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What's the Technology For? Teacher Attention and Pedagogical Goals in a Modeling-Focused Professional Development Workshop

Abstract. This paper explores the role that technology can play in engaging pre-service teachers with the iterative, "messy" nature of model-based inquiry. Over the course of five weeks, 11 pre-service teachers constructed models of diffusion using a computational animation and simulation toolkit, and designed lesson plans for the toolkit. Content analyses of group discussions and lesson plans document attention to content, representation, revision, and evaluation as interwoven aspects of modeling over the course of the workshop. When animating, only content and representation were heavily represented in group discussions. When simulating, all four aspects were represented to different extents across groups. Those differences corresponded with different planned uses for the technology during lessons: to teach modeling, to engage learners with one another's ideas, or to reveal student ideas. We identify specific ways in which technology served an important role in eliciting teachers' knowledge and goals related to scientific modeling in the classroom.

Keywords. Computational modeling; Simulation; Professional development; Scientific modeling; Teachers; Model-based reasoning

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A growing body of work has documented how constructing scientific models using technology-mediated tools and representations can support or enrich students' understanding of scientific models and modeling practice (Sherin, diSessa, & Hammer, 1993; Stratford, Krajcik & Soloway, 1998; VanLehn, 2013; White & Schwarz, 2005; Wilensky & Reisman, 2006). However, less research has investigated whether such experiences might also support *teachers*' developing understandings of scientific modeling (Louca & Zacharia, 2012). Studies of teacher professional development (PD) suggest that technology-mediated tools should be introduced in an integrated way alongside curriculum, pedagogy, and content (Lawless & Pellegrino, 2007; Mishra & Koehler, 2006; Gerard et al, 2011). However, few studies illustrate what such integration actually looks like, or describe how such integration is expected to influence teachers' developing knowledge over the course of professional development experiences.

In this paper, we explore how integrating a computational animation and simulation toolkit into a PD workshop focused on model-based inquiry might uncover insights into teachers' understandings of (a) scientific modeling, and (b) the role that technology can play in supporting scientific modeling in the classroom. Our approach differs work on teachers' understandings of technology and scientific modeling that rely on questionnaires, interviews, and artifact analyses to classify teachers as possessing more or less sophisticated views. Instead, we argue that teachers are likely to hold complex understandings of scientific modeling, which could manifest differently across different tasks or situations. Because of this, we document teachers' moment-to-moment understandings of modeling *in situ* as they engage in technology-integrated professional development. This allows us to uncover a more complete view of teachers' understandings of scientific modeling, and to explore whether and how those understandings may be elicited by, influenced by, or otherwise connected to technology use.

To do this, we explore 11 pre-service elementary teachers' treatment of scientific modeling as they participated in a five-week professional development workshop. During the workshop, participants used [Name]: a computational toolkit to construct stop-motion animations with craft materials, and computational simulations using programming by demonstration. Working in small groups, they constructed models of diffusion and wrote lesson plans for using [Name] in their own classrooms. We used content analysis to explore the degree to which teacher groups attended to four interrelated aspects of modeling emphasized in the science education literature—determining *content*, creating a *representation*, *evaluating* a model, and engaging in *revision*—when creating animated and simulated models, and when designing lesson plans.

Our findings support that integrating computational simulation into professional development experiences can promote pre-service teachers' engagement with different, and more diverse, aspects of scientific modeling. When building animations, three out of four groups focused on content and representation, and rarely discussed evaluation or revision of their models. When building simulations, all groups (to different degrees) engaged in all four aspects of modeling - especially when they encountered specific representational constraints within the simulation tool. However, the groups exhibited different patterns of attention when planning their own lessons using [Name], and articulated different visions for how [Name] could be used to support scientific modeling in their own classrooms. Our study contributes to this special issue a detailed look at how aspects of teachers' knowledge (in this case, about scientific modeling), and their perceptions of the role of technology in the classroom, can be elicited through the integration of technology into professional development experiences.

Background

Effective teacher professional development should involve an integrated approach that shows how curricular materials, technology-mediated tools, pedagogy and content are interconnected through classroom practice (Lawless & Pellegrino, 2007; Mishra & Koehler, 2006; Gerard et al, 2011). However, still little is understood about what these experiences look like for teachers "on the ground", during the actual implementation of technology-integrated professional development. In this paper we take an in-depth look at one such example: the integration of computational modeling tools into a professional development workshop focused on model-based inquiry. To inform our analysis, we draw from literature on technology integration in professional development, teachers' understandings of scientific models and modeling, and emerging models of teacher knowledge that suggest there may be important moment-to-moment shifts in teacher attention as they work across time and context.

The Integration of Technology into Professional Development

The integration of technology into science curricula is often described as a way to enhance or support *student* learning, but as an additional burden for *teachers* who must learn how to implement and support productive use of these tools in the classroom (Lawless & Pellegrino, 2007). Although technology is sometimes thought of as a distinct component of the knowledge teachers need to be successful, many agree that the introduction and use of technology-mediated tools should be situated within and connected to the particular content foci and pedagogical strategies they are meant to support (Mishra & Koehler, 2006). Part of the reason that such integration is likely to be successful is because there is evidence that teacher orientations toward science education reform are found to co-develop with views and use of technology-enhanced tools meant to support new pedagogical approaches (Campbell et al, 2014).

A recent review of professional development focused specifically on technology-enhanced, inquiry based science teaching (Gerard, et al 2011) suggests that effective professional development: (1) engages teachers with, and asks them to reflect upon, technology-mediated curricular experiences, (2) allows teachers to observe and evaluate data from the enactment of those same curricular experiences with students, and (3) encourages teachers to redesign those same activities in ways that adapt to their own classroom and pedagogical needs, over a sustained period of time that allows for classroom implementation and reflection. Here, we focus on the first phase—engaging with and reflecting on technology-enhanced curricular activities themselves—in eliciting teachers' developing understandings of technology mediated, model-based inquiry in the science classroom.

Pre-Service Teachers' Understandings of Scientific Models and Modeling

In our work, we define *modeling* as the iterative development and refinement of explanatory representations of scientific phenomena (*models*) that can be used to describe, predict, or otherwise reason about those phenomena (Schwarz et al., 2009; Lehrer & Schauble, 2006). The process of developing, refining, and testing models in order to advance the exploration and understanding of scientific phenomena is often referred to as *model-based inquiry*. Model-based inquiry is advocated as a way to expose learners to the nature of science as an iterative theory-building enterprise, supported by ideas, argument, systematic inquiry, and evidence (White & Frederiksen, 1998; Windschitl, Thompson & Braaten, 2008).

While there are nuanced differences in how certain researchers and policymakers conceptualize model-based inquiry, most agree that it is an iterative process that involves a number of interrelated aspects including (1) identifying the important components, processes, and relationships in a phenomenon of interest; (2) representing those components, processes and relationships using formal or informal representational systems such as diagrams, physical artifacts, mathematics, computer languages etc.; (3) evaluating those representations relative to their empirical validity and predictive, explanatory, and/or communicative power; and (4) iteratively revising the model based on those assessments. For the purposes of this paper, we will focus on these respectively as *content*, *representation*, *evaluation*, and *revision*.

Despite increasing calls to support model-based inquiry in K-12 science education (NGSS, 2012; OECD, 2013; Windschitl, Thompson, & Braaten, 2008), there are persistent concerns that teachers may not be prepared to do so (Louca & Zacharia, 2012). Some studies employing questionnaire or survey methodologies characterize teachers' knowledge of modeling in terms of stages or levels of sophistication. These studies have suggested that many teachers hold "limited" (p. 1151, van Driel & Verloop, 1999) or "poor" (p. 888, Danusso, Testa & Vicentini, 2010) conceptualizations of models as merely demonstrative tools or simplified representations of reality.

Other studies, however, suggest that teachers' knowledge about scientific modeling is more complex. Justi and Gilbert (2003) found that during open-ended interviews, teachers expressed a number of different characterizations of models, their uses, their predictive potential, and more. The authors argued that while some teachers did indeed more strongly subscribe to particular views of modeling (such as that models are simplified representations of reality), their overall understandings were more rich and complex than what could be characterized by a single level or set of questionnaire items. Instead, they describe teachers' understanding of modeling in terms of a collection of processes or activities, rather than as declarative knowledge about the nature of models (Justi & Gilbert, 2002). Some educators build on these findings to suggest it is important for teachers to understand multiple types and uses of scientific models (Oh & Oh, 2011; White & Collins, 2011).

While there is limited work specifically exploring the integration of technology into professional development focused on model-based inquiry, Crawford & Cullin (2004) found that after building and testing dynamic models, prospective science teachers exhibited more articulate and critical understandings of scientific modeling. They acknowledged, however, that their study relied on pre and post measures and could not offer specific insights into why such engagement led to teacher learning within the PD context, and noted that even after the intervention teachers still did not exhibit fully robust understandings of scientific modeling. Schwarz (2009) similarly explored the integration of computational supports into science teacher professional development focused on model-based inquiry. She found that teachers were frustrated by the software and did not understand how it was meant to support the modeling process in classrooms. In subsequent PD enactments, Schwarz leveraged an organizing framework that helped teachers structure their thinking about the nature and purpose of modeling as a pedagogical activity. However, analyses of these subsequent iterations of professional development did not return to explore whether teachers understood the role of technological tools in model-based inquiry in different ways with these additional supports in place.

Approaching Teacher Knowledge as a Dynamic System

Given emerging evidence that teachers' understandings of scientific modeling are likely to be complex and multifaceted, we adopt a *resources-based* or *conceptual dynamics* perspective to teacher knowledge and learning (diSessa, 1993; Hammer et al, 2005; Sherin, Lee & Krakowsi, 2012). This perspective suggests that learners—including teachers—already possess a great deal of useful knowledge (including knowledge about models and modeling) that they may not immediately view as relevant in academic contexts. Rather than radically shifting or replacing that existing knowledge, developing expertise involves refining when and how different useful components of knowledge are activated and brought together to make sense of a situation. Supporting teacher growth, then, is less a matter of identifying and repairing deficiencies in teacher knowledge, and more a matter of identifying the contexts and situations in which teachers leverage useful existing knowledge so that it can be more readily elicited and built upon.

Some have started to apply such resources-based frameworks specifically to explore teachers' understandings of models. Gouvea, Jamshidi & Passmore (2014) illustrate how one teacher's understanding of modeling during a multi-year professional development program resulted from small shifts in a number of beliefs about modeling, rather than larger shifts in "level" or general orientation toward modeling. Similarly, Harlow et al (2013) documented a number of pedagogical resources leveraged by pre-service teachers—including resources that might initially appear unproductive, such as believing that "the teachers' role is to provide the right answer" (p. 1108)—that nevertheless helped teachers construct robust understandings of model-based inquiry over an 11-week course. These studies illustrate how close analyses of teacher knowledge development over time can identify specific leverage points in professional development, and specific mechanisms by which teachers activate and expand upon their understandings of science and science pedagogy.

Objectives and Contributions of the Current Study

The goal of this study is to investigate pre-service teachers' understandings of scientific modeling during a multi-day, technology-integrated professional development workshop. Based on existing work, we expect that teachers may hold a variety of understandings about scientific modeling. For example, they may conceptualize modeling as the iterative construction and revision of explanatory representations of empirical phenomena, or as a means to communicate content, or as an idealized version of reality. Given our interest in the dynamics of teachers' knowledge, we are interested in whether integrating technological tools during the workshop may elicit certain understandings of scientific modeling over others. Furthermore, we are interested in teachers' views of the potential of such technology for supporting their own students' engagement with scientific modeling in the classroom.

To capture these dynamics, we explore the degree to which teachers attended to *content*, *representation*, *evaluation*, and *revision* while engaged in PD activities. Attending to these four aspects can offer some insight into how teachers are conceptualizing of modeling at any given time (we describe this in more detail below). We ask the questions:

- What were patterns in participating teachers' attention to *content, representation, evaluation, and revision* during technology-mediated activities in the professional development workshop? And,
- What were patterns in teachers' attention to *content, representation, evaluation, and revision* when designing technology-mediated activities for their own students?

Method

Our data are drawn from a five session (approximately 15 hour), face-to-face professional development workshop conducted in Spring 2014. The workshop was one of a required series designed to expose students enrolled in Elementary STEM Master of Arts in Teaching program at [Institution] to active research projects. The "[Name]" project is a design-based research (Cobb et al, 2003) project sponsored by the National Science Foundation [Grant number blinded] focused on engaging middle grades learners in scientific modeling. The project includes the development of an integrated, technology-mediated representational toolkit that allows users to create stop-motion animations and computational simulations (Authors, 2013), and accompanying activities to engage learners in creating models of familiar molecular phenomena such as evaporation, sound propagation, or smell diffusion.

We designed the workshop with two goals in mind. First and foremost, it served as a context to introduce the pre-service teachers to scientific modeling and model-based inquiry as central practices in the science classroom. Second, as designers, we recognize that practitioners may have different goals than we do (Fishman, 2014), and we were interested in how our tools and activities may be taken up by teachers. Therefore, we captured video data of teachers interacting with the [Name] tool, and sought explicit feedback from participants about how they expected to use such a tool in their own classroom. The intersection of these two goals yielded data that were particularly rich for exploring how teachers engage with, and discuss, the nature of scientific modeling through the lens of technology-mediated tools.

Participants. Eleven pre-service teachers (10 females and 1 male) completed the workshop, and all consented to participate in this study. Of these participants, nine were actively completing practicum experiences in elementary classrooms, one was completing a practicum experience in a museum setting, and one did not yet have an active teaching placement. For the majority of the workshop, participants worked in groups of 2-3 each. Only one participant held a STEM degree, and no participants had significant programming experience. Details about participants' backgrounds, group assignments, and teaching placements are available in Table 1. All participant names used in this report are pseudonyms.

	Participant	Background	Classroom Grade Level
	Egan	Philosophy	3/4 combined
Group 1	Brenna	Biology	Museum Settings
	Kelly	International Relations	5th grade
Group 2	Grace	English, Creative Writing	3rd grade

	Jucelia	Philosophy	2nd grade
	Sophia	Sociology	3/4 combined
Group 3	Stacey	History, Child Development	3/4 combined
	Sara	Puppetry	5/6 combined grades
	Caroline	History, Child Development	5/6 combined
Group 4	Abigail	Religion, Spanish	No active placement
	Heather	English Literature	2nd grade

Table 1. Overview of participant groups, backgrounds and classroom experience.

[Name] Tool. [Name] (Figure 1) is a web-based toolkit to engage middle-school students in a technology mediated modeling cycle: including theorizing, model construction, testing, sharing, and iterative refinement. It enables students to build stop motion animations using paper drawings or craft materials that are photographed in sequence. Those photographs can then be cropped to create programmable objects. To create a simulation, users drag one or more instances of the objects they created onto a simulation screen. Objects can then be programmed by double clicking and directly manipulating the object to define transformation rules (such as changing size, orientation or position). There are also additional menu options to set random behaviors, duplicate or remove objects, or create interactions with other objects on the screen. [Name] follows an *agent-based* paradigm, so every instance of a given object type will follow the same set of programmed rules. Once the simulation can be executed, users can analyze it using measurement and graphing tools. During the PD workshop, teachers engaged with the animation and simulation tools but did not use the measurement tools.

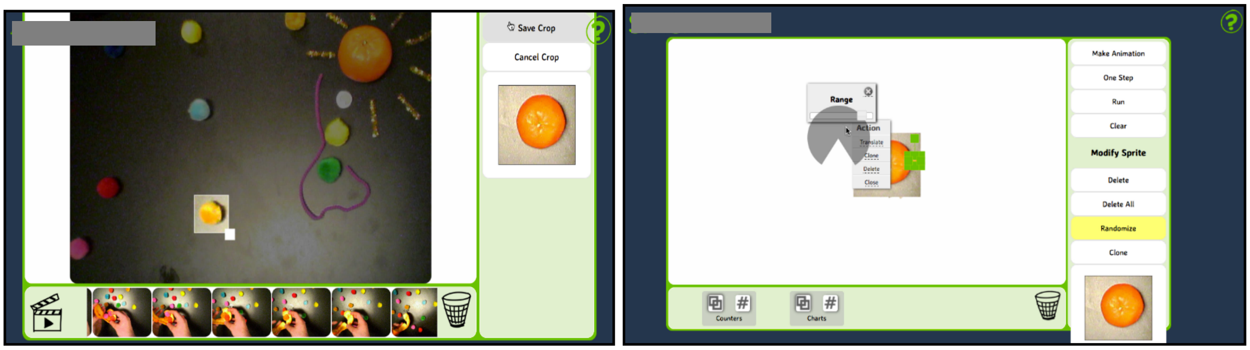

Figure 1. Screenshots of the [anonymized] modeling environment. Users create stop-motion animations (left). They can then crop images from those animations and import them to a simulation environment as programmable objects (right).

Sequence of Activities. Our workshop design, summarized in Table 2, was informed by literature that suggests professional development around technology-mediated inquiry activities should provide teachers with opportunities to (1) engage in and reflect on those activities themselves, (2) observe and analyze data of students, and (3) redesign activities to better accommodate their own needs and students (Schwarz, 2009; Gerard et al., 2011).

For the first three days of the workshop, the teachers used [Name] to do the same modeling activities and curricular materials that we use with students in classrooms. They were offered the option of creating a model based on prompts adapted from existing studies, dealing with sound propagation (from Wright, 2011), diffusion of smell (from Shwartz et al, 2008), or evaporation and condensation (from Johnson, 1998). The teachers chose diffusion of smell because as elementary teachers, they believed this topic would be most relevant and interesting for their own students.

On Day 1, each participating teacher created a drawing representing how they believed smell moved from an orange (source) to a smeller on the opposite side of the room (target). They then worked within their groups to create a stop-motion animation of the "smell spread" process. On Day 2, they reviewed and critiqued one another's animations, revised the animations, and discussed what they thought were markers of "good" models. On Day 3, they created simulations and discussed how different representational forms emphasized different aspects of their models, and allowed for different descriptions of and approaches to the phenomenon. During these first three sessions, we also assigned accompanying readings about models and modeling in science education (Lehrer & Schauble, 2002 and Schwartz et al., 2009; see Table 2).

On Day 4, the teachers were asked to watch and analyze video of a group of sixth grade students who had also created and revised models of smell diffusion across drawing, animation, and simulation (these data are reported in Authors; 2015). We used this video as a context to further discuss what modeling practice might look like in a classroom setting, and how prompts and technologies might promote (or impede) such practices. Finally, on Day 5, we asked each teacher to work in groups or individually to construct lesson plans appropriate for their own students that made use of the [Name] tool and activity sequences. We used these lesson plans as an opportunity to reflect more broadly on the roles of modeling, representation, and simulation as epistemic practices in the science classroom.

	Goals	In-Class Activities	Homework
Day 1	What makes a good explanation? A good model?	Drawing, share out, criteria for explanation, animation, share animations	
Day 2	Exploring the role of content knowledge in modeling	Discuss content objectives, critique animations, revise animation, talk about agent-based modeling, get to the idea of rules of modeling/animation	Lehrer & Schauble, 2002
Day 3	Exploring the affordances and constraints of different types of models	Discuss model-based inquiry, build simulations, reflect upon the activity	Schwarz et al, 2009
Day 4	What do student thinking, progress, and learning look like during model-based inquiry activities?	Watch video of girls doing the same modeling task, discuss modeling practices	Draft of lesson plan
Day 5	Reflecting on modeling and linking multiple model types as an epistemic practice in science.	Review lesson plans, talk about content/pedagogy/skill simulation as a form of knowledge construction	Finalize lesson plan

Table 2. Sequence of activities during the professional development workshop.

Data Collection. Throughout the workshop we collected video recordings of whole-class and small group interactions, written work and digital artifacts, and homework assignments and final projects. During computer-based activities, we used Camtasia (TechSmith, 2010) to record and synchronize on-screen activity and video from each computer's built-in iSight camera.

Analysis. Given that the majority of [Name]-related work and discussion was done at the small group level, we chose to focus on this unit for our analysis. We identified all video and student work at the group level: This included an animation construction session from Day 1, a simulation construction activity from Day 3, and final lesson plans submitted by each at the conclusion of the workshop. To analyze the animation and construction activities, we coded transcribed video of group discourse during the activities, using the raw video data when necessary to clarify codes. To analyze lesson plans, we coded teachers' descriptions of (1) lesson objectives, (2) planned supports during the simulation activity, and (3) anticipated student behavior within simulation environment according to whether they involved content, representation, evaluation or revision.

As described earlier, the primary goal of our workshop was the introduce teachers to model-based inquiry as a means for students to express, refine, and evaluate their understandings of scientific phenomenon. Therefore, we sought to what particular aspects of modeling teachers engaged in and attended to over the course of the workshop. Given the consensus descriptions of modeling in the science education literature, we identified (1) attention to scientific *content*, (2) consideration of how that content should be *represented*, (3) *evaluating* those representations for empirical validity and explanatory, predictive, and communicative power, and (4) *revising* representations as aspects that, together, help us understand how teachers are conceptualizing of modeling. For example, if teachers treat modeling as descriptive and didactic, we would expect them to focus primarily on the scientific *content* and how that content is *represented* during modeling activity. If instead, they are conceptualizing modeling as an iterative process of sensemaking, we would expect teachers to also grant attention to *evaluation* and *revision* in mutually informing ways. Of course, these categories dramatically oversimplify the modeling process; however, they nevertheless provided insight into the extent teachers engaged with scientific modeling, and how that engagement shifted over time and activity. They also allowed us to identify particular moments worthy of deeper qualitative analysis.

We operationalized these four aspects—*content, representation, evaluation,* and *revision* – as content codes as follows. We identified as *content* any explicit conversation about the specific elements, processes, or relationships involved in the scientific phenomenon being explored (in this case, the diffusion of smell). References to smell particles, the process of "spreading" or random motion, and decisions about what elements to include (smell source, air particles, etc.) would all be considered evidence of attention to content. Importantly, we coded any such considerations, not only those that are scientifically accurate or align with convention. *Representation* refers to explicit attention to how elements of the expressed model could or should be visually represented. Evidence of attention to representation include explicit reference to the use of materials, symbols, concern with clarity, and acknowledgment of or frustration with representational constraints (such as the inability to program a particular behavior). *Evaluation* refers to the explicit comparison of expressed model elements or outcomes with empirical evidence, through direct measurement, experimentation, or prior experience with the phenomenon. References to what happens in real life, the success or failure of a model to reproduce expected results in new arrangements, or concerns about the speed or intelligibility of a model all serve as evidence of attention to evaluation. Finally, *revision* refers to explicit consideration of, or application of, changes to the expressed model. Table 3 features examples of each code from each data source; additional examples are described in the results. We also include codes when we present transcript excerpts throughout the Results section.

Aspect of Modeling	Example from Model Construction Activities	Example from Lesson Plan
Content	Brenna: "Like I know eventually we want them [smell particles] to be spread out but like in even waves?" [Group 4]	"Students should be able to identify various sounds." [Group 2]
Representation	Grace: "Maybe we can do like one [particle], and we can even put it like on the orange to it looks like it just came out." [Group 2]	"Students will make a representation of what the inside of a cloud looks like using words, pictures, or symbols." [Group 4]
Evaluation	Stacey: "I think that that's showing, I don't know if you agree with me but I think that definitely shows what we were saying, they're starting to move out but they're also floating." [Group 3]	"Supports for students will include: Images of real rivers at multiple stages of erosion which students can use as reference." [Group 1]
Revision	Egan: "Do we want to like, try to adjust the randomize a little bit just to see? To tweak?" [Group 1]	"Supports for students will include: Feedback from peers after watching the simulation. Reflection time for students to think about things they want to add or change." [Group 3]

Table 3. Examples of *content*, *representation*, *evaluation*, and *revision* codes as identified in modeling activity video, and lesson plans.

We used ChronoViz (Fouse et al., 2011) to annotate and code intervals of video for discussion of content, representation, revision, and/or evaluation as aspects of modeling. Codes could co-occur; for example, a revision to an expressed model that is done because a group wants to change the content represented (for example, a revision to a simulation to add air particles as critical components of the diffusion system), would be counted as both *content* and *revision* simultaneously.

From this content analysis, we constructed timelines to visualize whether and to what extent the four aspects we coded for were reflected in teachers' talk. Each timeline features a row for code. The row is shaded for each 30-second segment of video that included evidence that teachers attended to the relevant aspect of modeling. Figure 2 shows different patterns of teacher engagement that become evident through this timeline representation. It reveals periods of time during which *limited codes* were identified—for example, if participants attended only to content and representation without evaluating or revising their model. It also reveals the extent to which teachers engaged in different aspects of modeling in an isolated or integrated way. For example, participants may evaluate their model with respect to its aesthetic or communicative, rather than scientific value. This would appear in the timeline as *non-overlapping codes*, with attention to evaluation being disconnected from attention to scientific content. Instead, if teachers are engaging in cycles of evaluation and revision that are tightly connected to the scientific content of the model, this would appear as *overlapping codes*.

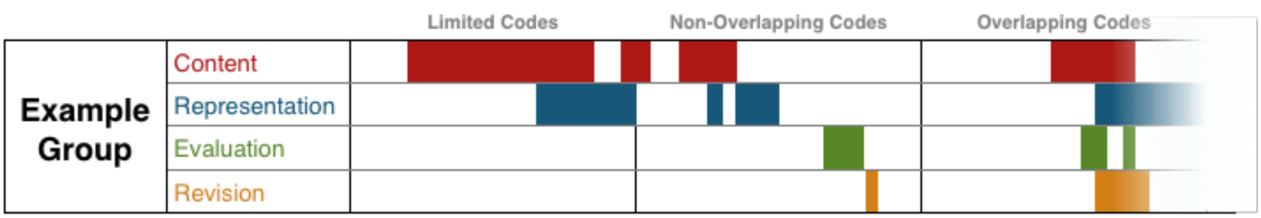

Figure 2. A hypothetic timeline analysis. Patterns of interest include whether only *limited codes*

Results

Here, we present the results of our analysis in two sections corresponding to the two research questions stated above. First, we report patterns of each teacher groups' attention to content, representation, evaluation, and revision in the two technologically-mediated activities in the workshop: creating animated and simulated models of smell diffusion. Then, we report teacher groups' attention to these four aspects of modeling patterns as reflected in the lesson plans they submitted at the end of the workshop. We supplement our content analysis with transcript excerpts that illustrate the nature of participant discussions.

Patterns of Attention During Technology-Integrated Modeling Activities

During the animation session, all four groups attended primarily to *content* and *representation* when constructing their models. Three of the four groups did engage in a brief revision to their model toward the end of the session, however, these revisions were typically to modify how content was *represented* in the model—for example, by adding more frames to slow down the animation or adding detail to their existing model. Figure 1 features coded timeline analyses of all four groups' discussions during the animation activity.

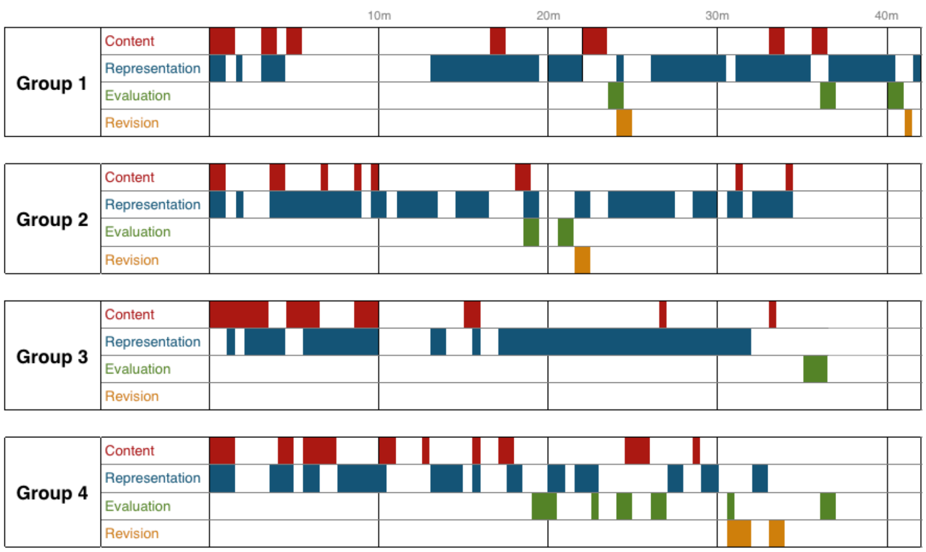

Figure 3. Codes represented in animation session

These patterns of attention suggest that during the animation, teachers exhibited a demonstrative, "simplified representation" view of the modeling activity. They focused the majority of their time on deciding what content to show, and how to show it in a way that was clear and aesthetically pleasing. Even when groups decided to revise their models, they typically did so with these communicative goals in mind. The revisions that groups 1, 2, and 4 each engaged in were related to their desire to make the animation longer, clarify underspecified aspects of the expressed model, or make certain represented processes animate more slowly. This is reflected in the timeline analysis by non-overlapping codes: groups did not often discuss evaluation or revision *at the same time as* content or how that content was represented, and as such these codes rarely co-occurred. The following excerpt illustrates the nature of this disconnection from content:

Group 3, Minute 35:00		**Codes Assigned**
Sara:	[claps]	
Stacey:	Oh look at that, it worked!	*Evaluation*
Stacey:	[laughing] They're so cool!	*Evaluation*
Caroline:	That's awesome. [group high fives]	*Evaluation*
Stacey:	That's so good.	*Evaluation*
Caroline:	Should we watch it again?	
Sara:	It worked so well!	*Evaluation*
Stacey:	It worked, it was so fast.	*Evaluation*
Sara:	I wish it would look like little bugs, though.	*Evaluation*

During the simulation session, we found dramatically different patterns of attention across participant groups. All four aspects of modeling—content, representation, revision, and evaluation—were represented repeatedly in all four group discussions. Furthermore, these codes often co-occurred, that is, the groups engaged in evaluation and revision *with respect to* content or how that content was represented. There was also considerable variation in patterns across groups, with revision and evaluation represented most strongly for Group 1, and most weakly in Group 4.

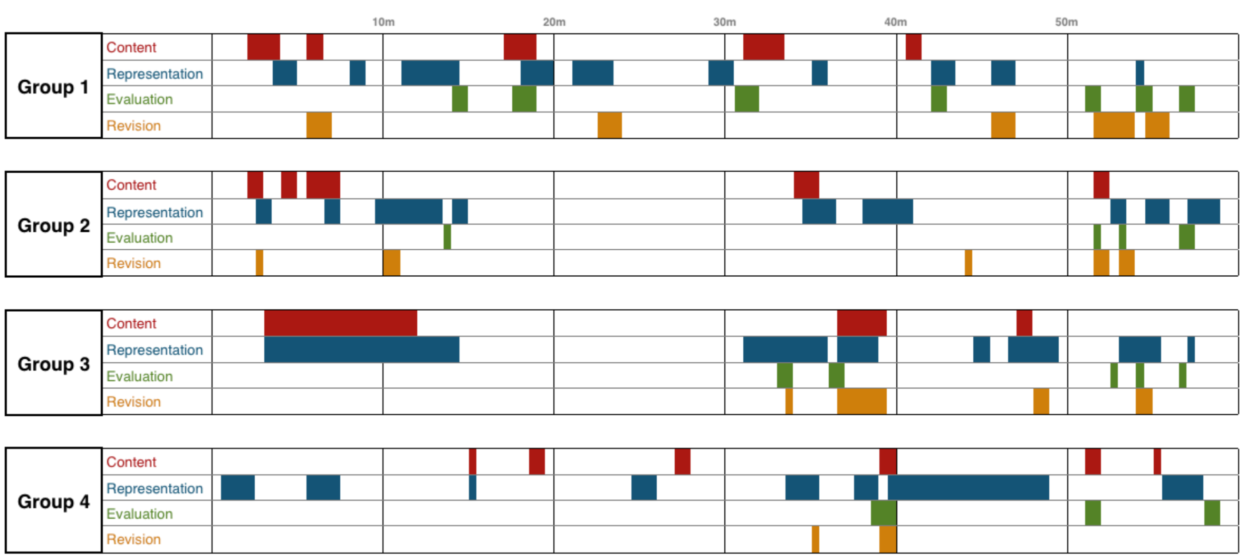

Figure 4. Codes represented by group during simulation session.

Upon deeper analysis, we found that all four groups engaged in cycles of evaluation and revision when they were confronted with obstacles that prevented them from creating their desired expressed model using the simulation tool. The [Name] simulation module was designed to privilege, and hence make it easier to represent, discrete objects, behaviors, and interactions at the expense of visual richness (a full justification for this decision is provided in Authors 2013; 2015). Each group began the simulation construction session with the intention of reproducing their animated model with as much fidelity as possible. The constraints of the simulation environment prevented them from doing so.

Group 1 noticed early on that reproducing their animated model with fidelity would be difficult within the simulation environment, which only allowed a limited number of objects, behaviors, and interactions among objects to be programmed. They adapted quickly to these constraints by deciding within the first 5 minutes of the session to select and import only a few of the most important components of their animated model, and iterate as needed as they were able to get those elements to behave in the ways they wanted.

Throughout the remainder of the session, Group 1 continued to engage in regular evaluation and refinement of their model, granting special attention to the relationship between the mechanisms of diffusion and their chosen representations. About halfway through the session, for example, the group began to evaluate whether a recent revision to their simulation that featured random motion of particles (rather than previously-featured outward-moving particles) was a better expressed model of the phenomenon of smell diffusion:

Group 1, Minute 30:50		**Codes Assigned**
Brenna:	I kind of like this.	*Evaluation*
Kelly:	It looks cool, but it doesn't actually represent, like what we, the way we think it works, right? Like we don't actually think it's random.	*Content, Evaluation*
Egan:	Well, but they are spreading out.	*Evaluation*

Brenna:	They are, and there is a tendency for them to kind of cluster around the middle, just because of—	*Evaluation*
Kelly:	Yea, it's interesting.	*Evaluation*
Egan:	I mean, that might actually capture the phenomenon better than, like this [*hand motion indicating outward motion*]. Like, or somewhere in the middle where they're kind of going out, but they're kind of sticking around. I don't know.	*Content, Evaluation*
Brenna:	Cause I mean this is how diffusion works.	*Content*

Unlike Group 1, who confronted representational obstacles by simplifying their initial simulated model, Group 2 grappled with representational obstacles by revising their simulated model in ways that were not reflective of their understanding of diffusion as a scientific phenomenon. For example, when they were unable to make the "molecules" of smell in their simulation move in different directions to represent diffusion, they decided to create and program a number of distinct "molecule" types, even though they agreed that all smell molecules are fundamentally the same type of object. This is represented in Group 2's coded timeline by a heavy engagement in representation and revision, sometimes without corresponding engagement with content and evaluation. Once Group 2 created a simulation that they thought satisfactorily *visually* represented their intended model of diffusion, however, they began to introduce revisions that they understood to better approximate the behavior of "real molecules". After introducing a random walk component to their model toward the end of the session, they began to evaluate the degree to which this random behavior approximates actual diffusion:

Group 2, Minute 56:30		**Codes Assigned**
Sophia:	Maybe not so much like that.	*Evaluation*
Jucelia:	That's not bad! I like it.	*Evaluation*
Sophia:	They're kind of swirling outward.	*Evaluation*
Jucelia:	That's nice! That's how molecules behave anyway, right? I like it. Floating in the air. Unless we have them more	*Content, Evaluation*
	outward. Maybe we can make them take bigger steps, because they're so tiny that it's taking a long time for them to get out.	*Revision*
Sophia:	Right, so they can move —	*Content, Revision*
Jucelia:	— bigger faster.	*Content, Revision*

Group 3 initially spent a lot of time debating what, specifically, from their animation they wanted to reproduce within the simulation toolkit: for example, whether they should include air currents and diffusion in particular dimensions, or assume the world is a vacuum. When they finally agreed to illustrate smell diffusion in still air, they decided to reproduce their initial animation by selecting multiple "scenes" to include as phases in their simulation. This group experienced obstacles with this approach when they cropped so many objects that the simulation toolkit began to fail, and facilitators during the workshop suggested the group focus on including fewer objects in the simulation.

The group adapted to this obstacle by revising their simulation to include only two entities: the orange that was to serve as the source of smell, and small orange rectangles meant to serve as small particles distributing throughout the space of the simulation. Once they made this revision, the group quickly generated a working simulation. It featured a number of particles concentrated on the orange that, when the simulation was run, would move away from the orange on a random walk. Satisfied that the results of this simulation approximated reality, the group spent the rest of their time exploring additional revisions to the model that would explain additional components of smell, such as that it would "replenish" or continue to emanate from the orange for some time:

Group 3, Minute 36:00		**Codes Assigned**
Stacey:	There we go, now they're definitely, they're definitely distributing. Except for this guy [indicates particle still located in center of screen], I'm not sure about this one.	*Evaluation*
Sara:	But that's ok because smell —	*Content*
Stacey:	— Yea, they'll float.	*Content*
Caroline:	I think that it's showing, I don't know if I agree with it, but I that's definitely showing that we're saying they move out, but they still kind of	*Content, Representation, Evaluation*
Stacey:	Random, yea.	*Evaluation*
Sara:	So now can we do what we were thinking of before,	*Revision*

which is to have new ones come out?

Group 4 took the longest to adapt to the constraints imposed by the simulation environment. Like the other groups, they initially decided to reproduce their initial animated model, which featured discrete smell particles, represented by puff balls, traveling among twisted chenille stems meant to represent air as a wavelike medium. They decided to import the wavelike medium as a background. This introduced difficulty since [Name] is designed to treat all objects included in a simulation as active elements of an expressed model. Any objects Group 4 decided to place over their "background image" detected and interacted with the image as if it was another discrete component of the simulation.

Group 4 spent a long time trying to understand this difficulty, and worked to find solutions that allowed them to preserve the background image. Finally, after considerable struggle with the toolkit, the group decided to adapt to the constraints of the software by selecting a single air wave object from the background image, and animating that object to reflect air as a medium. After learning about the randomize rule, the group decided to abandon their work with the representation of air to instead apply the rule to smell particles as they cloned, creating a burst of randomly dispersing particles.

Group 4, minute 38:30		**Codes Assigned**
Heather:	Ok, just make it, make it dance around a little bit. Yea. Now run.	*Representation*
Abigail:	That's what we wanted!	*Evaluation*
Heather:	[claps] Yay!	
Abigail:	It's perfect. It's exactly what I pictured smell to be like. We didn't even need air waves or a background!	*Content, Evaluation*
Heather:	I'm done. But we should make it centered on there [indicates clementine object as the source of smell].	*Revision*

These results are interesting: teachers participating in the course certainly experienced frustration and considerable limitations while trying to create models using the software we provided. However, the obstacles they faced provided them with opportunities to revise their models, and re-evaluate what constitutes success or validity in those models. In this way, we found that all four groups engaged in more robust modeling cycles during the simulation activity than during the animation activity, including engaging in model revision and evaluation that was directly related to content and predictive power, rather than only comprehensibility.

Patterns of Attention in Lesson Plans

The different levels of evaluation and revision we observed during each group's simulation activity corresponded in interesting ways to the learning objectives and activities they emphasized in their designed lesson plans. Group 1, the group that engaged in the most revision and evaluation of their expressed model over the course of the simulation activity, listed only content goals as the explicit objectives of their lesson. However, in their plans to support and assess students during the modeling activity, they emphasized that students should themselves engage in evaluation and revision, including through empirical investigation and by matching observed data with model predictions. In contrast Group 4, the group that engaged in the least revision and evaluation of their expressed model, listed engaging with content, representation, and revision of models as explicit lesson objectives. However, in their lesson plan, the group only included specific supports and planned assessments focused on content and the level of comfort students experienced when representing their ideas. The lesson plans produced by groups 2 and 3 featured less striking patterns, but focused primarily on representation and revision as the goal of planned activities.

In looking across the four groups' lesson plans, we identified different suggested uses and pedagogical goals for [Name] in the classroom context: as a tool for *modeling* (Group 1: construction, evaluation, and revision in service of a specific exploration of content), a tool for *sharing* (Groups 2 and 3: emphasis on representing ideas and revising based on peer feedback), or a tool for *showing* (Group 4).

	Topic	Listed Objectives	Supports for Students	Expected Modeling Practices
Group 1	What will happen to the path of a pictured river over 100 years?	Students will explore specific mechanisms of erosion and geologic change over long time scales.	Provided physical resources to try out their ideas, evaluate their simulations relative to real observations.	Students should learn that their models can be validated against empirical evidence, and revised to make more accurate predictions.
Group 2	Show how sound travels through a room.	Students will learn to identify various sounds, represent sound propagation, and learn to change their ideas based on feedback.	Support for using the software.	Students will learn to share ideas, revise based on feedback, and compare their models to sound in the "known world".
Group 3	The level of water in an open container lowers over time. Explain what happened to the water.	Students will explore evaporation, learn to represent something that cannot be "seen".	Support for using the software. Scaffolding to encourage students to engage with one another's ideas.	Students will learn to share ideas and revise them based on peer feedback.
Group 4	Show what the inside of a cloud looks like.	Students will think about the nature of clouds and vapor, learn about representation, learn to revise ideas.	Reassure students that the idea is more important than the picture or simulation.	Students should become comfortable expressing ideas.

Table 4. Summaries of lesson plans across groups.

Discussion

This study explored the conjecture that integrating technological tools into models-based professional development can offer a broader view of pre-service teachers' understandings of modeling, and of how they perceive its role in the classroom. This, in turn, can help designers and educators provide new leverage points for teachers to revisit and expand their understandings of scientific modeling, and its role in the classroom. We found that (1) simulation elicited more robust engagement in modeling on the part of participating teachers than animation, and (2) teacher groups exhibited very different views of the role of technology for supporting model-based inquiry in their own classrooms. Here, we discuss possible reasons for these patterns across groups, as well as limitations and alternative interpretations of our findings. We also describe implications both for the design of professional development and for the design of technologies to support model-based inquiry in classroom settings.

Simulation as a Way to Elicit Robust Understandings of Modeling

We found that in general, all four groups exhibited similar patterns of attention when creating animated models. These patterns of attention reflect what the literature typically describe as a communicative or demonstrative view of models and modeling. Three groups engaged in only one cycle of revision, attending to aesthetic rather than scientific factors such as whether the animation was too fast or slow. One group did not revise their animation at all. In brief, teachers focused on what content to include in their models and how, but did not iterate those models so that they better explained or predicted how diffusion works.

However, these same teacher groups exhibited more robust and more diverse patterns of attention when constructing simulations. They attended to evaluation and revision more frequently than during the animation session, and evaluated and revised their models with respect to the scientific content represented. Deeper analysis revealed that these patterns of evaluation and revision emerged especially when groups were confronted with the need to adapt their model to the representational constraints of the simulation toolkit. This evidence lends some support to our driving conjecture that the integration of computational modeling into modeling-focused PD may yield richer, and perhaps more predictive, manifestations of teacher knowledge.

There are a number of reasons that participating teachers may have attended more to evaluation and revision when creating simulations rather than animations. Animation is not testable in the same way simulation is—to create an animation, users define exactly what the end state should look like, whereas with simulation, users do not always know how the rules they define will interact and propagate over time (Sherin, diSessa, & Hammer, 1993; Wilensky & Reisman, 2006). This means that simulation naturally lends itself to evaluation, and unexpected outcomes to revision based on scientific expectation. Simulations are also defined by providing rules about mechanism, or how things work, rather than animation which is defined by how things look. This may have contributed to teachers' joint attention to both content (how things work) and evaluation and revision during the simulation activity. The task order and additional instructional activities we completed over the course of the workshop were also likely to contribute to the patterns we observed. We discuss these in more detail below. However, we note that the fact that the most substantive cycles of evaluation and revision that we observed occurred when teachers encountered specific constraints within the simulation tool suggest that the technology itself had at least some role in teachers' shifts in attention.

Multiple Roles for Modeling Technologies in the Classroom

Although there was some consistency in teacher groups' patterns of attention when working with animation and simulation technologies, there were dramatic differences in how each group envisioned using these technologies in their own classrooms. Group 1 focused on technology as a modeling tool, and their lesson included explicit opportunities for students to test their simulations against evidence and empirical tests and revise them accordingly. Groups 2 and 3 focused on technology as a way to share and critique ideas. Their lesson plans emphasized the importance of critique and revising models based on feedback from peers. Finally, Group 4 focused on technology as a way to show ideas, and emphasize the importance of students becoming comfortable sharing ideas with one another.

There are a number of possible reasons for these different perceived roles for modeling technologies in the classroom. One may have been the relative age and needs of participants' students. The members of Group 1 worked in the upper elementary grades, while members of Group 4 worked in early elementary. Teacher knowledge and comfort with scientific modeling may have also been a factor. It is notable that while all four groups did attend to all four aspects of modeling during the simulation session, Group 1 exhibited the most evenly distributed attention to those aspects, and Group 4 attended to evaluation and revision least frequently. Furthermore, Group 1 included participants who had strong backgrounds in science (a Biology major) and epistemology (a Philosophy major), while Groups 2-4 included participants with less experience thinking about science or the nature of scientific inquiry.

We note, however, that these differences in how participating pre-service teachers envisioned the role of technology in their classrooms do not necessarily represent poor or inadequate approaches to modeling. It is well established that fostering the classroom norms and culture needed to engage in authentic scientific or mathematical practice is critical (Engle & Conant, 2002; Yackel & Cobb, 1996). The objectives identified by participants in our study—being comfortable sharing and being held accountable for ideas, critiquing one another's work, and supporting claims with evidence and systematic inquiry are all necessary components to engage students in modeling.

Limitations and Future Work

This study focused on a small, short professional development session and reported on data only collected during the session. Because of this, one should be cautious about the generalizability of our findings. While we argue that the in-depth, fine grained analyses we present in this paper offer a new perspective into how teacher knowledge manifests in the context of technology-integrated professional development, there are also a number of plausible alternative interpretations of our results. For example, the professional development sessions we report here took place in the same order for all groups, amidst other discussions, readings, and activities related to modeling. The differences we found between the animation and simulation activity may simply reflect learning from these other materials. However, while this explains why groups would exhibit similar, simpler patterns at the start, it does not explain the across-group differences we observed in during the simulation activity, or why these differences persisted in the design of lesson plans.

Another interpretation of these different patterns is that teachers held, even at the beginning of the PD workshop, different ideas about the nature of modeling in science. Even if this was true, it is revealing that these differences did *not* manifest during the animation activity in the way they did during simulation or to an even greater extent in lesson plans. Some of the differences we observed across groups may have resulted from participants' different undergraduate preparation, which ranged from the humanities and social sciences to science fields. However, it is quite typical for pre-service teachers at the elementary level to come from a variety of backgrounds, so one might expect similar diversity of approaches in any professional development designed for elementary teachers.

One next step for this work is to investigate the degree to which teachers' engagement in, and planning for, modeling activities during our PD sessions translate to classroom practice. This is especially important given evidence that professional development that is not sustained for at least one year has little effect on classroom practice (Gerard et al, 2011).

Implications

Our findings point to implications both for the design of teacher professional development, and for the design of technology-based tools to support modeling in the classroom. In terms of teacher professional development, we view this as evidence that integrating simulation into modeling-focused professional development might provide teacher educators a way to elicit more robust understandings of, and engagements in, modeling by participating teachers than drawing or animation alone. Specifically, it suggests that teacher educators should encourage their students to reflect on how representational constraints and obstacles might require a re-evaluation or what counts as a model, why, and how that model might be evaluated.

In terms of the design of technology-based tools to support modeling in the classroom, our analysis reveals that teachers view the role of such tools as extending beyond simply supporting a model development cycle. For example, some teachers' designed lesson plans emphasized the potential role that simulation technology can play in encouraging students to engage with and critique one anothers' ideas, and to revise models based on such feedback, rather than specifically on use of the modeling tool itself as a source of evaluation. Others noted the importance of helping students become comfortable representing their ideas at all. While such goals are not reflective of a "complete" view of modeling, they do reflect important classroom expectations and norms that form a sort of prerequisite for modeling. As such, it makes sense that teachers might expect modeling-focused technological supports to also be useful in supporting modeling-focused classroom norms of interaction and communication.

Conclusions

In this paper, we explored how integrating technology into professional development can reveal new or different insights into teachers' understandings of scientific modeling. Given the dynamic nature of teacher knowledge, we argue that such integration holds potential not only for teachers, who must implement such tools in the classroom, but also for teacher educators, who can use such technology to elicit and build upon pre- and in-service teachers' preexisting knowledge and strengths, and for designers, who can gain new insights into how teachers view the role of such tools in their own classrooms.

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