A CATALYST FOR CHANGE: A TEACHER'S EXPERIENCES WITH SUPPLEMENTARY CURRICULAR MATERIALS ENRICHED WITH INTERACTIVE SIMULATIONS

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This study aims to understand a middle school mathematics teacher's instruction and reflections on her experiences with supplementary curricular materials enriched with interactive simulations—PhET interactive simulations (sims) and sim-based materials—over two years. We conceptualize Linda's (pseudonym) teaching in terms of both thinking and doing. Regarding Linda as doer, results show significant differences in Linda's instruction, favoring sim lessons compared to non-sim lessons. Regarding Linda as thinker, results show increased attention to problems of practice related to teaching, as well as more productive framing of problems of practice. When these two findings are taken together, shifts in what Linda did and thought illustrate the potential for high-quality supplementary materials to function as a catalyst for change as we map the flow of shifts in what Linda thought and did across two years.

Keywords: teacher learning, interactive simulations, problems of practice, framing

Purpose

In the light of research suggestions, teachers have been tasked to empower students to experience mathematics as a dynamic process of exploration (Boaler & Greeno, 2000; Langer-Osuna, 2017) rather than recalling a static body of knowledge. This task demands teachers to create a fundamentally different learning environment in which teachers "draw information out of students" (Boaler, 2003, p. 4) rather than transferring the information to students. Given the challenges of "moving away from a language of skills ('students will calculate slopes') to the language of understanding ('students will identify common features of linear growth')" (p. 62), to transition from one teaching approach to the other is not an easy task (Horn, 2012).

Even if many teachers engage in informal reflection on their teaching on a daily basis, it might be challenging for teachers to be critical about their instructional decisions and know what to change about their teaching (Hart et al., 1992). Then, the question becomes how to create opportunities for teachers to be critical about what they do in classrooms and "*rethink* their teaching, rather than merely extend their existing practice" (Horn et al., 2017, p. 51). Related to this question, there are some promising research findings on the use of technology (Goldenberg, 2000) and supplementary curricular materials (Matewos et al., 2019) in challenging routine instructional practices and the existing interplay between students, teachers, content, and activity (Zbiek et al., 2007). As a special technological tool, we focus on PhET sims (phet.colorado.edu) and supplementary curricular materials designed around them—sim-based materials.

Teachers often use online supplementary curricular materials with the intention of improving student engagement or learning (Polikoff et al., 2018). However, it is well-documented in the literature that teachers may end up being the ones engaging in learning. For example, in their effort to create a learning environment for students to engage in mathematics in more meaningful ways, Wood et al. (1991) realized how "the classroom had simultaneously and unintentionally become a learning environment for the teacher as well" (p. 588). Building on research on

learning through teaching, teachers often develop their understanding of students, content, and teaching as they use unfamiliar tasks (Leikin, 2005).

Building on the research findings on the potential of supplementary curricular materials and instructional technologies to be catalysts for change (Kaufman et al., 2018; Matewos et al., 2019), this study explores the potential of sims and sim-based materials to motivate shifts in a middle school mathematics teacher's approach to teaching mathematics. For this purpose, we recorded what Linda *did* in her sim and non-sim lessons and what she *thought* about her experiences with these materials over two years. Accordingly, we asked the following questions:

1. How did Linda's instructional practices in the sim and non-sim lessons compare in terms of instructional quality over two years?
2. What problems of practice did Linda identify as she used sims and sim-based materials over two years? How did she frame these problems of practice?
3. What, if any, alignments were there in Linda's identification and framing of problems of practice and her instructional practices as evidence of professional growth?

Conceptual Framework

Given the complexity of teaching, identifying shifts and changes is not an easy task. To capture a complete picture of teacher change, we conceptualize teachers as both *doers* and *thinkers* (Horn et al., 2017) (Table 1). The field of mathematics education made important progress in developing measures for instructional quality based on instructional practices aligned with a reform approach in which the instruction builds on student thinking and ideas (Boston, 2012; Marder et al., 2010; Thompson & Davis, 2014). Some observable indicators of what teachers *do* in the classroom include the rigor of tasks as planned and implemented, teacher questioning (e.g., exploring mathematical relations), accountability of student–teacher and student–student interactions (e.g., linking mathematical ideas), teacher's press for knowledge or thinking, and students providing knowledge or thinking in response (Boston, 2012).

One important resource to get access to teachers' *thinking* is problems of practice that they identify in their talk (Horn & Little, 2010; Vedder-Weiss et al., 2018; Windschitl et al., 2011). For example, 'students' difficulties in mathematics' can be a problem of practice that teachers may identify. In addition to identifying this problem of practice, how teachers frame the problem of practice (Dyer, 2020; Vedder-Weiss et al., 2018) adds an interpretive stance of teachers' *thinking.* Building on the same example, the teacher may frame the problem as an inherent student characteristic (e.g., some students are born with a "math gene" and some are not) or as a lack of learning opportunities available in the classroom (e.g., the context of the problem did not afford students to make sense of the content). These two framings have important consequences for what teachers might do in the classroom.

Aligned with the conceptualization of teachers as doers and thinkers, Clarke and Hollingsworth (2002) presented an interconnected professional growth framework including teacher reflection and enactment, showing the interplay between personal domain (e.g., knowledge), external domain (e.g., curricular materials), domain of practice (e.g., teacher's instructional practices), and domain of consequences (e.g., outcomes of teacher questioning) (Table 1). Our conceptual framework enabled us to capture what a teacher did and thought and the interplay between the two across the domains of interconnected professional growth model.

Table 1: Conceptual Framework

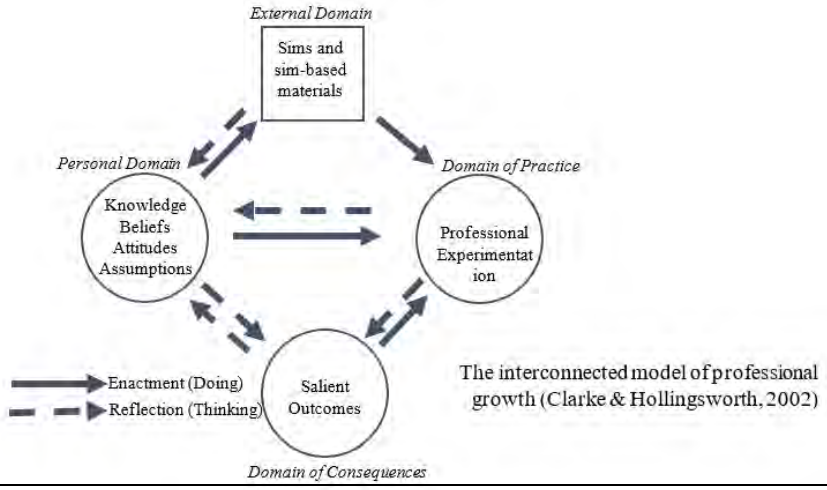
Teacher as a *Thinker*	Teacher as a *Doer*

- What *problems of practice* teachers identify (Horn & Little, 2010; Vedder-Weiss et al., 2018; Windschitl et al., 2011) in their talk.
- The way(s) teachers *frame* the problems of practice (Bannister, 2015; Dyer, 2020; Jackson et al., 2017; Snow & Benford, 1988; Vedder-Weiss et al., 2018) they identify in their talk.

- Instructional quality assessment (IQA) (Boston, 2012) comprised of eight rubrics below:
  - Potential of the Task
  - Implementation of the Task
  - Student Discussion Following the Task
  - Rigor of Teachers' Questions
  - Teacher's Linking Contribution
  - Student's Linking Contribution
  - Teachers' Press for Knowledge or Thinking
  - Students Providing Knowledge or Thinking
- Each rubric is scored on a scale from 0 to 4

Teacher as doer and thinker (Horn et al., 2017)

The Interplay between Thinking and Doing



Methods

Participant

Linda was a middle school mathematics teacher with 11 years of teaching experience at the beginning of the study. During her participation in the study, she was teaching in a Title 1 school in the southeastern United States. Her students were predominantly white (64%), with students who were identified as African American (15%), Hispanic (18%), and others (3%). Overall, Linda shared many characteristics not uncommon with other middle school mathematics teachers. She identified her teaching as teacher-centered. She was knowledgeable about student-centered pedagogy based on her professional learning experiences (e.g., undergraduate program). She was struggling with student engagement and looking for some resources to increase student engagement. At the start of this research, Linda participated in a two-day workshop where she was familiarized with PhET simulations and provided with sample sim-based lessons. Besides the workshop, she received no structured support (e.g., professional development). The instructional materials designed by the PhET research team and other teachers were accessible to her through the website. She decided which sims and corresponding sim-based materials to use.

Our goal with our case study selection was to understand a middle school mathematics teacher's use of supplementary curricular materials enriched with interactive simulations. Yin (2018) highlighted the goal of doing case study research is to develop "analytic generalizations"

(p. 23), which are defined as "The logic whereby case study findings can apply to situations beyond the original case study, based on the relevance of similar theoretical concepts or principles" (p. 349). We believe this case study can inform other teachers in situations beyond Linda's case and make connections to the theory of teacher learning (LeCompte et al., 1993).

Data Collection

We observed and recorded lessons in two of Linda's 7th grade math periods during the 2017–2018 and 2018–2019 school years. In the first year of the study, Linda taught three sim-based lesson modules, each comprised of 3–4 consecutive days of teaching with the use of sim-based materials, in one of her class periods in which data were collected. She taught the corresponding non-sim modules in another class period in which data were collected. The data set included video recordings of seven sim lessons and six non-sim lessons in Year 1 and 10 sim lessons in Year 2. Linda used the same sim-based modules in the first year and second year of the study. We also conducted interviews with Linda at three time points: the beginning of Year 1, the end of Year 1, and the end of Year 2, as well as collected written reflections after she taught each sim-based module (Figure 1).

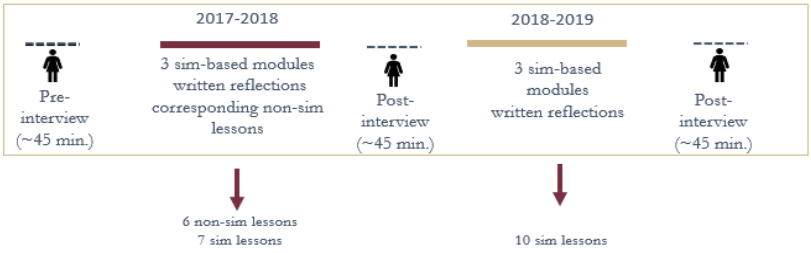


Figure 1: Data Collection

Data Analysis

To answer the first research question on what Linda *did,* we used video recordings of Linda's teaching in sim lessons and non-sim lessons. We analyzed the instructional quality of each lesson by using IQA (Boston, 2012; Matsumura et al., 2002) and assigned a rubric-specific IQA score for each type of lesson—sim lessons versus non-sim lessons. To examine whether sim lessons resulted in statistically higher levels of instructional quality, we ran seven permutation tests (one for each of our seven IQA rubrics) (Good, 2013).

We used Linda's written reflections and interviews to answer the second research question on Linda's thinking. We separated them into idea units (Jacobs et al., 1997; Tekkumru-Kisa & Stein, 2015). In each idea unit, we identified what problem of practice (Horn & Kane, 2015) Linda discussed and how she framed the problem of practice (Dyer, 2020; Snow & Benford, 1988). We organized our coding chronologically to identify shifts across two years.

To answer the last research question, we examined the interplay between what Linda did and thought as she started using sims and sim-based materials over two years by using the interconnected model of professional growth framework (Clarke & Hollingsworth, 2002). This framework enabled us to map the flow of change between four domains: external domain (e.g., sims and sim-based materials), personal domain (e.g., knowledge, assumptions), domain of practice (e.g., sim-based activities used by the teacher, questions the teacher pose to students), and domain of consequences (e.g., student engagement, student learning).

Results

Differences in What Linda Did in Class with a Focus on Instructional Quality

Regarding Linda as *doer*, results showed that IQA scores were significantly higher in sim vs. non-sim lessons on four rubrics: implementation of the task, student discussion following the task, rigor of teacher's questions, and teacher's linking (Table 2). More specifically, in sim lessons, Linda encouraged students to elaborate their thinking and explore mathematical meanings with some effort to make connections between their contributions. Thus, students had more opportunities to develop their own strategies and present their work and their thinking to the whole class. Please note that we excluded the rubric on the potential of the task because sim-based materials were provided to Linda. We were interested in what Linda was doing with sim-based materials when she used them in her lessons rather than the potential of these tasks.

Table 2: Mean of IQA Rubric Scores in Non-sim and Sim lessons

	Potential of the task	Implement ation of the task	Student Discussion Following Task	Rigor of Teachers' Questions	Teacher Linking	Student Linking	Teacher Press	Students Providing
Non-sim Lessons (Year 1)	2.50	2.00*	1.50*	1.50*	1.33*	1.17	2.17	2.00
Sim Lessons (Year 1 & Year 2)	3.80	3.20	2.80	2.87	2.07	1.80	2.93	2.67

*$p < .05$.

To give the reader a sense of what Linda's sim and non-sim lessons looked like, we briefly describe the lessons focusing on the same topic—scale factor, part of the unit on proportional relationships. In the non-sim lesson, Linda went through a worked example in the book, which comprised of three steps as follows: (1) write the scale as a fraction, (2) convert the fraction to a unit rate, (3) multiply the unit rate by actual length to find the missing value. In contrast, the sim lesson started with an open-play time for students to explore how the sim works (click to open the sim). After exploring the sim, Linda asked students to create a figure on the sim and scale it by a scale factor of 2 and 3, as well as to predict how the perimeter and area of the figures would change as the original figures were scaled. After students compare their predictions with the actual values (the sim can show the actual values of the perimeter and area of the figures with a click on a button), Linda asked students:

> What do you think happened to the area? Why was not as simple as it is, just multiplying it [the area of the original figure] by 3?... Any ideas of why you think that is? It [the scale factor] definitely affected the area differently? (Sim Lesson on Scale, Year 2)

Based on these qualitative descriptions, in the non-sim lesson, finding the missing values asked in the problems was the end of the discussion. Whereas, in the sim lesson, the scaled figures served as the data for students to develop a rule that explains how scale factor affects the perimeter and area of a shape—if they affect the perimeter and area differently, what was the reason? While these contrasts between sim and non-sim lessons were important, Linda's takeaway from this experience was worthwhile, as discussed below.

What Problems of Practice Linda Identified and How She Framed Them?

Regarding Linda as *a* thinker, there was a shift in Linda's attention from problems of practice related to students to problems of practice related to teaching. At the beginning of the study, Linda heavily focused on problems of practice related to students (e.g., students not engaged)

(89% of the problems of practice). In Year 2, by contrast, Linda focused on problems of practice related to *her* teaching (e.g., ask good questions) (62.5% of the problems of practice) (Table 3).

Table 3: Number of Problems of Practice Related to Students and Teaching

	Number of Problems of Practice related to Students (%)	Number of Problems of Practice related to Teaching (%)	Total Number of Problems of Practice (%)
Pre-Interview	8 (89%)	1 (11%)	9 (100%)
Year 1	13 (52%)	12 (48%)	25 (100%)
Year 2	9 (37.5%)	15 (62.5%)	24 (100%)

Aligned with Linda's increasing attention to her teaching, in the post-interviews, Linda talked about her struggle in asking good questions, limitations in her content knowledge, and how much to tell students to scaffold their thinking (Table 4a and 4b). In addition to these new problems of practice emerged, Linda's description of these problems got more sophisticated. For example, in Year 1, Linda framed the importance of teacher questioning especially for students who might struggle, whereas, in Year 2, Linda reframed teacher questioning as a tool to support student learning, not only for students who struggle but also for expanding student thinking as she said:

> Coming up with the right questions to ask them. Like both ends of the spectrum … when they are struggling but also … when they think they got it … there is always more. I mean, aside from the generic "explain your thinking," … how to encourage them… and also like "can you find another way," … for ones who are struggling but also when they do get it. And how to push them but not just give them more work to do. (Post-interview, Year 2)

Although these percentages show a shift in Linda's attention, it is important to note that an increase in the number of problems of practice related to teaching does not necessarily indicate a positive change over time. It is equally important to examine Linda's framing of these

Table 4a: Problems of Practice Related to Students Over Two Years

	Students not engaged	Students not motivated	Students have a mindset of "I am not good in math"	Some students struggle more	Some students play schooling	Do not notice patterns Linda expects	Struggle with working on open-ended tasks	Struggle with understanding math concepts (e.g., coming up with a rule)
Pre-interview	3	1	2	2	0	0	0	0
Year 1/Sim	0	1	1	2	1	2	6	0
Year 2/Sim	0	0	1	0	1	0	4	3

Table 4b: Problems of Practice Related to Teaching Across Two Years

	Attend student experience	Avoid mis-conceptions	Know your goal	Anticipate student struggle and responses	Teacher's limited content knowledge	Ask good questions	Decide how much to tell	Anticipate what students know	Step back
Pre-interview	1	0	0	0	0	0	0	0	0
Year 1/Sim	1	2	1	1	2	3	2	0	0

Year 2/Sim	0	0	1	1	1	9	1	1	1

problems of practice related to students and teaching. Our analysis of Linda's framing of these problems of practice showed evidence that Linda's conception of what it meant to be a good student was challenged. She was surprised about students who were typically on track and following instructions because these students struggled with new expectations in sim lessons and expected Linda to tell them what to do. In a post-interview, Linda said,

> Often in the sim activities, they [students] are asked a question that they do not know how to answer right off their head. So, there is an immediate pushback; well, I do not wanna do this, I do not wanna do this… but when I just stop giving them how to, there has been a difference. (Post-interview, Year 2)

Linda was also surprised by students who were typically unengaged because in sim lessons, these students made important contributions to the discussions. In her written reflections in Year 1, Linda wrote, "The students that surprised me the most were the students that are usually the 'unmotivated' ones." Thus, Linda's prior framing of students who were *on track* or *unengaged* was challenged. Another reframing was about student engagement. In the pre-interview, Linda expected sims and sim-based materials to increase engagement; however, she was not clear about what aspects of sims would make that difference. Starting in Year 1, Linda framed student engagement in connection to the curricular materials she used. In a post-interview, Linda said,

> I realized that me going over problems at the board and asking the students questions required little from the students… That is what I am trying to say in a sim lesson versus a non-sim lesson. There is not much opportunity for them to contribute their ideas, whereas, in sim lessons, there is much more opportunity, which is also a part of more engagement. (Post-interview, Year 2)

Students were contributing their ideas and figuring things out by themselves rather than following Linda going over the problems on the board, and that was the reason for increased student engagement in sim lessons.

The Interplay Between What Linda Did and Thought as Evidence of Professional Growth

Regarding the last research question, we identified three flows of change evident in the interplay between what Linda did and thought over two years. The first flow of change was about Linda's seeing students as more capable and problematizing who were motivated and engaged. As Linda started using sims and sim-based materials—external domain—she practiced not telling students what to do and encouraging them to explore—domain of practice. In response, she observed students figuring things out by themselves, especially the ones who were considered unmotivated and unengaged—domain of consequences. This consequence created an opportunity for Linda to reflect on her assumptions about who was engaged and motivated to learn mathematics and what students were capable of doing—personal domain. Overall, induced from her observations in her classroom, Linda started seeing students more capable and student engagement in connection to the curricular materials she used.

The second flow of change started with Linda stepping back and listening to students—domain of practice. Consequently, students brought different ideas and thoughts, often different than what Linda expected to hear—domain of consequences. Linda repeated her questions hoping that students would bring what she expected to hear; however, this did not happen, and Linda ended up limiting student thinking by asking close-ended questions through the end of the

lessons—domain of practice. This flow was reflected in Linda's personal domain as an expressed struggle in asking good questions to leverage student thinking. Importantly, not telling students what to do created a need for some practices that Linda was not readily comfortable with, and she showed ownership of the problems of practice (e.g., asking good questions).

The final flow of change was about teaching mathematics with a conceptual orientation. As Linda started using sims and sim-based materials, the nature of mathematics they were working on became more about the concepts, relations, and connections rather than procedures and computations. Thus, in sim lessons, she more frequently asked "why" and "how" questions to uncover student ideas—domain of practice. In addition to Linda, students also asked questions to make sense of the mathematical ideas and concepts (e.g., "What does random mean?") part of their effort to make sense of the mathematics. However, Linda and her students struggled in coming up with those explanations—domain of consequences—and this struggle was resolved with Linda's shift to procedural focus through the end of the lessons. Again, Linda identified this as a problem of practice related to her personal domain by identifying limitations in her content knowledge in connection to her struggle in maintaining the mathematical focus on conceptual ideas—personal domain. Although Linda was not readily capable of maintaining the conceptual focus, she developed an awareness and, more importantly, a need to improve her content knowledge.

Discussion and Conclusion

These findings support the recent findings on the potential of supplementary curricular materials in creating shifts in teachers' instructional roles and doubt induced by their own teaching (Matewos et al., 2019). Linda started using sims and sim-based materials with the intention of increasing student engagement; however, "the classroom had simultaneously and unintentionally become a learning environment" (Wood et al., p. 588) for her as well. She showed some shifts in her instructional practices, in the problems of practice she identified, and in her framing of these problems of practice. Using sims and sim-based materials created a rich experience where she problematized her previous conceptualization of student engagement as stable and connected it to the nature of work students are tasked to do. She started seeing students as more capable, became critical of her own instructional practices and content knowledge, and identified areas for improvement. These shifts, especially seeing students as more capable and student engagement in connection to what students are tasked to do, are important steps to engage in efforts to improve teachers' instruction (Jackson et al., 2017).

As discussed before, creating learning environments aligned with reform recommendations—more equitable learning opportunities for students—is not an easy task for teachers (Horn, 2012). Teachers' experimentation with student-centered pedagogy as they use well-designed supplementary curricular materials can create opportunities for teachers "to *rethink* their teaching" (Horn et al., 2017, p. 51), identify what particular practices need to be improved in their own teaching, and a desire to improve (Horn & Kane, 2015). Given the teachers' more frequent use of online resources and social media with the pandemic (Aguilar et al., 2021), teachers are becoming more aware of the available resources on online platforms. Thus, there is a need to understand the influence of these materials on what teachers *do* in their classrooms and what teachers *think* about their experiences with these materials. Doubt induced by teachers' own teaching and ownership of problems of practices (e.g., asking good questions) has the potential to further teachers' efforts to improve their instructional practices. In future work, we aim to explore the role of interactive simulations, tasks, and student contributions in affording the shifts we identified in what Linda did and thought over two years.

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