AN ANALYSIS OF SCIENCE TEACHERS' CLASSROOM DISCOURSE RELATING TO THE USE OF MODELS AND SIMULATIONS IN PHYSICS

Dana Gnesdilow, Garrett W. Smith, Sadhana Puntambekar

ABSTRACT

This case study provides an account of three teachers' first attempts in implementing simulation experiments within a design-based inquiry science curriculum. We examined how three in-service teachers used simulations and physical models in the classroom to promote students' understanding of the nature of models. We found that teachers mostly talked about the procedural aspects related to simulation use. While some of the teachers' dialogue focused on science ideas, there was very little explicit talk about the nature of models. Of the discourse concerning the nature of models, most focused on model evaluation, the affordances and constraints of models, and comparing multiple models. Critical incidents related to the nature of models are presented and discussed. All three teachers missed opportunities to help students understand the nature of models as they introduced simulation activities, facilitated simulation group work, and conducted final class discussions.

KEYWORDS

Nature of models, Simulations, Physical experiments, Teacher practice, Teacher discourse, Mechanics

INTRODUCTION

The construction, revision, and evolution of scientific ideas through the utilization of models has been identified as one of the most essential scientific practices (Linn, 2003; Chinn & Malholtra, 2002; Lehrer & Schauble, 2006; Treagust, Chittleborough, & Mamiala, 2002). While the notion of a model and the practice of modeling in science are complex and often inconsistently defined (Gilbert, 2004), Schwartz and White (2005) define a "scientific model as a set of representations, rules, and reasoning structures that allow one to generate predictions and explanations." (p.166) They further define scientific modeling as the process of building, evaluating, and revising models based on their underlying theoretical ideas.

Several researchers have advocated for engaging students in modeling practices in the science classroom (e.g. Schwartz & White, 2005; Windschitl, Thompson, & Braaten, 2008). While the use of models, such as physical experiments, has been a ubiquitous instructional strategy in science classrooms, other types of models, such as computer simulations, have also increasingly played a role in science education. Simulations in particular can enhance science instruction since they can provide students with access to phenomena that may otherwise be inaccessible. They also enable students to manipulate variables not ordinarily under their control to explore science concepts. While the use of simulations and other models in the classroom have been beneficial in helping students acquire content knowledge (e.g., Finkelstein et al., 2005) or undergo conceptual change (Hewson & Lemberger, 2000; Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001), simulations and other forms of models can additionally help develop scientific literacy, by enabling students to better recognize the nature of models. Several researchers have asserted that helping students to understand the nature of models promotes a better understanding of scientific practice (Coll, France, & Taylor, 2005; Gilbert, 2004; Grosslight, Unger, Jay & Smith, 1991). Further, some researchers claim that conscientiously combining simulations and hands-on activities, which is more consistent with professional science practice, can help students to better understand the nature and process of the scientific enterprise as well as foster conceptual understanding (Snir & Smith, 1995; Snir et al., 1995; Chinn & Malholtra, 2002).

Research on students' views of models has reported that students do not understand how models are used by scientists, generally viewing them as exact copies of the real thing (Grosslight et al., 1991; Treagust et al., 2002). One reason for their less sophisticated perspectives may be that most inquiry activities that take place in science classrooms have little resemblance to the authentic activities of professional scientists (Chinn & Malholtra, 2002). Even the ubiquitous physical science experiment has rarely been utilized in the science classroom to promote students' understanding of the nature of models and the modeling process (Lehrer, Schauble, & Petrosino, 2001). Another potential reason for students' misunderstanding or ignorance of models may derive from teachers' failure to stress the affordances and constraints of models (Treagust et al., 2002). Models are often presented as facts rather than theoretical entities and modeling activities in the classroom are often superficially enacted during instruction. This may do little to help students develop an understanding of the nature of models as essential elements of scientific practice (Linn, 2003; Snir et al., 1995; Snir et al., 2003, Treagust et al., 2002).

Several researchers have suggested ways to engage students in more authentic modeling practices in the classroom, such as helping students to make, use, analyze, and move between multiple forms of representational models as is done in actual scientific practice (Justi & Gilbert, 2002; Lehrer & Schauble, 2006; Snir et al., 1995). Properly designed classroom activities that engage students in the manipulation of ideas rather than things, such as hands-on inquiry (Hofstein & Lunetta, 2004), model building (Justi and Gilbert, 2002, Grosslight et al., 1991) and model building through the use of simulations (Linn, 2003; Snir & Smith 1995; & Snir et al., 1995) can help students to explore and learn in a manner consistent with the actual practice of scientists. Additionally, when using models and simulations, it has been suggested that teachers need to engage in explicit discourse about the modeling process and the central role that modeling plays within the scientific enterprise (Grosslight et al., 1991; Lehrer & Schauble, 2006; Schwartz & White, 2005; Windschitl, et al., 2008). Further, teachers need to establish classroom norms for inquiry and model use in the classroom in order to help students experience success and model based reasoning is likely to take a long time to develop, perhaps years (Lehrer & Schauble, 2006).

Gilbert (2004) asserts that consideration of curriculum design, teaching, and teachers' professional development pertaining to the explicit use of models and modeling in the science classroom "poses more questions than it provides answers." (p.119) This case study provides an account of three teachers' first attempts in implementing simulation experiments within a design-based inquiry science curriculum. We examined how these teachers used simulations and physical models in the classroom to promote students' understandings of the nature of models. Our aim in this study is to provide baseline observations of teachers' actual classroom practice when incorporating scientific models into their science instruction as well as offer a way to analyze teachers' discourse about the nature of models.

METHODS

Participants and Context of the Study

This study focused on two sixth grade teachers and one eighth grade teacher at two different middle schools near a mid-sized, midwestern city in the United States. For all three teachers, it was their first time teaching the CoMPASS simple machines curriculum (described below). Teacher A was a 6th grade teacher with 16 years of experience teaching science and certification in elementary education; Teacher B taught 6th grade and had 6 years of science teaching experience with a certification in elementary education and general science; and Teacher C, who taught 8th grade, had 3 years of experience teaching science and held a general science certification. While this was a sample of convenience and the teachers had differing years of experience, they all had limited experiences teaching *inquiry* science. Teaching through inquiry represented a significant departure from their normal teaching practice; a factor that we believe placed the teachers at similar levels of experience, despite the number of years of teaching.

Curriculum and Simulation Design

The simulations were part of the CoMPASS simple machines curriculum (Puntambekar, Stylianou & Goldstein, 2007), which integrates a digital hypertext environment, hands-on science experiments, and design challenges within cycles of inquiry. This curriculum has been shown to promote students' deeper understanding of physics concepts such as *force*, *work*, *energy*, and *mechanical advantage* as well as the connections between them (Puntambekar, 2006; Puntambekar, Stylianou & Goldstein, 2007).

Students conducted a series of physical and virtual experiments during the inclined plane and pulley sections of the curriculum, using physical materials and computer simulations. The simulations were designed to take advantage of particular affordances not available in a physical environment. In the physical experiments, students practiced setting up inclined planes and pulleys, received haptic feedback in feeling how much force was needed to lift an object, and measured, recorded, and analyzed real-world data. On the other hand, the simulations were designed to allow students to observe the intended phenomena in an idealized environment, such as zero friction. The simulation also displayed underlying variables in real time and provided multiple dynamic representations of data (see Figure 1).

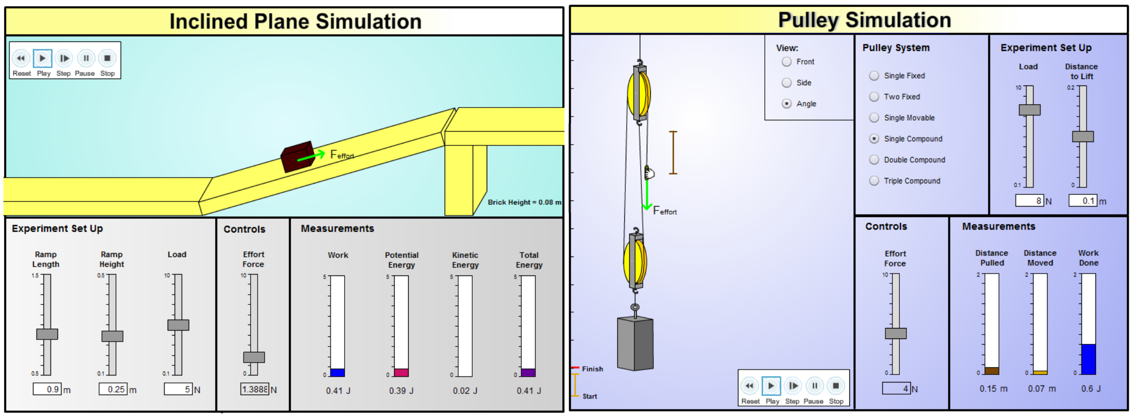

Figure 1. Screenshots of Inclined Plane and Pulley Simulation Environments

Before using the computer simulations, the teachers generally conducted a whole class or small group introduction, explaining the goal of the simulation activity. Students then worked in groups of three or four to conduct the simulation activity while the teacher roamed the classroom to facilitate the small group work. After students completed the activity, the teacher conducted a whole class discussion to talk about the results of the students' investigations and elicit students' understanding of the content. This process occurred for three simulation activities concerning inclined planes and one concerning pulleys (though in a few cases, some teachers omitted whole class discussions for some activities due to time constraints).

Data Sources and Analysis

Since teachers' explicit talk during science lessons influences students' learning (Lemke, 1990), we decided to analyze teachers' dialogue through a content analysis of their utterances. In doing this, we used Chi's (1997) Technique for Verbal Analysis in order to quantify the contents of the teacher's utterances as they facilitated instruction in the classroom. We examined classroom videos to understand teacher practices and discourse related to the use of models, in this case simulations and physical experiments. We transcribed teachers' and students' dialogue during three different types of instructional activities: 1) whole class or small group introductions to the simulations, 2) teacher facilitation of small groups during simulation experiments, and 3) whole class discussions after the simulation experiments. These activities constituted all of the simulation related talk, providing the most potential for the incorporation of nature of models related discourse within the CoMPASS unit.

Total video data consisted of approximately nine hours of video and approximately 221 pages of transcripts.

We first coded the transcripts at the macro level to examine the overall nature of teachers' discourse during simulation related instruction. Then, we coded the nature of models talk at the micro level, to understand in some detail how teachers discussed the role and nature of models in science. We computed the percentage of talk in each of the coded categories. Further, we searched for “critical incidents” to pinpoint when teachers conducted more extended discussions about the nature of models. Our coding rubric and process is described in the next section.

Macro Analysis of the Overall Nature of Teacher Dialogue

After a preliminary examination of transcript data we inductively identified five codes (see Table 1) to attempt to capture the overall nature of talk that the teachers engaged in as they worked with the students during the three simulation activities. The *procedural / managerial* code focused on dialogue such as giving directions and managing group or classroom activities. The *surface science* code centered on talk about science concepts, but focused on simple definitions and closed ended questions. The *science reasoning* code centered on discourse about science concepts on a deeper, more explanatory level by focusing on the “why” and “how” of science, or by posing more open ended questions. The *nature of models* code was assigned to any utterance that discussed scientists' practice and use of models and modeling. Finally, some teacher dialogue was *not applicable* because it was either unrelated to instruction, incomprehensible, or a one word response.

We coded the transcripts at the utterance level. Each utterance could be assigned multiple codes. Teachers' dialogue was coded within the context of the students' dialogue that occurred before and after the teachers' utterances. Discourse percentages within each the five coding categories were calculated by dividing the number of the teacher’s utterances categorized into a particular code by the total number of the teacher’s utterances that occurred. The first and second author coded approximately 15% of all of the transcripts and established an interrater reliability of over 86%. Disagreements were resolved through discussion. The first author coded the remainder of the transcripts.

Table 1. Coding Categories for Overall Teacher Dialogue during Simulation Instruction

Code:	Description:	Example:
Procedural / managerial	Teacher gives directions or manages group or classroom activities	“And right here is where you control the effort force ...You're gonna grab it and you're gonna move it up.”
Surface Science	Teacher facilitates discussion about science concepts focusing on definitions, the “what” of science, or closed ended questions	“Okay, using the long ramp required what? "More or less," "the same amount of," "I don't know" work?”
Science Reasoning	Teacher prompts students to think about science concepts on deeper level: focusing on the “why” and “how” of science ideas- or presents open ended questions	“Yes. Because as we go down the chart you'll notice our effort decreases. Why does our effort decrease? Why did it get "easier" to lift the object? What were we doing with our pulleys?”
Nature of Models	Talk referring to scientists’ construction and use of models, roles of models in science, models as abstractions, the affordances and constraints and multiple models, model evaluation	“What do you have so far? Difference between using a computer and doing it yourself. So what's a statement that -- that you could say...that the simulation would do better than yourself doing it?”

Not Applicable	Talk unrelated to instruction, unclear, or one word responses	“Do we get rid of the ‘e.’” or “Okay”

Micro Analysis of Nature of Models Dialogue

In order to understand the nuances of the discourse about the *nature of models*, we micro coded all teachers’ utterances that had been identified as talk about the nature of models from the macro coding analysis above. Six codes encompassing important aspects for understanding the nature of models were developed based on both the work of other researchers (Schwartz & White, 2005; Snir, Smith, and Raz, 2003) as well as from inductively examining the transcripts. The six codes are described in Table 2 below. Each utterance about the nature of models could be assigned multiple codes. The first and second author coded one 100% of the identified utterances pertaining to the nature of models into the six nature of models categories achieving an interrater reliability slightly above 96%. Disagreements were resolved through discussion.

Table 2. Nature of Models Coding Categories & Descriptions

Nature of Models Code	**Description**
Scientists’ Construction and Use of Models	Modeling as a primary part of the practice of scientists to construct scientific knowledge and develop theories
Role of Models	Scientists use models to explain and predict phenomena and to think about limited facets of reality
Models as Abstractions	Models as abstractions of reality that have underlying assumption…not exact replicas of the real thing
Affordances & Constraint of Models	Different models have different affordances and constraints
Multiple Models	The comparison and contrasting of different models to try to understand the underlying science ideas and develop explanations and theories
Model Evaluation	Models are not necessarily correct, but some are better than others for different purposes. You can assess them based on criteria such as accuracy, plausibility and utility.

Identifying Critical Incidents

After coding all the transcripts, we identified critical incidents that were indicative of the discourse relating to the nature of models. Critical incidents have generally been identified as events that make a ““significant” contribution, either positively or negatively, to the general aim of the activity” (Flanagan, 1954, p.338). As discussed earlier, we believe that explicit discussion about the nature of models is important to help students learn and participate in scientific modeling in more meaningful ways. Thus, we have defined a critical incident in our study as the clustering of three or more explicit utterances about the nature of models within a teacher’s dialogue during simulation instruction. These were identified within the coded transcripts.

RESULTS

Overall Nature of Teacher Discourse

As previously described, we developed five macro codes to analyze teachers’ utterances to attempt to identify the basic character of the discourse that occurred in the three different classrooms. The most predominant type of talk that all three teachers engaged in was procedural / managerial with about 60% of all of the teachers’ utterances coded into this category (see Table 3). The second most predominant type of talk for all teachers fell into the surface science category, with about 30-40% of their talk coded into this category. Less talk was coded as science reasoning; teachers engaged in this type of talk approximately 5-10% of the time. About 3% of all teachers' discourse was coded as related to the nature of models. Finally, about 12% of each teacher's utterances were not applicable to the study.

Table 3. Percentages of Utterances Coded within each Macro Coding Category

Code	Teacher A	Teacher B	Teacher C
Procedural / Managerial	62.4%	59.2%	59.5%
Surface Science	28.1%	41.6%	40.9%
Science reasoning	5.8%	10.8%	5.1%
Nature of Models	3.2%	3%	2.9%
Not Applicable	12.1%	11.2%	12.4%

Model Related Talk

To understand the extent of teacher discourse related to the nature of models, we further computed the percentage of talk in each of the six micro categories. As shown in Table 4, the majority of instances of model related talk were about the *affordances and constraints of models* (41% to 58%), *model evaluation* (42% to 77%), and *multiple models* (23% to 79%) categories. Overall, teachers engaged in much less conversation about the *role of models* (5% to 14%). Only Teacher A engaged in *models as abstractions* discourse at 9%. None of the teachers discussed *scientists' construction and use of models*.

Table 4. Percentage of Nature of Models Utterances by Micro Coding Category

Code:	Teacher A	Teacher B	Teacher C
Scientists' Construction and Use of Models	0%	0%	0%
Role of Models	13.6%	5.3%	13.3%
Models as Abstractions	9%	0%	0%
Affordances & Constraint of Models	40.9%	57.9%	53.3%
Multiple Models	22.7%	78.9%	53.3%
Model Evaluation	77.3%	42.1%	53.3%

Critical Incidents

In this section, we provide information about the number and context of the critical incident occurrences for each teacher. Then we provide and explicate a critical incident example from each teacher transcript.

We identified only one extensive critical incident within Teacher A's transcripts that occurred during the whole class discussion after all three inclined plane simulations. We provide an excerpt from this critical incident in Table 5 below. In line A1 Teacher A asks the students to think about the affordances & constraints of using the inclined plane simulation. Based on the student's response that the simulation is "more exact," Teacher A in line A3 probes students further by asking them a question to help them engage in some model evaluation about the affordance & constraints of the simulation. Teacher A continues to facilitate model evaluation talk with the students in lines A7 and A9. Finally, in line A13, the teacher discusses the accuracy of the simulation in comparison to collecting data in the physical experiments, stressing the affordances & constraints of models, model evaluation, and comparing multiple models.

Table 5. Teacher A- Critical Incident: Whole Class Discussion after Inclined Plane Simulations

Line	Utterance
A1	T: … what are the advantages of … using a simulation? What are the advantages of using [this] simulation up here? …
A2	S: Uh, it's gonna be more exact on the computer.

A3	T: What do you mean by more exact? Why would it be more exact?
A4	S: 'Cause like, it's not if, like, if you make one mistake when you’re like not doing the simulation it’s gonna((inaudible)).
A5	T: Where might you make a mistake?
A6	S: Like, when you're pulling it up the ramp...
A7	…T: Okay, so what is she referring to when she says you can't measure it close enough. There's a certain word that I'm thinking of right now. What do you think?
A8	S: It's not the exact [measure].
A9	T: Exact? Um. When you do the actual experiment, are you going to get...and exact, the exact answer?
A10	S: yes.
A11	T: I'm not sure...exact might work, but I'm looking for a word that starts with the letter "a."
A12	S: ((several)) Accurate. …
A13	T: Accurate! And she said that the simulation can be more accurate than doing the real experiment. And she said something about well, when you're pulling it back up and down...that that's where you can make a mistake.

We identified three separate critical incidents for Teacher B. All of these occurred during small group facilitation during the inclined plane simulation experiments. A critical incident that occurred as students were finishing up and reflecting on the final inclined plane simulation is presented in Table 6 below. Teacher B asks the students to think about the differences in the data that the students collected in the physical vs. simulation experiments. In doing so, Teacher B asks the students in line B1 to compare multiple models and evaluate the affordances & constraints of the simulation, since it has friction. In line B3, Teacher B continues to ask students to think about what they can learn about physics from comparing results from multiple models and further asks them to engage in model evaluation. Finally in line B7, the teacher asks the students to consider the affordances & constraints of models and engage in model evaluation by encouraging them to think about the reduction of measurement error that the simulation affords.

Two critical incidents were identified in Teacher C’s transcripts. One of these critical incidents occurred during a whole class introduction to an inclined plane simulation with zero friction and the other occurred during a whole class discussion after the students completed the pulley simulation. The critical incident that occurred during inclined plane simulation is provided in Table 7 below. Teacher C discusses the affordance of the ability to control the amount of friction in the inclined plane length simulation vs. the physical length experiment in lines C1, C8, C10, C14, and C16. In line C16, Teacher C also has students think about the science associated with multiple models by having them consider what they found when doing the physical experiment and (later in the transcript) make predictions about what they think they will learn by conducting the simulation.

Table 6. Teacher B- Critical Incident: Small Group Facilitation of Inclined Plane Simulation

Line	Utterance
B1	T: Okay so they were not the same in this experiment there was little friction which helped the effort and work force less than they were before. Alright so let me just look at your comparison your results. …Why do you think they were so different?
B2	S: Because the last one ugh ((inaudible)) friction ((inaudible)).
B3	T: But this one the friction that you used here was the friction that you calculated when you ran the brick on the board. And that's what this simulation was reenacting was brick on board. So what do you think may have happened in your experiment versus what happens on the computer that could have made your results seem different? Think about some of the things we really had to make sure we did when we did the physical experiment. What were some of

	the things we had to make sure we did.
B4	S: Had to make sure the spring scale was on zero.
B5	T: Okay so making sure the spring scale was exactly on zero. What else?
B6	S: ((Inaudible))
B7	T: Pulled the same. Okay what else? So think about those two things. Does the computer have to worry about always making sure the spring scale's on zero. Or making sure that there it's pulling exactly the same. So what may have caused …

Table 7. Teacher C- Critical Incident: Whole Class Introduction to an Inclined Plane Simulation.

Line	Utterance
C1	T: … Now, we're gonna do the same experiment with a simulation of our mini pool table moving up a ramp. In the simulation, there's zero friction. So in real life, there's always some friction but in the simulation we can investigate what would happen without friction. What is friction?
C2	S: When two force-when two objects rub against each other.
C3	T: Two objects rub against each other and then what? Creates friction?
C4	S: Creates friction.
C5	S: Creates friction.
C6	T: So where's friction in our length s-uh thing we did yesterday, in the lab? Between the brick and board there's friction?
C7	S: The pool table and the board.
C8	T: The pool table and the board there's friction. Um, in real life, if we wanted to do that lab again, could we get rid of that friction between the board and the brick?
C9	S: No.
C10	T: Or the pool table? No. We can't get rid of friction?
C11	S: We could hover the brick.
C12	T: We could get rid of some of it, what do you mean (J)?
C13	S: You could sand down it and then the board would be smoother.
C14	T: Okay. So what if we alter the surface a little bit it might change friction. Could we, completely get rid of friction?
C15	S: No
C16	T: No. So what we're gonna do, is use a computer simal-simulation to pretend that we can completely get rid of friction. In the lab yesterday, did friction help you, did it make you use less effort to get that up the board, or did it make you use more force to make you use more force to get up the board?

DISCUSSION

We found that on the whole, while all three teachers engaged students in the CoMPASS curriculum in slightly different ways, the nature of their discourse was similar. The combined science related talk in each classroom accounted for about 30-40% of the classroom dialogue. However, the majority of this talk was focused on surface science and little related to science reasoning and discourse about the nature of models. Further, much of the teachers’ dialogue pertained to procedural and managerial instructions. While part of a teacher’s work is to provide directions and manage classroom activities and dynamics, we would hope that if teachers are facilitating inquiry science instruction that there would be more discourse focused on helping students to reason about science ideas and engage in more authentic science practices.

Discourse about the nature of models was limited in all three classrooms, accounting for only about 3%. Within this limited percentage of discourse, none of the teachers explicitly informed students about the overarching scientific practice of modeling – that model building and revision is a primary part of the practice of scientists in constructing scientific knowledge and developing theories. There was little talk about the role that models play in predicting and understanding science ideas. Further, there was minimal dialogue aimed at helping students understand that models are abstractions with underlying assumptions. These findings align with other researchers' ideas as to why students have generally been found to hold unsophisticated views of the nature of models; the teachers in this study used the simulations in largely superficial ways (Linn, 2003; Snir et al., 1995; Snir et al., 2003, Treagust et al., 2002). This surface treatment of the nature of models during simulation instruction by the teachers might be explained by prior findings that teachers' ideas about the nature of models may not be coherent (Justi & Gilbert, 2003) and may be limited in scope (Windschitl, Thompson, & Braaten, 2008). Further, most science teachers have not been trained to teach students about models and the modeling process (Gilbert, 2004), including those in this study. These factors may explain the low percentage of explicit discourse about the nature of models during instruction. Even though the teachers in this study engaged in minimal discourse about the nature of models, teachers did talk more about the affordances and constraints of models, model evaluation, and multiple models. We believe that the design of CoMPASS curriculum, which conscientiously combined both physical and simulation experiments, may have encouraged the teachers' to engage in explicit discussion on these aspects of the nature of models. Though the level of the discourse about these aspects of the nature of models was limited, it provides a place to engage teachers in discussion about how to increase this type of talk to foster students' understanding of models and science.

While we did identify critical incidents related to nature of models for all teachers, these critical incidents also represent missed opportunities. In each of these incidents, the teachers could have gone farther and been more explicit and varied in their discourse about the nature of models to help students learn. Teacher C's critical incident, in Table 6, is a good example. Along with discussing the affordances and constraints of the first inclined plane simulation, Teacher C could have easily incorporated a metaconceptual conversation explaining how scientists construct and use models as a primary part of their practice to construct scientific knowledge and develop theories. Within this same critical incident, Teacher C could have also engaged students in a discussion to promote the understanding of the role of models and models as abstractions by engaging students in discourse about how the inclined plane simulation is a limited abstraction of reality with underlying assumptions, not an exact replica of the real thing, that students, like scientists, could use to understand phenomenon and make predictions. Teacher A and B could have also engaged in more elaborated and explicit discourse within their critical incidents. In particular, combining simulations and physical models in the classroom can provide diverse and novel opportunities for discussing the nature of models. Because the teachers could have asked the students to reflect upon the similarities and differences between the physical and simulation models at any time and rarely actually did so, all teachers in this study missed opportunities to discuss the nature of models throughout the entire corpus of transcripts.

In considering the main points discussed above, we believe that teacher professional development should help teachers to 1) understand the nature of models themselves and 2) develop skills and strategies for explicitly engaging students in modeling practices. To this end, Windschitl, Thompson, and Braaten (2008) claim that in order to help students develop an understanding of the practices of scientists, such as the nature of models, they need to work with a more "advanced other." However, they point out that most science teachers have not had this experience themselves and thus rarely explicitly talk about how scientists go about their work with students. In trying to remedy this problem, these researchers developed a semester long apprenticeship, called *heuristics for progressive disciplinary discourse*. The apprenticeship was created to help pre-service science teachers develop a better understanding of the modeling and inquiry practices of scientists. This was undertaken in hopes that these understandings would later translate into more explicit model-based instruction in their classrooms. While this program showed some success in working with pre-service teachers, an intensive semester long course may not be an option for practicing teachers. More research needs to be conducted to identify the best ways to help practicing teachers develop an understanding of the nature of models and modeling so that they may be better positioned to plan relevant activities and engage in meaningful discussions about this essential scientific practice with their students.

The findings of this study also have implications for researchers and designers. It may be beneficial for researchers and designers to be explicit with teachers about the goals, affordances and constraints of the multiple models students use within a curriculum in order for teachers to understand and be explicit with students about the roles that those models play within the scientific enterprise. Further, while several researchers have emphasized that explicit discourse about the nature of models is important to help students understand the nature of models (Grosslight et al., 1991, Lehrer & Schauble, 2006, Schwartz & White, 2005; Windschitl, et al., 2008), this study offers a way to analyze this discourse in the classroom.

Our study represents a first step in understanding how teacher facilitation of simulation instruction might promote students' understanding of the nature of models. We have examined the overall nature of teacher talk related to models within three inquiry-oriented classrooms. Because we did not collect pre and post test data about students' understanding of the nature of models in this study, we are not able to make any claims about how explicit nature of models teacher dialogue may (or may not) facilitate students' nature of models understanding. Designing a study to further test this idea may be a fruitful future line of research.

ACKNOWLEDGEMENT

CoMPASS research is supported by the National Science Foundation: IERI #0437660
& Institute of Educational Sciences: CASL #R305A08050

REFERENCES

Chi, M., T., H. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *The Journal of the Learning Sciences*, 6(3), 271-315.

Chinn, C. A., & Malholtra, B. A. (2002). Epistemologically authentic inquiry in schools: A theoretical framework for evaluating inquiry tasks. *Science Education, 86*(2), 175-218.

Coll, R., France, B., & Taylor, I. (2005). The role of models/and analogies in science education: implications from research. *International Journal of Science Education, 27*(2), 183-198.

Finkelstein, N., Adams, W., Keller, C., Kohl, P., Perkins, K., Podolefsky, N. (2005). When learning about the real world is better done virtually: A study of substituting computer simulations for laboratory equipment. *Physical Review Special Topics-Physics Education Research, 1(1)*, 10103.

Flanagan, J.C., (1954). The critical incident technique. *Psychological Bulletin*, *51(4)*, 327-358.

Gilbert, J. K. (2004). Models and modelling: Routes to more authentic science education. *International Journal of Science and Mathematics Education, 2*(2), 115-130.

Grosslight, L., Unger, C., Jay, E., & Smith, C. L. (1991). Understanding models and their use in science: Conceptions of middle and high school students and experts. *Journal of Research in Science Teaching, 28*(9), 799-822.

Hewson, P. W., & Lemberger, J. (2000). Status as the hallmark of conceptual learning. In R. Millar & J. Leach & J. Osborne (Eds.), *Improving science education: The contribution of research* (pp. 110-125). Buckingham: Open University Press.

Hofstein, A., & Lunetta, V. (2004). The laboratory in science education: Foundations for the twenty-first century. *Science Education, 88*(1), 28-54.

Justi, R. S., & Gilbert, J. K. (2002). Modelling, teachers’ views on the nature of modelling, and implications for the education of modellers. *International Journal of Science Education, 24*(4), 369-387.

Justi, R. S., & Gilbert, J. K. (2003). Teachers’ views on the nature of models. *International Journal of Science Education, 25*(11), 1369-1386.

Lehrer, R., & Schauble, L. (2006). Cultivating model-based reasoning in science education. In R.K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Science,* 371–387. Cambridge University Press.

Lehrer, R., & Schauble, L., Petrosino, S.J. (2001). Reconsidering the role of experiment in science education. In K. Crowley, C.D. Schunn & T. Okada (Eds.), Designing for Science: Implications from Everyday, Classroom, and Professional Settings. Mahwah, NJ: Lawrence Erlbaum Associates.

Lemke, J. L. (1990). *Talking science: Language, learning, and values.* Westport, CT: Ablex Publishing Corporation.

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

Puntambekar, S. (2006). Learning from digital text in inquiry-based science classes: lessons learned in one program. Paper presented at the Proceedings of the 7th international conference on Learning Sciences.

Puntambekar, S., Stylianou, A., & Goldstein, J. (2007). Comparing Classroom Enactments of an Inquiry Curriculum: Lessons Learned From Two Teachers. The Journal of the Learning Sciences, 16(1), 81-130.

Schwarz, C. V., & White, B. Y. (2005). Metamodeling knowledge: Developing students' understanding of scientific modeling. *Cognition and Instruction, 23*(2), 165-205.

Snir, J. & Smith, C. (1995). Understanding in the science classroom: Integrating laboratory experiments, students and computer models, and class discussion in learning scientific concepts. In D.N. Perkins, J.L. Schwartz, M.M. West, & M.S. Wiske (Eds.), *Software Goes to School: Teaching for Understanding with New Technologies,* 233-257. Oxford University Press.

Snir, J., Smith, C., & Grosslight, L. (1995). Conceptually Enhanced Simulations: A Computer Tool for Science Teaching. In D.N. Perkins, J.L. Schwartz, M.M. West, & M.S. Wiske (Eds.), *Software Goes to School: Teaching for Understanding with New Technologies,* 106-129. Oxford University Press.

Snir, J., Smith, C. L., & Raz, G. (2003). Linking phenomena with competing underlying models: A software tool for introducing students to the particulate model of matter. *Science Education, 87*(6), 794-830.

Treagust, D. F., Chittleborough, G., & Mamiala, T. L. (2002). Students’ understanding of the role of scientific models in learning science. *International Journal of Science Education, 24*(4), 357-368.

Vosniadou, S., Ioannides, C., Dimitrakopoulou, A., & Papademetriou, E. (2001). Designing learning environments to promote conceptual change in science. *Learning and Instruction, 11*(4-5), 381-419.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. Science Education, 92(5), 941–967.

Dana Gnesdilow
Graduate Student
Department of Educational Psychology
Email: gnesdilow@wisc.edu

Garrett W. Smith
Graduate Student
Department of Educational Psychology
Email: gwsmith@wisc.edu

Sadhana Puntambekar
Professor
Department of Educational Psychology
University of Wisconsin – Madison
1025 West Johnson Street
Madison, WI, USA
Email: puntambekar@education.wisc.edu