Teachers’ Mediation of Students’ Interactions with Physical and Virtual Scientific Models in Biology

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Abstract: This study explored the mediating role that teachers play in helping students utilize multiple models as tools for scientific thinking. We analyzed two teachers' discourse as they facilitated students' use of virtual and physical models and compared their students' understanding of and engagement with models during a biology unit. We found that one teacher had significantly more talk than the other about the affordances and constraints of models, and his students more purposefully used the affordances of the models to engage in scientific thinking on their own and seemed to learn more about affordances and constraints of scientific models than students in the other teacher’s class. Our findings suggest that the ways in which teachers talk about the affordances and constraints of scientific models is important for students to understand and utilize them as tools for thinking and building knowledge.

Introduction

Models and modeling play a central role in the practice of science, and teaching students to understand and use scientific models is an important goal of science education (Lehrer & Schauble, 2006; National Research Council, 2012; Windschitl, Thompson, & Braaten, 2008). Scientists use models to represent particular aspects of phenomena and to generate, test, and revise scientific ideas. In this way, scientists employ models as tools for thinking and building knowledge. Scientific models such as physical representations and lab experiments have been pervasive in classrooms, and other types of models such as virtual simulations are becoming increasingly prevalent. However, modeling is a complex practice, and the widespread presence of models in science classrooms does not mean that students know how to use them as tools for scientific thinking. Research has suggested that students often do not understand the practice of modeling in science, and teachers need to support students in learning this practice (Schwarz et al., 2009; Treagust, Chittleborough, & Mamiala, 2002).

From a sociocultural perspective, learning is mediated by interactions with cognitive tools and cultural resources (Vygotsky 1978, Wertsch 1991). Scientific models are cognitive tools that mediate thinking and have particular norms and practices that guide their use. Tools contain the intelligence of the maker (Pea, 1993), and by using a tool, it is possible to capitalize on and benefit from the distributed intelligence embedded in the use of the tool. Thus, tools can support thinking and reasoning in ways that may not be possible without the aid of the tool (Pea, 1993). Additionally, tools are designed to have particular affordances and constraints that influence their use. While the affordances of a tool are features intended to draw the user’s attention and guide effective use, such affordances are not always obvious to the user (Norman, 1988). Thus, the tool may not be used in ways that fully benefit the user. Further, being able to use or learn from a tool also requires understanding the cultural norms around its use (Cole & Engeström, 1993). From this perspective, using scientific models not only requires understanding the affordances of particular models, but also how the scientific community uses such tools to generate, test, and revise scientific ideas to build knowledge.

Teachers can play an important role in mediating students’ engagement with models to successfully utilize their affordances and realize their potential for supporting students’ learning. As discussed by Cole and Engeström (1993), while tools can mediate students' thinking, the ways in which students interact with and use a tool can be further mediated by a teacher. This mediation is often manifested in teachers' discourse as they interact with and support students during activity in the classroom. However, prior work suggests that teachers may not effectively mediate students’ interactions with tools in classrooms (Kozulin, 2003). This may be due to teachers’ beliefs or assumptions that the meaning and affordances embedded in tools are explicit enough for students to understand on their own, and thus do not necessitate mediation (Kozulin, 2003), or due to teachers themselves not understanding the meaning and affordances of tools.

Additionally, mediation from a teacher may be increasingly important in environments where different types of models or tools are being employed to help students learn. In science, different types of scientific models can provide unique affordances and are often used to provide students with alternative ways to experience scientific phenomena. For example, virtual models such as simulations afford altering the time and visual scale of phenomena to allow for fast experimentation about unobservable or slow processes and allow students to constrain complex systems (de Jong, Linn, & Zacharia, 2013; Olympiou & Zacharia, 2012). Physical representations, on the other hand, can expose students to authentic problems and complex systems about real phenomena, provide concrete qualitative and quantitative observations or measurements, and raise challenges students would not face in a virtual experiment (de Jong et al., 2013; Olympiou & Zacharia, 2012). Previous research on using models in science has explored students' learning from conducting experiments with either virtual *or* physical models, as well as participating in different sequences of virtual and physical experiments (e.g., Zacharia & Olympiou, 2011). This work has yielded mixed results about the most beneficial modality and sequencing for learning science content. Rather than focusing on one type of model, using virtual and physical models *together* offers the potential of capitalizing on the unique affordances of both types of models to support students' learning (Olympiou & Zacharia, 2012). Initial investigations into how students are able to coordinate information from virtual and physical models suggest that understanding and utilizing the affordances of these models may be quite challenging for students (Martin, Gnesdilow, & Puntambekar, 2017). Thus, while there is great potential for utilizing the unique affordances of both virtual and physical models to support students' learning, these previous findings suggest that this potential will not be reached without proper support and orchestration by the teacher. Despite calls for teaching students via modeling in K-12 science education and research showing that students have difficulty using models, little is known about how teachers actually mediate students' effective use of models in the science classroom.

Given the difficulties students' face in understanding and coordinating virtual and physical models to take advantage of their unique affordances, we explored the mediating role that two teachers played in helping students to utilize multiple models to learn science. Specifically, we aimed to answer the following two-part question: How do teachers mediate students' interactions with multiple models to help them: a) use models as tools for scientific thinking and, b) understand the affordances of different models to learn science? To explore this question, we analyzed two teachers' discourse as they facilitated students' use of virtual and physical models and compared their students' understanding of and engagement with models during a biology unit.

Methods

Participants and Context

The participants in this study were two experienced 8th grade science teachers, Mr. Fox and Mr. Smith, and the students in each of their science classes (n = 27, n = 21 respectively). The teachers taught at different urban middle schools in the same U.S. Midwestern city. The students at Mr. Fox's school were 64% white, 18% Hispanic, and 8% black or African American, and 55% were economically disadvantaged. The students at Mr. Smith's school were 78% white, 10% Hispanic, and 4% black or African American, and 40% were economically disadvantaged. Mr. Fox's class happened to be designated as a "challenge" class, in which students were often given more open-ended tasks. Mr. Smith's school did not offer challenge classes, thus his class consisted of students with a range of abilities including students who could have succeeded in a challenge class. This was a design-based research study in which we did not purposefully select these two classes for comparison a priori, but rather we selected these teachers because we had a complete corpus of teacher and students data to pursue our research question.

This study was a part of a larger project aimed at helping students learn biology by engaging them in solving 21st century real-world bio-engineering problems. Both teachers taught the same 10-12 week design-based, biology curriculum that incorporated the use of both virtual and physical models. The curriculum challenged students to design a compost that would break down quickly and contain a lot of nutrients, to reduce the amount of waste going into landfills. Students learned key concepts related to energy transformation and matter cycling in ecosystems to solve their challenge. To study decomposition and collect data to justify their compost designs, students worked in small groups of three to four to build, monitor, and refine a physical bio-reactor during the unit. Given that decomposition takes several weeks, towards the middle of the unit students also used a virtual compost simulation to investigate how abiotic factors influence decomposers' ability to break down matter. In their small groups, students conducted three sequential virtual compost experiments related to the carbon to nitrogen ratio, amount of moisture, and particle size of the materials in compost. Based on their findings from the virtual experiments, students were asked to revisit their physical bio-reactors and use the science ideas and data from the virtual experiments to make decisions and justify a change to increase decomposition in their physical bio-reactors. Teachers facilitated small-group and whole-class discussions as students engaged in these activities throughout the unit.

Data Sources and Analysis

We used three data sources: i) classroom videos of teachers' interactions with their students as they conducted all three virtual experiments, ii) audio-recorded student conversations during the last virtual experiment, and iii) students' pre and post scores on an open-ended question about the affordances and constraints of physical and virtual models in science, taken at the start and end of the unit.

We examined the classroom videos of both teachers to investigate each teacher's discourse as they mediated students' work with the virtual compost simulations and physical compost bio-reactors. We selected particular lessons in which students used the virtual simulations to investigate factors affecting decomposition in their physical bio-reactors, because these lessons captured opportunities for students to interact with *both* their physical and virtual compost models and allowed us to investigate how teachers mediated students' thinking and use of multiple models to learn science. We used a mixed-methods approach to quantify the qualitative discourse data present in the videos (Chi, 1997). The videos were transcribed and teachers' turns of talk were deductively and inductively coded to capture how teachers supported students' interactions with the virtual and physical models. Based on previous literature suggesting that students likely need support to learn about the nature of models (Schwarz et al., 2009), the affordances and constraints of models (Kouzlin, 2003; Norman, 1988), and how to coordinate multiple scientific models (Martin et al., 2017), we were particularly interested in how teachers discussed the general nature of models, the affordances and constraints of virtual and physical models in this context, and connections between the models. Additionally, we were interested in how teachers used the virtual and physical models to support students' learning of science content and practices. This resulted in the five mediation codes described in Table 1. The *nature of models* code was adapted from our prior work on teachers' discourse related to using models (Gnesdilow, Smith, & Puntambekar, 2010), while the codes for *affordance and/or constraint of virtual or physical models*, *connecting models*, *science content*, and *science practices* were developed to specifically capture important discourse about the virtual and physical models in the context of this study. Some talk was coded as not applicable, which often consisted of managing procedural and social interactions. Turns of talk could receive multiple codes if multiple forms of mediation discourse were present. Ten percent of the teachers' turns of talk were coded by the first and second author and an 84% agreement was achieved. The remaining discourse was coded by the second author. We then calculated the proportion of the different types of talk that both teachers engaged in as they mediated students' use of the models. These proportions accounted for the different amounts of overall teacher talk during all the virtual experiments, so the proportion of each type of talk could be compared between teachers. To do this, we divided the frequencies for each type of mediation discourse from Mr. Fox and Mr. Smith by the total number of turns of talk for that teacher. We then conducted a Chi-squared test of homogeneity of proportions to compare the prevalence of talk related to mediating students' use of the virtual and physical models between teachers.

Table 1. Coding scheme for teachers' discourse to mediate students' interactions with models.

Code	Description	Example
Nature of Models	Talk referring to scientists' construction and use of models, roles of models in science, models as abstractions, model evaluation	"What's a model? Your bio-reactors right? Alright, and your bio-reactors are a model for what? What are they trying to model for you, what are they trying to show you?"
Affordance and/or Constraints of Virtual or Physical Models	*Explicit or implicit talk about usefulness of virtual model to:* quickly run multiple trials*;* constrain the complex system by isolating variable*;* input current physical conditions into the simulation to quickly run trials to make predictions *Explicit or implicit talk about usefulness of physical model to:* understand, explore messiness of complex system in real world*;* raise challenges*;* provide concrete observations*;* quantitative & qualitative measurements	"…What's the advantage of using a computer simulation of a compost pile, or of a compost? …We can control it better because we don't have variables outside of what we're just looking at. Ok? So, that's what these, uh, virtual experiments are meant to do." "You gotta think about this and doing it on a large scale, too. Remember the challenge. The challenge is: compost, doing this at our school, with, fast, and a lot of nutrients. Right? Well, what would happen to a compost pile at school? With regards to, adding greens or browns?"
Connecting Models	Explicit or implicit talk about how to use both virtual and physical models in tandem **to synthesize ideas and learn science**. Helping students to see connections between information provided by both models, or to **use information provided by one model to guide or justify usage** of other model.	"After you run your particle size (virtual experiment) then you as a group need to talk about what changes you think you could make or what problems you have (in bio-reactor) ....What problems do you have, what could you do about it...what's your evidence, and then what one do you think is going to improve"

		"And then we can use that information, that you find in the (virtual) experiment, and apply it to what you've got going on in your bottles. Ok?"
Science Content	Using results or information from one or both models to help students understand science concepts	"What do the bacteria in your decompo- the bacteria that are acting as decomposers, what are they doing inside your compost? What are they doing with the carbon?"
Science Practices	Using one or both models to scaffold students' ability to conduct fair tests, collect accurate data, analyze, and draw conclusions	"You're gonna start looking at these variables that we can control and, and, manipulate. If we're controlling one, say the carbon to nitrogen ratio. Should we, change, where we're placing the bioreactor?"

To investigate how students' discussions around the virtual and physical models may have related to the mediation provided by the teachers, we also analyzed conversations from all the small groups of students that we had audio-recorded during the unit (n=3 for Mr. Fox, and n=3 for Mr. Smith). These groups were chosen for audio-recording by each teacher at the beginning of the unit as representative, average-performing groups in the class. We selected students' conversations from the third virtual experiment, in which students investigated how the size of particles in compost affected the rate of decomposition. We chose this last experiment as an outcome measure to examine how students used the virtual and physical models as tools for their inquiry, since they had received mediation from their teacher during the prior two experiments. When examining students' discourse during the experiment, we looked to identify any patterns or themes in the types of interactions that students engaged in as they used the models to better understand if there were any key differences in the ways that the students in each teacher's class used the virtual and physical models as tools for scientific thinking.

Additionally, we used students' pre and post scores on an open-ended question about the affordances and constraints of physical and virtual models in science. The question presented students with a scenario in which one student conducted an experiment using a virtual computer simulation and another student conducted the same experiment using physical models. Students were then asked to describe reasons why the two students in the scenario might have gotten different results from their experiments. Students received a score of 0 for responses that were incorrect or lacked any mention of an affordance of either type of model, a score of 1 for responses that discussed one affordance that could contribute to different results, and a score of 2 for responses that discussed two or more affordances. We used a non-parametric analysis of covariance (Young & Bowman, 1995) to compare students' post-test scores based on the teacher they had, with students' pre-test scores as the covariate. This test was chosen because our dependent variable (post score) was categorical and our sample size was small, and thus the data were non-normal.

Results

Teachers' Mediation of Students' Interactions with Models

To better understand how the teachers mediated students' interactions with multiple models to promote the utilization of the affordances of different models to learn science, we conducted a Chi-squared test of homogeneity of proportions to compare differences in teachers' talk within our 5 coding categories.

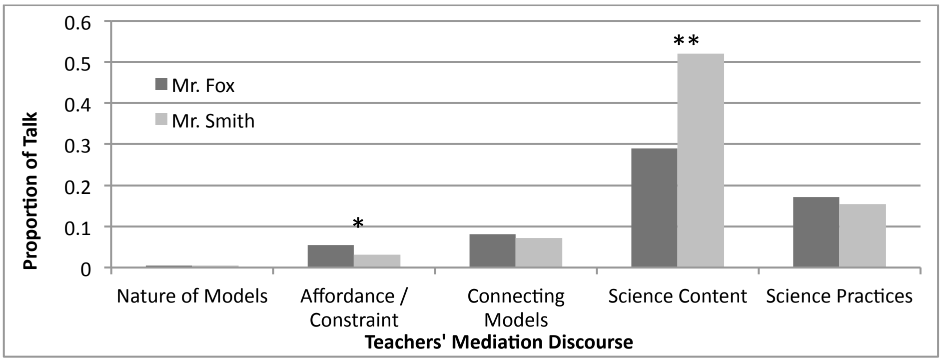

Figure 1. Proportion of teacher talk to mediate students' interactions with virtual and physical models. * Result significant at $p < .05$. ** Result significant at $p < .001$.

As seen in Figure 1, our results showed that Mr. Fox had a significantly higher proportion of talk about the *affordances and constraints of models* (0.05) than Mr. Smith (0.03) ($p < .05$). Additionally, Mr. Smith had a significantly higher proportion of talk about learning *science content* (0.52) than Mr. Fox (0.29) ($p < .001$). However, there were no significant differences in the proportions of talk that Mr. Fox and Mr. Smith engaged in about *science practices* (0.17 & 0.15, respectively), *making connections between the models* (0.08 & 0.07, respectively), and the *nature of models* in general (0.005 & 0.004, respectively).

Students' Use and Understanding of Models

Examination of Groups' Discourse

We examined groups' conversations (n=3 groups for Mr. Fox, n=3 groups for Mr. Smith) to understand how students' discussions about and interactions with the virtual and physical models may have been influenced by the mediation they received from their teacher. By examining students' discourse while they conducted their particle size simulation experiment, we identified several interaction patterns that revealed key differences in how students used models in Mr. Fox's and Mr. Smith's classroom. A major theme we identified was that Mr. Fox's students showed several instances of purposefully using the affordances of the models to engage in scientific thinking, while Mr. Smith's students rarely took advantage of these affordances and, instead, focused on procedural aspects of completing the experiment and getting a "good result." Below, we provide a general overview of the groups' discussions in each teacher's class and an excerpt from one group in each teacher's class to clearly illustrate the differences in the types of discussions that groups had depending on their teacher.

During the particle-size virtual experiment, all three groups of students we audio-recorded in Mr. Fox's class had conversations about inputting conditions from their physical model into the virtual simulation to make connections between the two models, and they utilized the affordances of the virtual model to explore science content. For example, in the excerpt below, one group used the visualizations presented in the virtual simulation to *test their ideas* about how air circulation might affect the rate of decomposition in compost. To do this, they took advantage of the affordance of quickly comparing the visualizations in the model of both smaller and larger particle sizes to analyze, make inferences, and explain how the amount of space between particles might affect air circulation in compost. They then used this information to decide on an optimal particle size of 50mm for their physical bioreactor.

Student 1: Did they talk about the air circulation in this simulation?
Student 2: Um, we talked about it the other day. I don't think it talked about it in the simulation. But I mean, here, make it really small. Like make the particle size really small. Make it 5. And then put some in. And then make it 100.
Student 1: What?
Student 2: Now make it 100.
Student 1: Right now?
Student 2: Yeah.
Student 1: You can't.
Student 2: Yeah you can.
Student 1: It just deletes. (*Note: the simulation only allowed students to use one size particle per trial, deleting previous particles if a student tried to add multiple sizes to the virtual compost*)
Student 2: Oh. Well you saw how much was in there for 5?
Student 1: Yeah.
Student 2: And then, you know, you go to 100…
Student 1: And there's more pockets, there's more space.
Student 2: Exactly. So there'd be better air circulation the bigger the particle size.
Student 1: But if it's too big there's too much air and not enough moisture.
Student 2: Exactly. So you'd have it, like 50.
Student 1: 50 would be perfect. 'Cause it's in between 15 and 75.

This excerpt exemplifies how Mr. Fox's students used the virtual simulation not only to complete their experiment, but to actually capitalize on the visualizations afforded by the simulation to use this model as a tool for scientific thinking. Rather than just focusing on the size of the particles, students discussed the concept of air circulation and its relationship to the rate of decomposition. Further, they chose to compare the amount of space created between the smallest and largest particle sizes allowed by the simulation, instead of choosing random particle sizes, to optimize the visualization to test their ideas. Understanding the relevance of air circulation in the simulation was important for being able to think about air as an abiotic factor that influenced decomposition in their physical compost bio-reactor. The students used the simulation as a tool to think through these ideas.

In contrast, the groups we examined in Mr. Smith's class predominately capitalized on the efficiency of the virtual simulation to *quickly conduct trials* and find the particle size range that was ideal for decomposition so they could answer the questions at the end of the lab. Overall, the students seemed to use the virtual simulation as a game to find an ideal result, rather than as a tool to help them think more deeply about the science content or test their science ideas. For instance, in the excerpt below from one group, Student 1 described how he was "messing around" with the simulation, happened to get a "good result," and was excited that he had "won." When Mr. Smith interacted with this group shortly after, it was clear that the students' main goal was to find the upper and lower bounds of the ideal particle size range, without using the affordances of the virtual model to think about what was important about particle size from a scientific perspective.

Student 1: Okay. I just gotta, I'm just messing around this first time okay?
Student 2: Whoa.
Student 1: I actually did good. I did good. I did good. I won. I just put it to a random size and shook it all in there and-
Student 2: It was at like 74. Yeah, see 74. That's our first simulation.
Student 3: Set it there.
Student 1: I didn't even try, how did I, like what? Particle size 74…Rate of decomposition fast. Temperature, ideal. Odor, normal…What is the result? It's a good result.
…
Mr. Smith: So what are you guys thinking? What have you guys found?
Student 1: Um the smallest is way too slow to decompose.
Mr. Smith: And what was the smallest?
Student 3: 5mm, right? Millimeters that's the double m?
Mr. Smith: Millimeter. Yeah. So you guys started with, what is that?
Student 1: 74.
Mr. Smith: 74 is where you started?
Student 1: Yeah. So then 50 now it goes back-
Mr. Smith: So you guys are all over. So you guys were just trying to hit the upper and lower immediately?
Student 2: Yeah.
Student 1: Yeah I was messing around the first time and then it actually worked.

This excerpt is one of many that could have been used to demonstrated that students in Mr. Smith's class commonly used the simulation in a trial-and-error fashion, rather than thoughtfully identifying parameters to test their ideas in a scientific way. Further, the students in this group and the other groups in Mr. Smith's class never talked about why different particle sizes influenced the rate of decomposition. For example, they never used the simulation to go beyond finding the "right" answer and to discuss the cause-and-effect relationships between particle size and aerobic versus anaerobic conditions or how larger particles have less surface area for decomposers to break down. The simulation gave students comments, questions, and visualizations to help them think more deeply about factors that influence decomposition, but they did not utilize these affordances.

Examination of Students' Pre - Post Performance on Open-Ended Question about Affordances and Constraints of Models

To further examine if there were differences between Mr. Fox's and Mr. Smith's students' understanding of the affordances and constraints of virtual and physical models, we compared students' pre and post responses to an open-ended question about the affordances and constraints of virtual and physical models. We used a non-parametric analysis of covariance (Young & Bowman, 1995) due to our small sample size. When using the pre scores as a covariate, we found that Mr. Fox's students' post scores were significantly higher than Mr. Smith's students' scores ($p < .01$). This showed that Mr. Fox's students learned more about the affordances and constraints of virtual and physical models than Mr. Smith's students.

Discussion

Research suggests that the use of tools can be further mediated by a teacher to support students' learning (Cole & Engeström, 1993). Scientific models are tools that help students engage in the practices of science. Therefore, the ways in which teachers talk about the affordances and constraints of scientific models is important for students to understand and utilize them as tools for thinking and building knowledge. Our findings supported this idea and provided evidence that the type of mediation students received from their teacher may have influenced their understanding of and engagement with models. Mr. Fox engaged in a greater proportion of talk about the affordances and constraints of models than Mr. Smith, and Mr. Fox's students utilized the affordances of the virtual simulation more purposefully and in intended ways to think and reason about science content. Further, Mr. Fox's students seemed to learn more during the unit about the affordances and constraints of models than Mr. Smith's students, as indicated by better performance on an open-ended question about the affordances and constraints of models. This suggests that teachers' mediation to help students understand the affordances and constraints of models may have been important to help students understand how to use the models as tools for scientific thinking. Given that the affordances of tools are not always obvious to the user (Norman, 1988) and that explicit mediation may be needed (Kozulin, 2003), differences in the teachers' discussion about affordances may have differentially helped students see and understand how to take advantage of the intelligence built into the models. This offers a more nuanced understanding of prior findings that teachers' discourse can play an important role in mediating students' interactions with models to help them meaningfully use the affordances of models in science (Martin et al., 2017).

Overall, both teachers discussed science content and practices more than models, which is consistent with prior research (Gnesdilow et al., 2010) and the suggestion that teachers may not explicitly support students to understand the meaning and affordances embedded in tools (Kozulin, 2003). However, while the teachers' proportion of explicit talk about the affordances and constraints of models was low in comparison to their talk about science content and practices, we found that even the small proportion of talk by Mr. Fox about the affordances and constrains of models may have had a big impact on his students' use of and learning about them. Thus, it may be that minimal, but *purposeful and explicit,* discussion about the affordances and constraints of models by a teacher can have important benefits for students to understand the complex process of scientific modeling. A productive avenue for future work could be to further investigate the utility of working with teachers on conducting such discussions with their students, or designing prompts about affordances and constrains of models within curricula and technologies such as the virtual simulation used in this study.

Another significant difference in the types of mediation that the teachers provided their students was that Mr. Smith engaged in more discourse focused on science content. It is not clear whether Mr. Smith's discourse contributed to or was a result of his students' use of the models. For instance, was it the case that Mr. Smith's students did not take advantage of the models as tools for thinking, as Mr. Fox's students did, because Mr. Smith did not talk about the affordances and constraints enough? Or, was it the case that Mr. Smith spent most of his time discussing science content to redirect students' attention from procedural aspects of the virtual simulation to get them to think more deeply about the underlying science? Asking students questions related to science content may have been productive to engage students in scientific thinking in the moment while the teacher was present, but perhaps this type of mediation was not sufficient for supporting students to use the models to engage in scientific thinking when they were on their own. Thus, while Mr. Smith engaged in some deep conversations about science content with his students, our results suggest that this type of mediation may not be sufficient to help students understand and utilize models as scientific tools. As suggested by others, balancing support for science content with science practice, the practice of using models in this case, seems crucial for student learning (e.g., Lehrer & Schauble, 2006; Windschitl et al., 2008).

While Mr. Fox rarely discussed the nature of models overall, his talk about the affordances and constraints of the models seemed to help his students use them in ways that were intended. However, we do not know if this understanding would transfer to students' use of other models or other contexts in the future. Since tool use is situated and context dependent (Kozulin, 2003; Pea, 1993), it will be important to further investigate what forms of teacher mediation are needed for students to be able to do this. For instance, we still do not know the extent to which explicit discourse about the general nature of models might further help students use a variety of scientific models effectively, since the teachers engaged in little of this type of mediation. Future research with more teachers in different contexts will be important in exploring these questions. Additionally, the fact the Mr. Fox's class was a "challenge" class at his school with students capable of engaging in more open-ended activities may have contributed to his students needing less mediation than Mr. Smith's students. Higher ability learners might be able to better take up mediation provided by a teacher or simply be able to better use the affordances of multiple tools. Future research could further investigate how teachers' mediation might affect students of different abilities to use multiple models for scientific thinking.

Even though scientific models are pervasive in K-12 science classrooms, students often have difficulty using scientific models as tools for thinking and building knowledge without the help of a teacher (Schwarz et al., 2009). As multiple models are employed in future science classrooms, helping students to capitalize on the unique affordances of virtual and physical models will be essential to support their learning. It is important that students understand how to use these types of models together as tools for scientific thinking and for teachers to know how to support this learning. It is well documented that students struggle to understand and utilize scientific models (Schwarz et al., 2009; Treagust et al., 2002) to learn. Yet, little research has investigated how students use both virtual and physical models in an integrated way to learn science (Olympiou & Zacharia, 2012), and even less research has investigated how teachers can mediate students' interactions with these models to support students' scientific modeling practices. Our paper begins to address this gap and highlights the important role of teachers' discussions about the affordances and constraints of multiple models in helping students to understand and use models as tools for scientific thinking.

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