Asking a question requires teachers to negotiate potentially competing agendas: a divergent lesson agenda that prioritizes exploring student ideas and reasoning, and a convergent lesson agenda that prioritizes moving toward a clear statement and understanding of scientifically accepted model. The data suggests that Mr. P spent more time pursuing a divergent agenda through his use of follow up questioning to develop the model. Mr C spent more of the discussion time pursuing a convergent agenda through his use of presentation and IREs to develop the model.

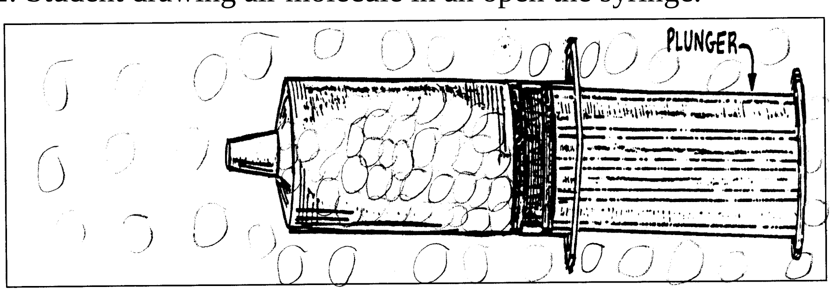
Applying Scott's Communicative Approach framework, we can place the teachers along a Dialogic-Authoritative spectrum. Viewing the totals in the bottom rows of Tables 20a and 20b, we see that both teachers used both Dialogic and Authoritative modes. However, Mr. P spent more time pursuing a dialogic mode of discussion. As a result Mr. P spent more time probing student ideas with follow up questions before the simulation, but this left him less time to use the simulation to converge on the target model. Mr. C spent more time pursuing an authoritative mode of discussion. Mr. C spent less time probing student ideas but this left him more time to use the simulation to converge on the target model.

Figure 21. Placing the two teachers on the Dialogic- Authoritative spectrum.

Mr. C **Mr. P**
Authoritative -- Dialogic

Scott, Mortimer, and Aguiar (2006) argue that lessons with content goals should involve both authoritative and dialogic modes of interactions. Finding the right balance between authoritative and dialogic episodes in a lesson can be challenging, because when a teacher probes the student point of view, he can uncover significant and unexpected divergence from the target model. For example, some students in Mr. P's class were observed drawing air molecules compressing themselves in an open syringe without the student pushing on the plunger. Mr. P asked a series of follow up questions about this drawing, and discovered that this belief was based on a misconception about the relative size of the opening in the syringe compared to the air molecules. It took time to discover this belief and then give the students and teacher a chance to respond to those who where convinced that the syringe geometry would trap the air molecules, "letting molecules come in but not let them out."

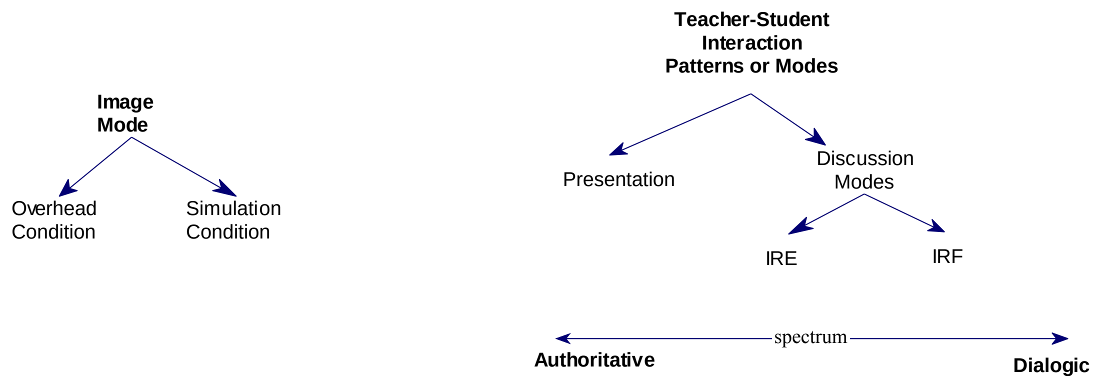
Figure 22. Student drawing air molecule in an open the syringe.



Responding to divergent student ideas in ways that foster norms for student participation and reasoning is a complex task. Journal entries made by Mr. P revealed that he was surprised by the length of time that this part of the discussion took. He continued to pursue follow up questions, because students were reasoning with their models and he thought that this student reasoning might converge on the target concept: air molecules equally distributed inside and out side of the open syringe. He avoided negative evaluation of student ideas, because he was "curious to see where their ideas came from" and he didn't want "to dampen the class norms that foster this kind of thinking." To maintain these norms, he felt it was important to "listen carefully to student ideas" since they had "risked stating them publicly to their peers."

Pursuing student reasoning in this way can result in lessons taking longer than planned and these longer lessons can force subsequent lessons to be compacted or omitted in order to meet the time demand of the school curriculum. One can see this on a small scale in Mr. P's lesson in which the use of the simulation was compacted. In this lesson, Mr. C and Mr. P managed the tensions between dialogic discourse and authoritative discourse differently. Mr. P's overall approach was more dialogic, since it pursued divergent student ideas, but it left less time for the simulation. Mr. C's overall approach was more authoritative, since it did not pursue divergent student ideas, and this left more time to discuss the simulation.

Figure 23: Taxonomies used in this study.



<u>Part 3: Examining the effects of teacher and image mode conditions</u>

In part three we report on a cross comparative study where effects due to teacher differences and image mode are considered. This section will address the questions: 1) Were discussion moves associated with particular interaction patterns? and 2) Did teacher interaction pattern choices change after an image mode started?

3.1 Moves and Interactions

By combining the data from part one and two, we were able to count the times each interaction pattern occurred during an image based discussion move.

Table 24 contains combined data from all classes, and it shows how the most common moves could be used in three different interaction patterns: presentation, IRE, and IRF. Orienting, Highlighting, and Linking moves were associated with all three interaction modes. Predicting (asking student students to predict future states of the simulation) was, of course, associated with questioning (IRE or IRF). Highlighting, which involves describing the dynamics shown in an image, was done most frequently via teacher presentation instead of questioning. The other moves were observed too infrequently to comment on any association with interaction patterns.

Figure 24: Combined data from all classes showing the interaction patterns associated with each move

	Presentation	IRE	IRF
Orient	5	5	2
Predict	0	1	3
Highlight	15	3	1
Link	12	2	2
Extend	0	0	0
Critique	3	0	0
Situate	1	0	0
Wrap	3	0	0
totals	39	11	8

Part 3.1 Conclusion

The image based discussion moves Orienting, Highlighting, and Linking can be accomplished via teacher presentation or by questioning. This data reveals that moves were accomplished was by teacher presentation almost twice as often as they were accomplished by questioning (IRE or IRF).

3.2 Interaction patterns after an image mode was started.

The data in Figures 25a and 25b show that Mr. P used more IRE interactions after the simulation mode was started and Mr. C used more IRF interactions after image mode was started.

Figure 25a. Table of interaction pattern data from Mr. C's class

Mr. C	Time	Presentation (P)	IRE	IRF	OTHER
Non-sim discussion	17:48	36%	11%	0%	53%
Simulation discussion	17:11	39%	10%	26%	25%
Total discussion	34:59	37%	10%	13%	40%

Figure 25b. Table of interaction pattern data from Mr. P's class

Mr. P	Time	Presentation (P)	IRE	IRF	OTHER
Non-sim discussion	30:18	34%	6%	40%	20%
Simulation discussion	5:41	43%	35%	19%	3%
Total discussion	35:59	35%	10%	37%	18%

The change in visual mode may have changed the interaction mode profile. One possible explanation for this is that simulation, as a complex imagistic statement of the model, could have an impact on teacher interaction patterns.
As of 3.9.12

Part 3.2 Findings

Applying Scott's Communicative Approach framework, we can place the teachers along a Dialogic-Authoritative spectrum and diagram a possible effect of image mode on discussion mode. Without the simulation, Mr. P spent more time pursuing a dialogic mode of discussion through his use of IRFs. With the simulation, he spent more time pursuing an authoritative mode through his use of IREs. Mr. C's pattern was just the opposite. Without the simulation, Mr. C spent more time pursuing an authoritative mode of discussion through his use of IREs. With the simulation he spent time in a dialogic mode through his use of IRFs. An overall effect was that the simulation appeared to bring these two teachers closer together in the middle of the Dialogic/Authoritative spectrum, as shown in Figure 26.

Figure 26: Comparing teachers' placement on the Dialogic- Authoritative spectrum during different image modes.

Non-Simulation discussion (before the image was projected)

Mr. C **Mr. P**

Authoritative --- Dialogic

Simulation discussion (while the image was projected)

Mr. P **Mr. C**

Authoritative --- Dialogic

We offer a speculative hypothesis that the simulation may be supporting the teachers as they transition between dialogic and authoritative discussion modes. As a strong statement of the model, the simulation might limit, constrain, or bound student divergence and reduce the potential for conceptual divergence in student responses. The simulation's ability to restrict divergence of student response may be supporting Mr. C's willingness to ask potentially divergent questions and allow students to have a larger role in articulating the model.

On the other hand, the simulation may be supporting Mr. P's attempts converge on the target model while asking questions that allow the students to articulate the target model. As a complex image, the simulation can be difficult to interpret. The need to interpret a complex image opens a space for generating a line of questioning that converges on the target model. These convergent question episodes (IREs) allow students to articulate how their internal model is being used to interpret and reason with the external representation of the model (the simulation).

SUMMARY OF CONCLUSIONS

Part 1: Summary of effect of image mode on discussion.

We identified strategies that the teacher used to navigate discussion. These image-based discussion moves are summarized in Table 27.

Table 27: Image-based Discussion Moves

Moves	Central question of the move
ORIENT	What are we looking at?
PREDICT	What will happen if...? Why?
HIGHLIGHT	What is happening?
LINK	What is causing this?
CRITIQUE	What is wrong with this image?
SITUATE	What if you were in the image?
FRAME	Why are we looking at this image?
EXTEND	Where else would this image apply?

Compared to the Overhead condition, the Simulation condition produced a) more time discussing the image, b) more moves, and c) more variety of moves, d) more scripted moves in the lesson plans, and e) more spontaneously generated moves in the discussion. We hypothesize that simulation effects a, b, c could be caused by an interaction of d and e. Observations d) and e) suggest that the simulation provides an interesting affordance for planning and enacting discussions.

More speculatively, we hypothesize that this affordance may be associated with the simulation's capacity to be quickly and easily manipulated to display clear and accurate images of multiple states of the model. Also, we hypothesize, again speculatively, that this affordance may be associated with the way in which these images help the teacher think about the model while planning, and may provide a reference point that can be used for generating clear statements and productive questions about the model.

Part 2: Summary of differences in the behavior of the two teachers.

Mr. C spent more than twice the time discussing the simulation as Mr. P (17:11 minutes compared to 5:41 minutes). Mr. C was also observed presenting the school science point of view more than twice as often as Mr. P. (41 times compared to 18 times). Mr. P spent more time engaging in IRF interactions than Mr. C (13:01 minutes compared to 4:30 minutes). Pursuing and clarifying student meanings through follow up questions takes more time than directly presenting the model.

This data leads us to hypothesize a possible cause for the teacher effect on image use seen in Figure 10. In this lesson, Mr. C and Mr. P managed the tensions between dialogic discourse and authoritative discourse differently. Mr. P's overall approach was more dialogic, since it pursued divergent student ideas, but it left less time for the simulation. Mr. C's overall approach was more authoritative, since it did not pursue divergent student ideas, and this left more time to discuss the simulation.

Part 3: Summary of the effects of teacher and image mode conditions

The data in Figure 24 reveals that moves were more often accomplished through teacher presentation rather than through teacher questions. The data also shows that at least three image based discussion moves can be accomplished by questioning (Orienting, Highlighting, Linking).

The data in Figure 25a and 25b show that Mr. P used more IRE interactions after the simulation mode was started, and Mr. C used more IRF interactions after the image mode was started. We hypothesize that the visual mode may have changed the interaction mode profile. One possible explanation for this is that simulation, as a strong and complex imagistic statement of the model, could have an impact on teacher interaction patterns. The simulation's strong statement of the model may constrain the discussion, while the simulation's complexity may leave room for student interpretation. These two features of a simulation may provide a space for discussions that can support teachers' attempts to keep students in a "reasoning zone" while the teachers can converge on target models at the same time.

Limitations

In this study, we attempted to develop a method for coding and analyzing classroom transcripts in a way that speaks to questions about the kinds of strategies different teachers use in different image mode settings. Our hypotheses developed for the small sample that we have analyzed so far need to be evaluated by analyzing more cases. We plan to do this by adding more comparative case studies with a third teacher and with other lessons.

Implications

A simulation is often considered useful simply because it has a dynamic mode. This study suggests that a simulation can also be useful because it is easily modified. Each overhead provided one static image that teachers used to generate questions that probed and developed student thinking. The simulation can act as a reservoir of different static and dynamic images, since the simulation can be started, stopped, and modified multiple times. Each state of the simulation can be used to generate questions and promote student reasoning about the model. By considering a simulation as a set of images, a teacher, during planning of a discussion, can tailor each image by setting various parameters of the simulation and then, by rehearsing how questions about that image might promote reasoning and convergence on the target concept. For example, a teacher could set the simulation to represent an extreme case and generate prediction questions that prompt students to run their model.

The concept of an affordance as a *perceived* advantage reveals that a challenge for research is to expand teachers' view of a simulation beyond its use as a tool for *presenting* a model and begin to see it as a tool for *questioning* students about a model. In this study, moves used to discuss the images were more likely to be accomplished by presentation rather than by questioning (Figure 24), but this pattern could change if teachers perceived a simulation as a tool for generating questions about images. The moves in Figure 27 are one attempt to articulate some general questions teachers could ask students about simulations that might help teachers move away from using the simulation only as a presentation tool.

The differences we observed in teachers' use of the simulation suggest that accessing the affordances of a simulation was associated with asking questions about the multiple images it can display. In one mode of use, a simulation is a strong statement of the model that teachers can use to constrain the divergence in student ideas to manageable levels. If a teacher tends to follow a convergent path through a discussion as a way of avoiding student divergence, a simulation might provide a discussion environment with natural constraints that a teacher can use to open the floor to more student contributions, with the confidence that the discussion won't take unproductive turns. Teachers use or avoid follow up questions (IRFs) as a way of managing the divergent and convergent tensions in a large group discussion. The simulation may create a discussion environment that develops teacher, and student, proficiency for using IRF interactions patterns.

A simulation is also a complex statement of the model that teachers can use to prompt interpretations by various student models. If a teacher tends to ask questions in order to pursue surprising, yet time consuming, divergent student ideas, a simulation's complexity might offer teachers an opportunity to follow a different, more convergent line of questioning. The complexity of the simulation allows room for discussions in which students are asked to articulate their point of view, or model, as they interpret the image. These discussions can still be managed by questioning, but these questions are productively constrained by the simulation's strong statement of the model, and thus can follow a path that converges on the lesson's target concept.

In these ways, the simulation might support teachers as they attempt to navigate the tension between pursuing divergent student thinking and converging on content goals. More research is needed to describe how teachers manage the transition between dialogic (divergent) and authoritative (convergent) modes. Understanding how to navigate these transitions might help teachers more easily oscillate between them and thus more fully engage student reasoning. By learning to use image based discussion strategies, such as predicting and highlighting, teachers may be able to use a simulation to engage student reasoning in the service of generating, evaluating, and modifying student models. Simulations may create a bounded discussion space for student reasoning and assist teachers as they attempt to use different interaction patterns to transition between dialogic and authoritative modes in order to reach the content and reasoning goals of the lesson.

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