INTEGRATING INTERACTIVE SIMULATIONS INTO THE MATHEMATICS CLASSROOM: SUPPLEMENTING, ENHANCING, OR DRIVING?

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High-tech tools can be integrated to serve a number of purposes in the mathematics classroom, with different purposes being appropriate for different learning goals. We focus specifically on the various purposes for interactive simulations (sims). This study followed three experienced middle-school mathematics teachers integrating PhET sims into their classrooms for the first time. Using both our data and literature about high-tech tool integration, we offer a framework defining three categories of purpose for sims in the classroom and describe how the teacher positioned the sim to meet that purpose. We also touch on each teachers' beliefs about high-tech tools in the classroom and the link between their pedagogical beliefs and sim integration practices. We believe this framework contributes to the field by defining varying categories of integration for a tool with growing utilization in the mathematics classroom.

Keywords: Teacher Beliefs, Technology, Modeling

The last two decades have seen an upsurge in the number of high-tech tools being introduced in classrooms. However, effective instruction is not guaranteed by mere inclusion of such tools (U.S. Department of Education, 2010). Despite easy accessibility to computers, teachers often integrate them to complement teacher-centered practices, rather than to transform the classroom environment to one that is more student-centered (Cuban, Kirkpatrick, & Peck, 2001). Even when a teacher holds positive views towards the advantages of technology, their teaching practices may be hindered by various classroom constraints (e.g., high-stakes testing, packed curriculum, limited planning time) (Ertmer, 1999; Hew & Brush, 2007).

We focus on one particular high-tech tool in mathematics: interactive simulations. We define interactive simulations (sims) for mathematics as dynamic environments that model a mathematical concept, relationship, system, or phenomenon and allow users to interact with the model within that environment. Sims may facilitate the use of multiple representations, support students' efforts to construct their own knowledge, focus student attention on conceptual ideas, and allow immediate feedback (D'Angelo et al., 2014; Hensberry, Moore, & Perkins, 2015).

Though sims offer great potential to benefit mathematics classrooms, it is how the teacher integrates this tool that will determine its effectiveness. In this article, we define a framework categorizing three different purposes sims serve and describing how the teacher may position the sim to meet those purposes. We also investigate how teachers' pedagogical beliefs influence how they position sims in their instruction. Specifically, we examine how teachers' views on whether sims offered affordances or created constraints to their teaching affected the sim's purpose and positioning in the lesson. We find this research pivotal as we consider a path for technology integration beyond mere tool inclusion, but rather a path where such tools offer opportunities to drive the lesson in new, transformative ways. Our research questions are as follows: (1) What purposes do sims serve in mathematics lessons, and how do teachers position sims to meet those purposes? (2) How do teachers' positioning of sims relate to their pedagogical beliefs about integrating high-tech tools and meeting content standards?

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Conceptual Framework

High-Tech Tool Integration

In lessons involving high-tech tools, teachers assign various roles to such tools. We define this assignment of roles as *positioning*. Harré and Van Langenhove (1998) discuss positioning as the dynamic roles between members of a group. These positions hold varying levels of authority (e.g., leader, follower) that determine who is driving any particular activity in the classroom. Wagner and Herbel-Eisenmann (2009) note that positioning is "immanent," meaning that actors do not hold a permanent role, but instead hold roles that vary depending on the other actors surrounding them. They also describe positioning as "reciprocal," meaning that when one actor takes a leader role, other actors are positioned as followers. In applying positioning theory to sims, the sim's role is dependent on the tasks the teacher has set up for the students. The same sim could be positioned to drive the lesson in one task or to supplement lecture-style instruction in another. Student positioning will be reciprocated by the sim's positioning.

With these two aspects of positioning in mind, we examined integration frameworks from the literature with an eye for how high-tech tools like sims may be positioned in multiple ways and how other actors' positioning is affected. Such frameworks are beneficial in understanding what characterizes expert use of a high-tech tool, as well as the pedagogical beliefs associated with such use. Three frameworks, each outlining multiple categories of integration, guide our understanding of the purposes sims may serve in a lesson and how teachers position sims in the classroom to meet those purposes. The Technology Integration and Curriculum framework focuses on the relationship between high-tech tools and lesson content (Ertmer et al., 1999). The SAMR Model is concerned with the influence of high-tech tools on lesson tasks and instruction (Puentedura, 2010). And a tool-specific framework (featuring interactive whiteboards (IAWs)) provides an example of how specific, high-tech tool features can be considered when describing sophistication in integration practices (Miller, Glover, & Averis, 2005). We have built our framework with each of these three lenses in mind.

Pedagogical Beliefs

Teachers' beliefs about how students learn are manifested alongside their beliefs about how various classroom constraints (e.g., time, resources, testing, student behavior) are appropriately managed (Skott, 2001). These constraints often have both an intrinsic and extrinsic component; the teacher cannot influence their existence, but she can decide how they should best be managed (Philipp, 2007). For the purposes of this paper, we define *pedagogical beliefs* as comprising teachers' beliefs both about how students learn and beliefs about the balancing and resolution of these classroom constraints.

Research on successful technology integration finds successful teachers are confident in their ability to use high-tech tools (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012). These teachers overcome internal barriers by having a well-defined classroom vision that focuses on the affordances such tools offer (Ottenbreit-Leftwich, 2007). Teachers must be motivated for change by taking "positive approaches"—actively and autonomously *choosing* change in their classrooms with high-tech tools (Kershaw, 2016).

Research Methods

Setting

This study took place at a large, public charter school with a diverse student population reflecting state demographics. We focus on three middle-school mathematics teachers new to using PhET sims in their instruction who agreed to integrate PhET sims centrally in some of their lessons. All teachers

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were female and had at least seven years' experience teaching mathematics. Two members of the PhET research team introduced the teachers to the project through two introductory workshops. The three teachers taught a total of 11 lessons involving sims, each of which spanned one or two class sessions. Nine of the 11 lessons were observed and recorded by the researchers. Ten out of 11 lessons were authored by the teachers (with feedback provided from the researchers) and one was authored by one of the researchers.

Data Sources

Data sources consist of videos from end-of-year reflective interviews with the teachers, group meetings involving the three teachers and the researchers, nine lessons involving PhET sims, and six "business-as-usual" lessons in which the teachers did not use sims. We also collected the worksheets and lesson plans from the sim lessons. Finally, email correspondence was collected as supplemental data that enabled us to capture the interaction between the teachers and researchers concerning the teachers' lesson planning progress.

Methods of Analysis

To answer Research Question 1, we first took a grounded approach to define different categories of sim positioning. We began by investigating the recorded sim-based and business-as-usual lessons through a process of open coding in which we charted the lesson structure and noted various teacher instructional methods within each lesson (Savin-Baden & Major, 2013). We also inspected the worksheets teachers provided to students during each lesson and discussed how the various questions and directions contained on the worksheets positioned the sim in the tasks students completed. Through this preliminary descriptive analysis of the lesson videos and worksheets, we were able to define an initial set of sim positioning categories based on the kinds of tasks the students were asked to complete and the instructional methods implemented.

After this grounded analysis, we then took a more theory-driven approach by drawing on extant high-tech tool integration frameworks (Ertmer et al., 1999; Miller et al., 2005; Puentedura, 2010) to situate our framework in the current literature. We used this combination of data-centered and theory-driven analysis to iteratively revise our sim positioning categories. This process resulted in a three-tiered framework that defines three general purposes sims serve in mathematics lessons and describes how the teacher positions the sim to meet those purposes.

To answer Research Question 2, we used multiple-case study analysis (Yin, 2009) to create a profile for each teacher that described the affordances and constraints teachers faced in relation to integrating sims. These profiles were grounded in the interview data and email correspondence and were informed by themes and barriers highlighted in the literature. We completed a cross-case synthesis by identifying similar themes and concerns in the teachers' remarks about sims in the classroom. We also used pattern matching and explanation building to unpack each teacher's pedagogical beliefs and relate those beliefs to her sim positioning tendencies. The first author presented the teacher profiles to the second and third authors for evaluation and further revision. We noted distinct characteristics about each teacher's beliefs and categorized them under cross-cutting themes that seemed consistent across all three (see Table 1). Finally, the researchers mapped the teacher profiles to the framework categories, giving careful attention to how the profiles connected to kinds of sim positioning enacted in the classroom. The results are thus grounded in the available data and represent the consensus of the authors.

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Table 1: Cross-Cutting Themes

Vision	Alignment	Barriers
Teacher's description of ideal classroom environment and the role that high-tech tools/sims should fill in this environment	Remarks about success or difficulty in adapting a sim to meet certain content standards and whether sim integration competed with meeting content standards	Remarks about other difficulties involving sim lessons, such lack of adequate planning time, low self-efficacy, and other concerns about high-tech tools

Results

Supplement, Enhance, Drive (SED) Sim Positioning Framework

Based on our analysis, we created a framework to define different categories of purpose for sims and the respective roles sims are assigned in these categories. Those categories are as follows: Sims positioned to supplement the lesson, enhance the lesson, or drive the lesson. We unpack each category by providing a general description and an example from our data.

Supplement. In this category, the sim aids the teacher in implementing a lesson with no critical differences from the lesson that the teacher might otherwise administer. The sim supplements the learning goals by making the lesson more precise or time-efficient, but the content is unchanged in terms of both depth and scope, and the tasks students complete are fundamentally the same. Sims in this role may act as a direct tool substitute or lesson add-on.

As an example of this category, Arlene used the "Graphing Lines" sim to supplement her lesson. Graphing Lines allows users to create lines on a Cartesian coordinate plane by moving points to define the line and seeing the slope equation adjust automatically. Arlene's two-day lesson had students first complete several rate problems and graph the ratio pairs on a Cartesian coordinate plane. After completing several rate problems on paper, students plugged in the values from the tables into the sim by creating a line with points matching the coordinate pairs they had recorded by hand. Students then recorded the slope values resulting from these lines.

While the sim afforded more precise graphs and verifications of slope calculations, Arlene did not position the sim to expand the range of content addressed or to enrich the presentation of the mathematics beyond what a paper or whiteboard drawing could accomplish. Students' attention was not drawn to the sim's dynamic features; rather, they focused on the static result after having inputted the numbers on their worksheet. The task that students completed with the sim was an extension of the task completed by hand to verify answers. For these reasons, we conclude the sim was positioned to supplement this lesson.

Enhance. In this category, the teacher integrates exclusive sim features to enhance lesson tasks beyond saving time or increasing precision. Opportunities for pattern-noticing and sense-making are made available through the sim's dynamic, interactive environment to enrich the content. Learning goals are influenced by this enrichment but are ultimately accomplished afterwards with the sim serving as a launching vehicle to meeting learning goals. Unique sim features are integrated but do not reinvent the tasks students complete. The content addressed is enriched without being expanded or reoriented to a new perspective.

Becky's sim lesson using "Equation Grapher" fit the enhance description. Equation Grapher allows students to observe dynamic changes in the graph of a linear or quadratic equation as the coefficient sliders are adjusted. Becky's learning goal focused on having students explain how changes to the parameters of a linear equation are reflected in its graph. Becky used this learning goal as an opportunity to emphasize the use of correct vocabulary when describing shifts in the graph. The

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lesson alternated between timed episodes of worksheet-directed sim use and episodes in which selected students responded to closed-ended prompts from Becky.

Even though Becky's lesson incorporated unique sim features (e.g., sliding coefficient scales resulting in dynamic changes to graph), these features served as a vehicle to enhance the lesson's procedural learning goal. The learning goal was addressed during the teacher-centered dialogue between Becky and the students and involved the sim as a common reference point. This task of applying vocabulary was certainly influenced by students' interaction with the sim, but this lesson was not set up for students to accomplish the learning goal solely through their interaction with the sim.

Drive. For this category, the sim serves as an impetus for lesson transformation as learning goals are accomplished in students' meaningful exploration and interaction with the sim. The range of content is expanded and/or an innovative perspective is achieved.

In Carmen's lesson involving the "Graphing Lines" sim, students were instructed to create various systems examples and comment on them. For example, "Do you think these lines will ever cross again? Why do you think that?" At one point, students were asked to create two lines they thought would never intersect. Carmen positioned the sim as a setting for exploration and discovery. As students moved through the worksheet, they collaborated with their neighbors and tried to identify patterns and generalize results. Carmen circulated around the room, challenging students to use precise language and supporting students who were struggling. During a summary discussion, Carmen had students share their answers and pushed for explanations.

Carmen did not position herself to introduce mathematical ideas; she instead created opportunities for students to share sense-making moments they had experienced while working with the sim. Carmen took a facilitating role that encouraged students to articulate their own connections more clearly. This contrasts with an enhance positioning in which the learning goals are accomplished away from the sim and depend on heavy teacher guidance.

Table 2 presents the SED Framework, which builds on the foundational lenses discussed in the Conceptual Framework to elaborate on each category as it applies to sim use.

Table 2: SED Framework

	Supplement	Enhance	Drive
Curriculum	Sim supplements presentation of mathematics by making the lesson more precise or time-efficient.	Sim enhances and enriches presentation of mathematics through engaging graphics and interactive features.	Sim drives presentation of mathematics by facilitating innovative perspectives and/or making new content accessible.
Nature of the Lesson Tasks	Students use sim to check and verify work completed by hand or to complete an unrelated, non-critical task.	Students complete a task that is influenced by their engagement with unique sim features. Sim is common reference point	Students complete task directly with the sim that directly addresses learning goals. Post-sim discussion is student-centered.
Unique Features	Interactive, dynamic features are largely absent from the lesson.	Interactive, dynamic features are present and tangentially influence the completion of the learning goals.	Interactive, dynamic features are present in the lesson and are used by students to directly accomplish the learning goals.

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Sim Positioning and Pedagogical Beliefs

The teachers in our study demonstrated a range of approaches to positioning PhET sims into their instruction. Our findings indicated that sim purposes and positioning were influenced by each teacher's beliefs about whether the sim would bring affordances or create constraints for her teaching. We captured each teacher's perspective regarding sim affordances and constraints by coding her interviews for three emergent, cross-cutting themes: Classroom vision with sim, alignment between sim and content standards, and barriers to implementation. We next present each teacher's profile and connect their profiles to their sim positioning tendencies.

Arlene's profile: Sims as a tradeoff. Arlene's sim lessons consistently positioned sims in a supplementary role. Her vision for high-tech tools was constrained, most notably, by her concern that having students behind screens would detract from teacher–student interaction. She viewed these tools as creating hindrances within her vision of a normal classroom environment. Arlene stated that sims often worked best toward the end of the unit after students are familiar with the content; otherwise students might be confused and fail to engage with the sim productively.

Arlene's views regarding alignment between the sims and the content standards were partly demonstrated in her selectivity with choosing sims. She frequently mentioned that there were not a lot of options on the PhET website for sims that could be used in 6th grade math. She struggled to find PhET sims that she saw as aligned with the content standards or to find a way to adapt the available sims to her needs. Arlene described sim lesson planning as an "awaking moment" where "things just pop up," suggesting that she perceived creating a sim lesson as being more like waiting for a stroke of brilliance rather than systematic planning that she could control.

In summary, Arlene viewed sims as something to accommodate into her lesson. While she frequently talked about being excited to learn more about using high-tech tools and about liking sims, that optimism did not translate into a smooth, sophisticated integration. Arlene's lack of an established vision for how sim lessons could enhance or drive her lessons left her to dwell on concerns about what she might lose by integrating sims. We believe this lack of vision explains her frequent positioning of sims as an extension to traditional, business-as-usual tasks.

Becky's profile: Sims as a visual aid. Becky's classroom vision had sims positioned to enhance the lesson, allowing students to visualize the mathematics they were working on. She remarked that student understanding was facilitated by "seeing" rather than "memorizing." She was excited during the interview as she recounted how students would commonly reference the sim as they motioned and verbally described the shapes and shifts of various graphs. She viewed sims as a means to launch the class into various mathematical tasks later on.

Becky initially struggled to balance PhET recommendations of facilitating student discovery with her perceived need to move quickly through the "packed" Algebra I curriculum. In response to that tension, she felt the need to cut discovery time short and fall back on more traditional, teacher-centered instruction, even though she saw value in letting students discover.

Becky demonstrated a compromise positioning in both of her sim lessons that included opportunities for sim-driven student exploration, but ultimately sidelined the sim as a reference tool during teacher-led discussions. She used students' experience with the sim as a reference point from which to draw from as she directed the class' pivotal discussion times.

Carmen's profile: Sims as an advantage. Carmen, who positioned the sim to drive the lesson in 2 of her 4 recorded sim lessons, articulated a vision that focused predominately on what sims could afford. She described high-tech tools as a central focus of her lessons. She cited the necessity of sims and similar tools for fostering increased student engagement, facilitating opportunity to do mathematics as students might in a real job, and creating space for discovery. She also had strong opinions on sims being best incorporated at the beginning of a unit: "I mean it's not discovery learning if you've already told them all the rules."

Carmen valued student discovery while also acknowledging students' tendency to get off track if left to work unsupervised for too long. She referred to the moments where she brought the entire class together as "checkpoints" to ensure that they were still heading in the right direction and to better understand what they were gathering from their activities with the sim.

Like Arlene, Carmen mentioned limitations to the PhET math sims available at the time; however, she was able find science sims that could be linked to relevant mathematics. Carmen believed that her sim lessons appropriately prepared students for standardized testing. She saw making connections between the standards and available sims as an intriguing challenge. Rather than feel constrained by the lack of sims clearly linked to 7th grade mathematics, Carmen seemed to approach sims with an open mind and found creative ways to relate them to the standards.

While Arlene and Becky both focused on external barriers or constraints related to integrating sims, Carmen primarily focused on the affordances. Barriers were things to be overcome. Her classroom vision for high-tech tools clearly articulated the many affordances of sims and provided motivation for sim-centered lessons. Like Becky, Carmen valued the importance of creating space for student discoveries, but for Carmen, the importance of discovery was not diminished by the need to meet standards. She avoided that tension through her flexible integration of both mathematics and science sims and her ability to facilitate student discussion toward learning goals. Carmen's comprehensive technology vision combined with her flexible sim integration practices explain how she positioned sims to drive her lessons.

Discussion and Conclusion

The SED framework identifies three distinct roles in which sims may be positioned in math lessons and describes the purposes of each role—supplementing, enhancing, or driving. We see this framework serving the research community by applying knowledge of high-tech tool positioning to a growing collection of sims with great potential to drive classroom learning environments.

Although the SED framework consists of defined categories, we do not see the categories as describing a hierarchy of less to more effective. We believe that all three sim roles can be appropriate in different situations. For example, Carmen administered two sim lessons at the driving level, but toward the end of the year, she decided to position the "Graphing Lines" sim as a demonstration tool to introduce the Pythagorean Theorem. That does not mean that Carmen's pedagogical beliefs changed or that she had a fluke lesson; she simply saw an opportunity where one particular sim supplemented her lesson by saving time and aiding in the teaching of a mathematical idea.

In classifying these three teachers as consistently embodying one of our categories, we have chosen to highlight certain moments that we believe will help readers understand each category. But we also recognize that each teacher is complex and aggregately reflects characteristics of all three categories. No teacher fits a perfect pedagogical stereotype, but instead exemplifies both traditional and reform-based teaching practices (Crespo, 2016). Similarly, we believe teachers may articulate pedagogical beliefs from multiple categories of our positioning framework.

There were fundamental differences in how each teacher chose to position sims and in their related pedagogical beliefs. Constraining views about what sims could and could not do narrowed what Arlene and Becky considered to be in the realm of possibility. Enabling a teacher to envision a purpose for sims across the spectrum—from supplementing to driving the lesson—and likewise position the sim to accomplish that purpose seems inextricably linked to whether she sees sims as tools to be administered under constraints or tools that unleash possibilities.

Endnote

This material is based upon work supported by the National Science Foundation under grant number 1503510. Any opinions, findings, conclusions, and recommendations expressed in this material are those of the authors and do not necessarily reflect the views of NSF.

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