Supporting the integration of technology and computing in middle school mathematics classrooms: Three studies exploring student and teacher engagement

By

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Overview of Three-Paper Dissertation

As the use of technology is becoming ubiquitous in everyday life, digital tools for learning are also becoming more common. About 95% of teachers use technology to support learning (Vega & Robb, 2019), and mathematics courses are a common context for technology integration. For instance, the National Council of Teachers of Mathematics believe "it is essential that teachers and students have regular access to technologies that support and advance mathematical sense making, reasoning, problem solving, and communication" (NCTM, 2015). The use of technology is also embedded throughout the Common Core State Standards for Mathematics (Kitchen & Berk, 2016; National Governors Association Center for Best Practices & Council of Chief State School Officers, 2010; Polly, 2013), highlighting policy-makers' efforts to include more technology in K-12 mathematics.

However, many of the tools teachers consider the most effective for learning are actually the least used in classrooms, such as digital creation tools and tools that supplement content learning, especially in mathematics (Vega & Robb, 2019). At the same time, granting students access to the digital tools is not sufficient: teachers are critical in mediating how tools are used (e.g. Roschelle et al., 2010; Suh, 2010). Given that so many teachers are making use of technology in their classrooms, research is needed that will help teachers integrate technology effectively, especially those tools that teachers most want to use but have difficulties incorporating into their classrooms.

The overall purpose of the three studies in this dissertation is to begin to better understand what happens when teachers integrate digital tools into their mathematics classrooms and how to better support teachers in their use of educational technology. All three papers include middle school mathematics teachers using educational technology for the first time. The first two papers focus on the integration of a digital game to enhance mathematical engagement in specific content that has been shown to be difficult for students to understand - ratio and proportion. Digital games are an example of one of the tools that teachers consider effective in mathematics classrooms to supplement or deepen understandings but might have difficulty implementing (Stieler-Hunt & Jones, 2017; Vega & Robb, 2019; Watson & Yang, 2016). Paper three involves a tool for digital creation - another type of technology that teachers find highly effective but have difficulty implementing in their classrooms. Many teachers also lack access to effective professional development which supports the integration of educational technology (Code.org et al., 2020; Vega & Robb, 2019; Wachira & Keengwe, 2011; Yurtseven Avci et al., 2020). My third paper begins to address this issue by exploring in-service teacher professional development, specifically a PD focused on a set of activities to teach programming through integration with mathematics and art. The rest of this overview describes each of the three papers in greater detail.

The first two papers describe how teachers supported mathematical engagement during a video game, *Boone's Meadow*, which was designed to be integrated into lessons on ratio and proportion in middle school mathematics classrooms. Although many teachers are using digital games in their classrooms (Fishman et al., 2014), a choice supported by research demonstrating the potential of digital games for learning (Barab et al., 2007; Clark et al., 2016; Gresalfi & Barnes, 2015; Pareto et al., 2011), it is unclear what integration actually looks like for these teachers. The goal of these two papers was to begin to understand different ways teachers integrate games into their classrooms, especially while supporting disciplinary thinking. The papers focus on an example of a video game that was designed to incorporate teacher-student interactions rather than to replace instruction. The analyses draw on Gresalfi and Barab's (2011) framework for supporting different forms of engagement: procedural, conceptual, consequential, and critical.

Specifically, paper one - *The Role of Digital Games in a Classroom Ecology: Exploring Instruction with Videogames* (Bell & Gresalfi, 2017b) - compares how four teachers integrated the video game into their classrooms for the first time. The focus is on understanding diversity of implementation and exploring how teachers' practice around the game enhanced or decreased students' opportunities to learn. We ask: 1. How do teachers support students' mathematical thinking? 2. Who has the mathematical agency to solve problems? And 3. How do teachers interact with students around the narrative of the game? The primary source of data includes videos and transcripts of teachers' interactions with students during gameplay. Findings point to the central role that teachers play in establishing the overall learning ecology around the game. Not surprisingly, students learn more and have more opportunities to engage with the mathematics content of a game when teachers interact with students during gameplay, but it is important for those interactions to be around both mathematical content and around the narrative of the game. Students also engage more deeply in the content if they are given agency to develop their own solutions to problems in digital games.

One factor that can potentially contribute to the integration of a digital game in a classroom is teachers' experience with the game. More knowledge or experience with a technology contributes to successful implementation and affects teacher practice (Ertmer & Ottenbreit-Leftwich, 2010; Ertmer et al., 2006; Mumtaz, 2000). Therefore, paper two - *Teaching with Videogames: How Experience Impacts Classroom Integration* (Bell & Gresalfi, 2017a) - delves deeper into one of the teachers from paper one to see how her experience using the game over two years impacts the ways she integrates the game into her classroom. We ask: 1. How does the teacher's support of students' mathematical thinking change as she gains experience with the game? 2. Who has the mathematical agency to solve problems, and does that change as the teacher gains experience with the game? And 3. How do the teacher's interactions with the students around the narrative of the game change as the teacher gains experience with the game? Data includes videos of the teacher interacting with students around gameplay, pre and post-tests, and interviews with the teacher. Findings illustrate that even one prior experience teaching with the game changes the teacher's practice. When the teacher implements the game for a second time, she is able to support deeper mathematical engagement in conversations with students, make more connections between the mathematics and the narrative of the game, and give more problem solving agency to students during gameplay. However, some issues with the assessments are identified to better capture students' thinking around the game.

Paper three - *How Flexible Designs Supported Productive Disciplinary Engagement in a Teacher Professional Development for Computer Science* - also centers on teachers integrating technology with mathematics, but instead of a video game, this paper focuses on mathematics teachers learning computer programming. The teachers participated both as learners and as teachers preparing to implement a curriculum integrating programming and mathematics for middle school students. The analysis explores a professional development with four in-service mathematics teachers learning to program in NetLogo, participating in embodied programming activities, then editing a curriculum to co-teach programming in a summer camp. The data comes from the first year of a multi-year project studying the integration of computational thinking and mathematics. In the first two papers, I focus on student engagement, while the third paper explores teacher engagement during professional development. Using productive disciplinary engagement (Engle & Conant, 2002) as the framework for analysis, I ask: 1. Is there evidence that productive disciplinary engagement (PDE) occurred? If so, what did PDE look like in this context? And 2. How were the principles of productive disciplinary engagement (problematizing, authority, accountability, and resources) embodied? Like the other two papers, the primary source of data includes videos and transcripts, along with teacher interviews and surveys. Findings point to the importance of flexible designs to support productive engagement, especially in professional development for in-service teachers. This study illustrates that productive disciplinary engagement can occur when experienced teachers learn computer science. It also provides an example of how the four principles of PDE can be embodied in a teacher professional development context and points to the importance of designing for flexibility by focusing on teacher expertise, authority, and choice.

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CHAPTER I

THE ROLE OF DIGITAL GAMES IN A CLASSROOM ECOLOGY: EXPLORING INSTRUCTION WITH VIDEOGAMES

This chapter is adapted from the previously published book chapter listed here, with the permission of the publisher, the editors and my co-author, Melissa Gresalfi:

Bell, A., & Gresalfi, M. (2017). The role of digital games in a classroom ecology: Exploring instruction with video games. In M.F. Young & S.T. Slota (Eds.), *Exploding the castle: Rethinking how video games and game mechanics can shape the future of education*, (pp. 67-92). Information Age Publishing.

Introduction

Over two decades of research have established that computers, on their own, do little or nothing to change the nature of teaching and learning (Mouza, 2008; Penuel, 2006; Pierson, 2001; Windschitl & Sahl, 2002). However, there are exciting examples of what can happen when technologies are integrated into classrooms in ways that attend to the intersection between particular forms of technology, teachers' ideas about and knowledge of technology, and the particular content area that is being taught (Mishra & Koehler, 2006). Digital games in particular have demonstrated potential for supporting student learning across disciplines (Barab, Sadler, Heiselt, Hickey, & Zuiker, 2007; Pareto, Arvemo, Dahl, Haake, & Gulz, 2011; Squire, 2006). The diversity of game designs makes it challenging to pinpoint exactly why games support learning, but much has been said about the potential of games to motivate and capture student attention (Dickey, 2007; Garris, Ahlers, & Driskell, 2002; Lepper & Malone, 1987; Malone & Lepper, 1987), to situate disciplinary learning in realistic contexts (Barab, Pettyjohn, Gresalfi, Volk, & Solomou, 2012; Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Clarke & Dede, 2009), and to offer consistent and substantive feedback about reasoning (Gresalfi & Barnes, 2015; Mayer & Johnson, 2010; Nelson, 2007; Rieber, 1996). Three recent meta-analyses compared learning from digital games to a non-game control for k-12 students and generally found that digital games led to higher cognitive outcomes (such as learning and retention) than traditional instruction (Clark, Tanner-Smith, & Killingsworth, 2015; Vogel et al., 2006; Wouters, Van Nimwegen, Van Oostendorp, & Van Der Spek, 2013). These general findings support the enthusiasm around integrating game technologies into educational environments. However, all reviewers noted the small number of articles that they were able to include in their reviews based on the paucity of literature that compares games to other learning environments (Young et al., 2012).

Despite their potential, integrating digital games into schools is not simply a matter of making the tools available (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012; Ertmer, Ottenbreit-Leftwich, & Tondeur, 2014; Takeuchi & Vaala, 2014). How and when games are used in relation to other instruction, the role that teachers take as they are playing the game, and how the game is integrated into the overall classroom ecology all play a role in whether and what students ultimately learn. Indeed, it could be argued that research that simply examines the "efficacy" of games misses out on what will ultimately be more generative, that is, the potential of games to transform (for good or for ill) the overall classroom learning ecology (Barron, 2004, 2006).

Currently very little is known about the integration of games into instruction, although we do know that teachers are using digital games. A recent survey of teachers (Fishman, Riconscente, Snider, Tsai, & Plass, 2014) found that 57% of survey respondents used games in their classrooms at least once a week, and over 80% say they are moderately comfortable using games in their classrooms. However, teachers also reported many barriers to implementing digital games, including the challenge of finding games that connect to the school's curriculum (47% of respondents), and being unsure about how to integrate games into instruction (33%). What integration looks like for these teachers, however, remains unclear.

This paper seeks to contribute to our emergent understanding of what teaching using videogames can look like, focusing on a specific example of a videogame that was designed to incorporate teacher-student interactions, rather than to replace instruction. In this context, the teacher's role is central to implementing the game successfully. In this study, our goal was to understand diversity in implementation, and to explore whether and how teachers' practice around the game enhanced or decreased students' opportunities to learn. Here we are not talking about whether or not teachers implemented the game *with fidelity,* as is a common concern. Fidelity typically refers to the extent to which an innovation is used in ways that are consistent with the goals or plans of the designer. Instead, the decision to adopt this type of curricular innovation is, by Rogers and Murcott's (1995) definition, an "optional innovation-decision," in that teachers often have the autonomy to adopt, and use, innovations on an individual basis. Although an innovation offers potential benefits that the current practices do not, it by definition also involves newness and therefore a degree of uncertainty (Rogers & Murcott, 1995). Furthermore, what might appear beneficial to the designer might not be perceived as beneficial by the teacher. Clearly, adoption of a curriculum is not a one-to-one mapping or "rubber stamping" of the designed environment to the

K-12 classroom. Instead, teachers must always adapt the curriculum for their local use, and this adaptation occurs as part of their goals, their students' needs, and the overall instructional context.

It is with this understanding that we investigated the use of an immersive videogame, called *Boone's Meadow.* Boone's Meadow is an interactive problem solving experience that involves engaging mathematical ideas related to ratio and proportion, important and difficult concepts for middle school students to understand. Using four cases selected from three different schools, we explore how teachers integrated the game into their instructional practice by focusing on teachers' interactions with students during gameplay and the types of mathematical engagement afforded by those interactions. There are myriad questions to be posed about the role of the teacher in using and supporting games. As an initial starting point, we focused on teachers' interactions with students that specifically related to supporting their mathematical problem solving during gameplay. We think about problem solving as a movement between understanding the constraints of the problem, thinking mathematically about how to solve the problem, and understanding the outcomes of choices (depicted in the narrative of the game). Specifically, we investigated teachers' roles in supporting problem solving during gameplay by addressing the following research questions:

1. How do teachers support students' mathematical thinking?
2. Who has the mathematical agency to solve problems?
3. How do teachers interact with students around the narrative of the game?

We addressed these questions by analyzing four case study teachers using Boone's Meadow. The findings illustrate how teachers with similar resources can implement a game very differently, which points to needed improvements to the supports teachers receive when using games for learning.

Theoretical Framework

Much of the videogame research that has been published to date examines the "effect" of the game on student learning. This lens fails to account for how the introduction of a game into a classroom necessarily interacts with other elements of the classroom system, including the teacher. For that reason, in our research on how to design games to support student learning, we focus not only on the students' use of the game and students' learning, but also how other elements of the classroom system connect to the use of the game or are transformed or changed by the introduction of the game (Davis & Sumara, 1997; Osberg & Biesta, 2008). We conceptualize the classroom activity as only one aspect of the learning environment, based on significant prior work that has demonstrated that elements of the classroom system work together and influence one another in order to support (or thwart) student learning (Gresalfi, 2009; Hand, 2010; Wortham, 2004).

In this paper, we consider two elements of the classroom system in relation to how the game was used and ultimately what students learned through playing it. The first has to do with what students already know and understand about the mathematical content targeted in the game. It is well known that individual students' prior knowledge about a particular topic strongly influences their problem solving behavior (Bielaczyc, Pirolli, & Brown, 1995; Chi, Glaser, & Rees, 1981; Jonassen, 1997; Lee & Chen, 2009). Relatedly, we also know that when students are struggling with a problem, teachers are often tempted to step in to scaffold their thinking, thus reducing the cognitive load of the task (Henningsen & Stein, 1997; Stein, Smith, Henningsen, & Silver, 2000). Taken together, it is reasonable to assume that, when working on complex mathematical problem solving tasks, the individual students' prior knowledge is likely to influence both how students act on the opportunities in the game and how their teachers support students' interactions with the problems in the game. Relatedly, the second element we consider includes teachers' interactions with students around problem solving and the narrative of the game. Together, these elements of the classroom profoundly influence to what extent a game can support learning.

The Game

Boone's Meadow is an immersive game that involves exploring a virtual world through the first-person lens of an avatar. Students play the central protagonist who has applied for a job as "wildlife rescue assistant." The core problem that students work to solve involves figuring out how to rescue and save an injured eagle, a task that is based on part of the *Adventures of Jasper Woodbury* series (Cognition and Technology Group at Vanderbilt, 1997). As in the Jasper series, students must decide which information they need to use to solve a complex, multi-step problem, which has the potential to link to other curricula (we have seen teachers incorporate literacy standards, social issues, and some basic science concepts).

In the Boone's Meadow digital game, an eagle is located in a remote field, and the only way to get to her in time is by flying an ultralight (a small plane). Players must choose between three different ultralights to use based on fuel efficiency, speed, and payload (how much weight it can carry). Players must also plan the route to take to pick up the eagle and safely return her to the veterinary clinic in time, choosing whether or not to stop for gas along the way. Figure 1.1 shows a picture of the map of the game world with the veterinary clinic, the gas station, and Boone's Meadow as the three main points. If players decide to stop for gas once or twice at Hilda's Gas Station, they can choose to fill up the gas tank all the way or only partially. Cost is also a minor factor in the game, as the veterinary clinic hopes to save money to open a new animal shelter. Players have two attempts to save the eagle, and they can use the second try to find a more optimal solution (taking less time, using less gas, and spending less money) or test another route. The game includes several short writing prompts with questions about the choices students made in the game (route, plane, gas), whether or not they saved the eagle and why, and what convincing recommendation they would make to the veterinarian clinic as a final plan for saving the eagle. Teachers can respond to or return students' answers to the prompts using an online platform referred to as the Teacher Toolkit. Teachers can also use this platform to monitor students' progress in the game. The game is designed to take approximately 3-4 hour-long classroom sessions, including supportive instructional time.

Saving the eagle requires making calculations that involve ratio and proportion. Multiplicative reasoning is a foundational idea of ratio and proportion (Lobato, Ellis, & Zbiek, 2010), so we designed the specific problems students needed to solve so that they could be reasoned about multiplicatively, without needing any formal instruction about algorithmic solutions.

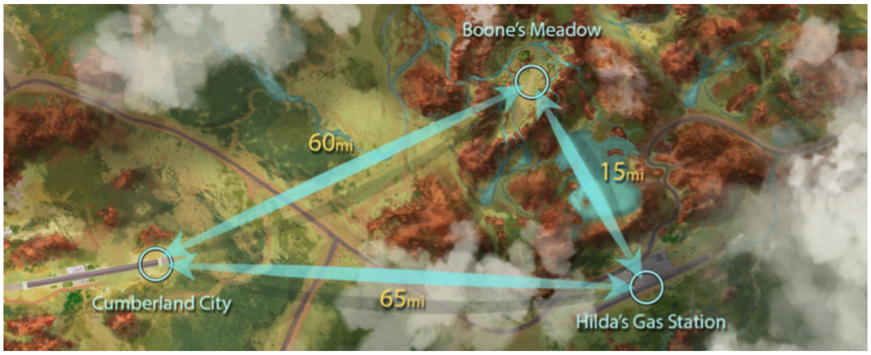

Figure 1.1: Map of the game world in Boone's Meadow.

Methods

For this paper, we employed a contrasting case methodology (Stake, 1995). We chose to look in-depth at a small number of cases because of our interest in broadening our understanding of not *whether* teachers are using games in their classroom (they clearly are: e.g. Fishman et al., 2014), but rather how games are used differently in relation to elements of the classroom ecology, including existing classroom practices, students' prior knowledge, etc. We selected contrasting cases for their potential to illuminate important patterns that can be hidden when looking at a small number of similar cases. For this paper, we selected four teachers who worked with students who had very different prior knowledge about multiplication. Two seventh grade teachers, Ms. Lynn and Ms. Donald, taught students with very limited prior knowledge about multiplication, as indicated by the teachers and evidenced by the presence of "multiplication charts" on all students' desks that were used and referenced repeatedly throughout the implementation. In contrast, Mr. Doyle and Ms. Vann taught 6th grade students with higher levels of prior knowledge about multiplication; the majority of students were able to generate benchmark multiplication facts without support. Calculators were available to students in all four classrooms, although we did not encourage their use.

Prior knowledge of students is just one of many factors that could have been selected for these contrasting cases. We were especially interested in prior knowledge because we observed that what students already understood about math influenced how teachers interacted with students during gameplay. We wanted to explore this in more detail, particularly as games are often used *either* as "remediation" or "reward." Thus, understanding how teachers connect with the content of the game based on what students already know has implications for the ways games are integrated into instruction.

Setting and Participants

This analysis focuses on four teachers: Ms. Lynn, Ms. Donald, Mr. Doyle, and Ms. Vann (pseudonyms). To recruit teachers, we first contacted principals and asked if they had teachers who might be interested in participating in our study; they connected us with math teachers at their schools, and we followed up with a meeting to describe the goals and content of the game. Importantly, we made it very clear that participation in this study was completely voluntary and we discouraged principals who felt that all teachers should be using the game. Thus, teachers who worked with us did so because of interest.

All four teachers had more than 5 years of teaching experience, but this was their first time implementing Boone's Meadow. Ms. Lynn, Ms. Donald, and Mr. Doyle participated in a professional development session held by the researchers the summer before they implemented the game which lasted a full day; Ms. Vann, who played the game in Year 2 of the study, met separately with researchers during planning time. The PD session and the face-to-face meeting generally covered the same content, although in the PD session, teachers also had time to play the game, while in the face to face session, teachers were expected to play the game separately on their own time.

In the PD session and face-to-face meeting, we talked about students' difficulties with ratio, what teachers wanted students to learn from the game, the problems students solve in the game, and how teachers might fit the game into their curricula. The teachers wanted their students to develop good procedural understandings of the traditional ratio algorithm, and to be able to solve problems involving rates. The design team had no commitment to teaching or using the traditional ratio algorithm, and in our meeting and PD session we actively encouraged teachers to instead support students' reasoning about unit ratios and the ways they scale (Lobato, Ellis, & Zbiek, 2010). Likewise, there was quite a bit of discussion about the fact that the game did not include a single correct answer, and that in fact there were multiple ways to be right (and save the eagle) and multiple ways to be wrong (and kill the eagle). Some teachers thought this was a great feature of the game that would keep students' interested (Lynn, Donald, Vann). Others worried that this might confuse students and cause them to give up (Doyle). In sum, although the teachers were excited to use the game and had high hopes for their students' use of it, it was clear that their vision of what high quality use of the game would look like was not identical across teachers, nor was it perfectly aligned with our own vision.

We also gave all four teachers a set of teacher materials, which we designed. The teacher materials included pacing suggestions, including which "missions" in the game students should complete each day, questions to guide whole class discussions before and after gameplay each day (involving ratio, components of the narrative, and the use of tools in the game), suggestions for thinking conceptually about ratio, and supplemental mathematics problems to discuss rates, ratio, and proportion with students. The game implementations lasted three to four days in each classroom. Ms. Lynn and Ms. Donald used the problems from the teacher guide quite frequently; Ms. Vann used the pacing guide by informing her students how far they needed to get each day; there was no evidence that Mr. Doyle relied on the teacher materials in any significant way.

Ms. Lynn and Ms. Donald both taught 7th grade mathematics at school A. They each taught three mathematics classes every day, and they had large class sizes: over 30 students in each class. 92% of students in school A were eligible for free or reduced lunch, 30% were English language learners, and only 26% scored proficient on the state math test.

In contrast, Mr. Doyle taught four classes of 6th grade mathematics at school B. 32.7% of school B's students identified as economically disadvantaged, only 2% were English language learners, and 64.4% scored proficient or above on the state math test. His class size averaged 25.

Ms. Vann taught two 6th grade math classes at school C. 64.7% of school C's students received free or reduced lunch, 3.4% were English language learners, and 70% scored proficient or advanced on the state math test. Her class size also averaged 25. From this school data, we can expect to see that Ms. Vann's and Mr. Doyle's students had higher levels of prior mathematical knowledge before playing the game. In fact, Ms. Lynn's and Ms. Donald's 7th grade students struggled with multiplicative reasoning, which is a foundational concept for understanding ratio and proportion. On the other hand, Ms. Vann's and Mr. Doyle's 6th grade students had strong multiplicative reasoning skills and good procedural understandings of ratio before playing Boone's Meadow.

Data Collection

Each day during the game implementations, a camera was set up in the back of the room to capture the teacher's talk and actions. A researcher panned and zoomed the camera to follow the teacher's movements. The entire class period on game days was recorded, so even if students only played the game for 10 minutes, the entire 50 to 140 minute class period was recorded (length of classes varied because of modified schedules and time students spent traveling and settling in between classes). Students were also given pre- and posttests to check their understandings of ratio and proportion. While data were collected for all class periods taught by teachers, we chose to analyze the class for each teacher with the highest pre- to posttest change. Since research already tells us about the difficulties of using games in classrooms, we wanted to focus on the classes that demonstrated the most learning gains in order to talk about what worked successfully. We interviewed a subset of teachers informally after the game implementations both years, and we used their responses to triangulate our findings. We also collected data on students' interactions using separate cameras on student groups, written work students produced in game notebooks, and students' progress and responses to questions in the game. However, since our goal was to analyze the teachers' practices, we mostly focused on the videos from the teacher cameras in this analysis.

Analysis

As previously stated, our goal in this paper is to understand how teachers integrate and potentially transform the game in their classroom instruction by considering how teachers supported student problem solving and learning as they played the game. To address these questions, we analyzed the pre and post assessments as an initial indicator of learning, and then looked in-depth at the interactions that took place between the teachers and students. We used common coding schemes across all four classrooms, because our questions, for this paper, were comparative.

Assessments. A team of four researchers developed a system for scoring the pre- and posttests. Most questions were scored on a scale of 0 to 2, 0 being totally incorrect or no answer, 1 being correct calculations or procedures or evidence of thinking but some sort of error in the answer (either a calculational error or missing labels so it was not clear what their numbers referred to), and 2 being completely accurate. Using the pre- and posttest scores, we calculated the average pre- to posttest change for each class. We used these results to determine focal classes to analyze further.

Videos. To answer our questions about how teachers implemented Boone's Meadow in their classrooms, we transcribed the talk from the teacher videos from each of the focal classes. With our research team, we watched the teacher videos several times along with the transcripts to identify major themes around how teachers' supported students' mathematical problem solving during gameplay. This helped us begin to identify codes that we could analyze further with each research question to determine what the teachers did differently during gameplay.

For our first research question, we asked about how teachers' support mathematical reasoning during gameplay. To answer this question, we analyzed the talk in the interactions between teachers and students during gameplay. The teachers' talk was coded by utterance defined as a turn of talk (a switch in speakers) or a change in the person the teacher was addressing (if Ms. Lynn said something to student A and then said something else to student B, that was counted as two separate utterances). We used student responses to make sense of what the teachers were saying in context, but we coded teacher utterances because we wanted to capture what the teachers in particular were doing. Drawing on Gresalfi and Barab's (2011) work, we distinguished between four different types of mathematical engagement: (1) procedural – following procedures correctly, (2) conceptual – conceptual understandings of procedures or ideas, (3) consequential – examining how the procedures used relate to the outcomes, and (4) critical – questioning why one procedure should be used over another. Four researchers coded all the transcripts, and instances of uncertainty were discussed until we reached agreement.

We were also curious about how much time teachers actually spent interacting with their students during gameplay. The research team reviewed the teacher videos for the focal classes again and noted the video timestamps each time the teacher sat at her desk, got up from her desk, spoke with a researcher, talked with a student or group of students, ended a conversation with a student, wandered around the room, etc. From these timestamps, we calculated the total time each teacher spent on these activities during gameplay to compare how much time teachers spent interacting with students.

Our second research question asked about the agency to solve problems in the game. To answer this question, we coded the gameplay transcripts by utterance again for teacher agency or student agency. We defined agency by asking who has the ability to decide how to approach a mathematics problem, which procedures to use, and what to do (Gresalfi, Martin, & Hand, 2009). We counted an utterance as *teacher* agency if the teacher gave an answer or specified a procedure to follow, meaning the teacher had the agency to solve the problem. We coded an utterance as *student* agency if the teacher asked an open question that gave the student agency to decide how to approach the problem and which procedures to use. Four researchers coded all the transcripts again, and uncertainties were discussed until we all reached agreement.

For our third research question, we asked how teachers interacted with students around the narrative of the game since the narrative provided the main source of feedback for students' problem solving in the game. The major narrative outcome of the problems in Boone's Meadow is saving the eagle, so we looked for instances when teachers interacted with students around saving or killing the eagle. We marked entire interactional episodes that involved talk about the eagle outcomes. An episode started when a teacher or student reacted to saving or killing the eagle and ended when the teacher changed to a different topic or left to talk to another student. These episodes were marked by two researchers, and uncertainties were discussed for agreement.

Findings

Here we present findings about each case and contrast the teachers with the goal of beginning to identify petite generalizations (Stake, 1995) about the integration of videogames into classroom practice. Table 1.1 shows the average pre- and posttest scores from each teacher's classes. The pretest scores reveal information about students' prior knowledge, which matches the reported state test scores from each school. Ms. Lynn and Ms. Donald's students had the lowest average pretest scores. The students in school A generally struggled with concepts of ratio and proportion, in large part because they had little familiarity with multiplicative reasoning. As an example, all students in these 7th grade math classes had a laminated multiplication chart on their desks, which they referenced frequently when doing multi-digit multiplication and division problems. In contrast, Mr. Doyle and Ms. Vann scored above 53% on the pretests for this study. They already demonstrated good procedural understandings of ratio before playing the game, and appeared to be comfortable reasoning multiplicatively. Ms. Vann's students scored highest on the pretest, but did not show any learning gains on the posttest, which we discuss below. Ms. Lynn's, Ms. Donald's, and Mr. Doyle's students all showed significant learning gains on the posttest. In what follows, we explore how teachers interacted with their students around the mathematics in the game and how that might relate to students' prior knowledge.

Table 1.1: Average pre and post test scores for the four teachers' classes.

Teacher	Average Pre Score	Average Post Score
Ms. Lynn	36%	51.9%
Ms. Donald	36.2%	42.6%
Mr. Doyle	53.2%	57%
Ms. Vann	67.8%	67.3%

Question 1: How do teachers support students' mathematical thinking during gameplay?

To investigate how teachers supported students' mathematical reasoning, we coded teachers' talk for the types of mathematical engagement it afforded. Table 1.2 includes the code counts for each teacher across the four types of mathematical engagement (procedural, conceptual, consequential, and critical). We found that over 80% of the talk for each teacher was coded as procedural. This means that when teachers interacted with students around the mathematics in the game, teachers mostly created opportunities for students to engage procedurally with the mathematics, and teachers provided very few opportunities for students to engage more deeply. In particular, Mr. Doyle had the most math talk out of the four teachers, but all of his talk was procedural. The following interaction between Mr. Doyle and one of his students exemplifies how much of his talk afforded procedural engagement[1]:

1. Mr. Doyle: Rate is miles per hour. Distance is what?
2. Student: 60.
3. Doyle: Divided by
4. S: XXXX
5. Doyle: Rate. 60 miles. 60. Distance divided by rate, so, so it's gonna be 60 miles, and 90 miles an hour
6. S: So divided by 90.
7. Doyle: Yeah. 90. 90. So distance, 60 divided by rate.

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[1] Transcript conventions: S indicates talk from a student, X's represent talk that is inaudible, … indicates a pause, and gestures/actions are written in brackets *[in italics]*.

In lines 1-7 above, Mr. Doyle helped a student calculate the time it took a plane traveling at a speed of 90 mph to go 60 miles. He immediately proceduralized the problem by giving the student the definition of rate as "miles per hour" in this problem, then in line 3 told the student to divide. In line 5, Mr. Doyle gave the student the procedure to follow: "distance divided by rate," and he even filled in the numbers ("60 miles, and 90 miles an hour"). He did not ask the student to think conceptually or critically about the problem. For instance, he could have asked why you divide to find the answer or if there is another way to solve the problem. Instead, Mr. Doyle's talk afforded procedural engagement in the mathematics. This was inconsistent with the way these problems were modeled in the teacher materials, and the ways the game presented ratio. Instead, this framing of ratio was consistent with previous practice in Mr. Doyle's classroom, as further evidenced by Mr. Doyle frequently stating, "remember how we did that kind of problem?"

Table 1.2: Number of teacher utterances coded for affording types of mathematical engagement during gameplay in focal classes.

Teacher	Procedural	Conceptual	Consequential	Critical	Total
Ms. Lynn	68 (93.2%)	1	4	0	73
Ms. Donald	57 (82.6%)	9	3	0	69
Mr. Doyle	105 (100%)	0	0	0	105
Ms. Vann	17 (85%)	1	2	0	20

Ms. Vann had very little math talk with her students (only 20 utterances across all four days of gameplay in her focal class). Since her students scored high on the pretests and already had strong procedural understandings of ratio, perhaps she thought her students could solve the game's ratio and rate problems on their own. However, like Mr. Doyle, when she did talk with students about the math, almost all of her talk afforded opportunities to engage procedurally.

It is interesting to note that Ms. Lynn and Ms. Donald, whose students had the lowest levels of prior knowledge, had the most utterances affording conceptual and consequential engagement. For example, when talking about one of the planes whose average maximum speed was 60 miles per hour, the following exchange occurred:

1. Ms. Donald: No, listen to what I'm asking. I'm asking you to find out how many miles you would go in one minute.
2. Student1: So, do we divide it.
3. Donald: Would that make sense?
4. Student2: One.
5. Donald: Why is it one?
6. S2: Because one is one minute.

7. Donald: Because one minute would be one mile, right?
8. S1: Yeah.

In the exchange, Ms. Donald worked with her students to think about how many miles an ultralight would travel in one minute based on its speed in miles per hour. Instead of telling the student which procedure to follow, Student1 suggested using division in line 2 and then Ms. Donald questioned why that might make sense in line 3. This was coded as conceptual engagement because Ms. Donald created an opportunity for the student to think about why you might divide to find the answer, rather than just following the procedure. She also followed up with the student's correct answer of one mile in one minute by asking "why is it one?" in line 5. In a few other exchanges like this, Ms. Donald went beyond reviewing procedures and helped her students think deeper about why the answers or procedures made sense.

Along with mathematical engagement, we also captured how much time teachers spent interacting with students during gameplay in Table 1.3. Not surprisingly, Ms. Vann, who had the fewest utterances coded as mathematical talk, also spent the least amount of time talking with her students during the game. Instead of interacting with students, Ms. Vann spent the majority of her time sitting at her desk, monitoring students' progress with the online Teacher Toolkit or working on other things. Ms. Vann mostly let her students play the game without help or management, an indication of Ms. Vann's confidence in her students' abilities to solve the problems in the game.

Table 1.3: Percent of gameplay time teachers spent doing different activities.

Teacher	Percent of Gameplay Time Talking with Students	Percent of Gameplay Time Sitting at Desk
Ms. Lynn	69.04%	6.93%
Ms. Donald	81.42%	5.37%
Mr. Doyle	88.99%	3.5%
Ms. Vann	7.33%	81.70%

In summary, we observed some variation among the teachers in terms of the amount of time they spent talking with students and the kinds of questions that they asked. Perhaps surprisingly, interactions did not seem to be predictable based on students' prior mathematical reasoning. Across all four cases, almost all teacher talk emphasized procedural reasoning, despite the fact that the game and teacher materials emphasized justification and developing unique strategies to solve the problems. The interactions that we observed were consistent with teachers' practices before using the game, and thus it appeared that teachers incorporated the game into their existing classroom routines. This is entirely consistent with previous research about technology integration and attempts to change teaching practices more broadly.

Question 2: Who has agency to solve problems in the game?

Figure 1.2 displays the results of our codes for teacher and student agency of teachers' talk, showing significant variations between the teachers. As we showed above, Ms. Vann spent little time interacting with her students about the math in the game, so she also had very few utterances coded for agency. On the other hand, Mr. Doyle spent almost all of his time interacting with students. But Mr. Doyle's talk involved almost exclusively teacher agency, meaning he often told students the answers to problems when they asked questions or he told students which procedures to follow. In several instances, Mr. Doyle took control of students' computers and typed in the answers for them. For example, the following was an interaction that began with a student asking for help:

1. Mr. Doyle: Okay. Let's start filling this stuff. So your load is 78 pounds. You've got to use XX maximum fuel, 12 gallons. *[starts murmuring to himself]* 7 miles per gallon XXXXX. Confusing. Distance. *[Mr. Doyle orients the computer towards himself, begins clicking on the screen]* Fuel used is distance divided by miles per gallon.
2. Student: So 60
3. Doyle: 60 divided by miles per gallon
4. S: Seven
5. Doyle: *[pointing to a calculator]* Calculator
6. S: *[getting a calculator and beginning to type into it]* 60 divided by
7. Doyle: 7. Yeah, so this is a mixed number, so 8. Change to *[takes the calculator from student]* fraction decimal. 8 and 4/7 *[Types answer into the computer]* Time is equal.
8. S: Distance and rate
9. Doyle: Distance divided by rate

In this example, Mr. Doyle worked with a student on calculating the fuel used by one of the ultralights, using the procedure distance divided by miles per gallon (or fuel efficiency). In line 1, Mr. Doyle oriented the computer towards himself and typed in answers for him. Mr. Doyle also gave the student the procedures to follow, saying "fuel is distance divided by miles per gallon" and then specifying "60 divided by miles per gallon" in line 3. In these interactions, agency was distributed to the teacher, who made decisions and determined which procedure to use. Student agency in this interaction was limited to typing in numbers and observing the execution of the correct procedure.

Ms. Donald and Ms. Lynn had more balanced levels of student and teacher agency, meaning about half their utterances were coded as student agency and the other half as teacher agency. When students asked for help, both teachers responded by asking open questions that allowed students to think about their own solutions. In particular, Ms. Lynn scaffolded students' problem solving by first giving students the agency to solve the problems, then specifying some elements to pay attention to when students seemed confused, and finally helping students calculate precise answers using the procedures the students suggested. Ms. Lynn gave students agency, then took back some of the agency to scaffold their problem solving if students continued to struggle.

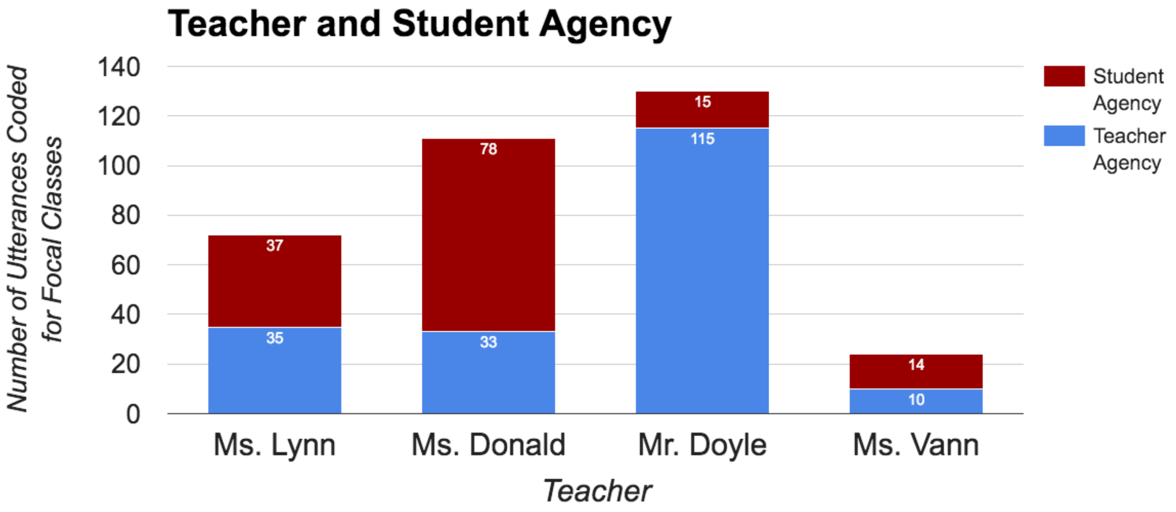

Figure 1.2: Number of teacher utterances coded for teacher or student agency during gameplay.

With respect to the distribution of agency, our cases looked quite different from each other, and this difference was somewhat surprising. Given the low number of teacher utterances in Ms. Vann's class, it is difficult to draw many conclusions about the distribution of agency (indeed, one might argue that Ms. Vann's class distributed almost all agency to the students and the game, given the low number of teacher utterances). When looking at the two lower performing classrooms, the amount of agency that was distributed to the students is surprising. In interviews with Ms. Lynn and Ms. Donald, they shared that they felt they needed to "reteach" the content that 7th grade students should already have learned (multiplication, division), while simultaneously moving ahead with the 7th grade standards (ratio, proportion). Thus, these moments when the teachers pushed students to declare how they might solve a problem might have been opportunities for teachers to gain insight into student understanding. In contrast, Mr. Doyle shared his opinion that "understanding" the content in the standards can be seen through accurate execution of procedures, and thus did not feel it necessary to push beyond reminding students about "how to do" such problems. Thus, here again it seems clear that the larger context of the students' needs, combined with the teachers' vision of what it means to know and understand mathematics, framed the ways that the teachers interacted with students around the game, and particularly around the mathematics in the game.

Question 3: How do teachers interact with students around the narrative of the game?

Along with mathematical thinking and agency, the narrative outcomes of the game were an important source of feedback to students about their problem solving efforts and, in the design of the game, were conceptualized as an important resource for mathematical thinking. We analyzed how teachers interacted with students around the narrative outcomes of the game--what happened to the eagle. To give a sense of scale, each student in the class had two opportunities to try to save the eagle, and thus in each class, there were between 50-60 times when a student might have talked with the teacher about what happened to the eagle. Our observations of Ms. Lynn's and Ms. Donald's classes, who played the game first, suggested that teachers were not talking about the eagle outcomes as much as we had envisioned, and thus we sought to find a way to make the eagle outcomes more salient to teachers. To do this, we created eagle state stickers for subsequent implementations (beginning with Mr. Doyle, including Ms. Vann). These stickers showed either a live, injured, or dead eagle, and teachers were invited to distribute the stickers to their students based on their game outcome. Our goal in creating these stickers was to make in-game outcomes more salient to teachers, and, we hoped, to launch some conversations about why these outcomes took place. Students in all implementations have valued these stickers highly, displaying them prominently on their shirts, folders, and even faces, and as a consequence, students often tell teachers about their eagle outcomes. Thus, we would expect to see higher counts of discussion about eagle outcomes in Ms. Vann and Mr. Doyle's classrooms (with the eagle stickers) than in Ms. Donald and Ms. Lynn's classrooms (no eagle stickers). In fact, this was not quite the case; although Ms. Vann had many instances when she talked about eagle outcomes with her students, Mr. Doyle's discussion of eagle outcomes was quite low (see Figure 1.3).

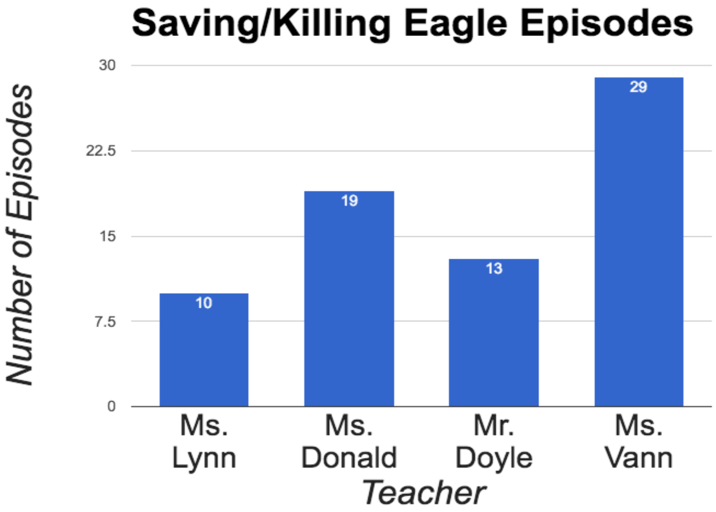

Figure 1.3: Number of interactional episodes around saving or killing the eagle.

Of course, merely talking about what happened to the eagle is not the same as leveraging the outcomes to prompt a discussion about mathematical problem solving (the ultimate goal for giving the feedback; c.f. Gresalfi & Barnes, 2015). Thus, we examined each episode when the eagle was discussed during game play and coded it for "narrative only," "problem solving," and "mathematics." An exchange was coded as "problem solving" when the teacher prompted the student to think about where the plan went awry (for example, running out of gas, choosing a route that took too long). A code of mathematics was reserved for times when the teacher and student talked about mathematical thinking or calculational errors that might have led to the eagle outcome. None of the teacher cases in this paper discussed mathematical thinking in relation to the eagle outcomes.

Consistent with the findings about the distribution of agency in the classrooms, we found that Ms. Donald and Ms. Lynn were more likely to leverage the eagle outcomes as an opportunity to think about what went wrong than Mr. Doyle, whose response to eagle outcomes almost always involved acknowledgement of the outcome without any elaboration. Of the 13 times the eagle was discussed in Mr. Doyle's class, 9 of them involved no mathematical or problem solving elaboration. The other four times were coded as *problem solving,* such as in this exchange:

1. Doyle: Did you make it? There you go. (*long pause*) You crashed and you killed the eagle
2. S: ran out of gas
3. Doyle: Yeah you didn't plan your flight very well. When you're done, you need to go to the reflection piece. Answer those questions.

In contrast, Ms. Lynn and Ms. Donald were more likely to use the eagle outcome as an opportunity to discuss problem solving, although they did not delve into the mathematics behind decision-making. For example, Ms. Donald discussed problem solving in 8/19 exchanges, such as in the following:

1. S: I, I didn't quite get to the Dr. Remi in time. I know why though.
2. Donald: Why?
3. S: I, I took the risk of going to the gas station both times. Coming back.
4. Donald: Oh to really make, I see. So now, next time, what are you gonna do different?
5. S: Have … gas.

Likewise, Ms. Lynn also was more likely to discuss problem solving when talking about the eagle (7/10 exchanges were coded as problem solving). For example, in an exchange with one student, she said: "It's saying, oh, no. You killed the eagle. Oh no. Oh no. You ran out of gas from, you didn't have enough gas to go to Hilda's. Oh no. Oh no. Okay. So, it's your first try. So, close out. And then, go, you're gonna tell Dr. Remi what you did. Okay. Tell Dr. Remi you killed the eagle, and then, try again using your mathematical calculations. You've gotta make sure you have enough gas!"

Finally, as previously mentioned, Ms. Vann spent very little time talking about the math problems with her students and almost all of her time on the computer monitoring students' progress and responding to their written reports in the game. However, Ms. Vann had 29 episodes reacting to students saving or killing the eagle, the most out of all four teachers in this study. In these episodes, Ms. Vann cheered students who saved the eagle or teasingly booed students who killed the eagle, but she did not ask them to think carefully about how their choices led to those outcomes and how they could refine their plans to save the eagle. Ms. Vann focused her attention on the narrative outcomes, but she did not relate the outcomes to the mathematics in the game. For example:

1. Student1: We killed the eagle!
2. Ms. Vann: Bad eagle killers! Aaaaaarggg. Dead Eagle alert!
3. Student2: We saved the eagle!
4. Vann: Eagle salvation over there! *[rings bell]*

In summary, teachers' use of the narrative consequences of the game fit into the classroom system in predictable ways. Teachers who tended to turn agency over to students were more likely to use the feedback as an opportunity for students to think about what they had done wrong, or what they could do differently. Teachers who were more focused on accuracy used the feedback as an indicator of success or failure but did not take the feedback further to open a discussion about problem solving or mathematical reasoning.

Discussion

While we cannot generalize widely from only the four cases in this study, these close level analyses of interactions between the teachers and their students offer insight into teaching with videogames and how to better support teachers to successfully integrate games into instruction. First, our four case study teachers demonstrate what an important role teachers play in the learning that occur when students are playing games; teachers are a central part of the overall learning ecology that develops around the game. Perhaps this is most obvious when considering the case of Ms. Vann, who spent the majority of gameplay time sitting at her desk, not interacting with students. Additionally, almost all of Ms. Vann's talk with students involved reacting to the narrative outcomes of the game instead of talking about the math. Ms. Vann's students were the only ones out of the four case teachers' classes who did not show learning gains on the posttest, despite having room to grow; her students only scored 67.3% on the posttest. It is important to note that Ms. Vann wasn't a disinterested or unapproachable teacher; she prepared slides that framed the goals of game play, and even created additional homework asking students to reflect about what they had learned from playing the game. However, while playing the game, Ms. Vann did not push her students to engage conceptually, consequentially, or critically with the mathematics. Therefore, we suggest that students learn more and have more opportunities to engage with the mathematics content of digital games if teachers interact with students and talk about the math during gameplay.

Second, we found that during teacher-student interactions about the math content, it is possible for teachers to appropriate student agency rather than allowing students to try their own solutions. This is consistent with literature about using tasks in classrooms, which suggest that when students have questions or are confused, teachers often narrow the problem, thus lessening the rigor of the task as designed (Stein et al., 2000). Instead of offering answers or procedures right away, teachers can scaffold students' problem solving with open questions that give students agency to develop solutions and procedures first. Ms. Lynn's work with her students exemplified this idea. When a student asked for help, she first asked him/her a question that allowed the student to suggest a strategy or procedure to use. If the student still struggled to come up with a solution, Ms. Lynn suggested what to do next or what the student might need to think about to solve the problem. We conjecture that this type of scaffolding helped her students understand different solution strategies; perhaps because of this, her students had the highest learning gains of all four teachers' classes on the posttest. On the other hand, in Mr. Doyle's class, most of the agency was distributed to the teacher, meaning Mr. Doyle offered a strategy or answer right away, thus diminishing some of the cognitive demand of the task. While the students in Mr. Doyle's class did have pre-post gain, we believe that the emphasis on teacher agency limited students' opportunities to think critically about the mathematics problems. We conjecture that students learn more if they are given agency to develop their own solutions to problems in digital games. This is a question worth further exploration.

Findings from this study also point to important design changes for Boone's Meadow and suggestions for others working with digital games. For instance, even if students perform well on tests and appear to have good procedural understandings of ratio and proportion, students can still learn from engaging conceptually, consequentially, and critically with the mathematics in the game. Therefore, we need to work more with teachers to help them recognize opportunities for students to engage deeply in the game's content and respond to narrative feedback from the game. Teachers do not always notice those opportunities or know how to support students to go beyond procedural engagement. We need more research on how teachers can recognize and scaffold potential moments of deeper mathematical engagement. In addition, we need to examine how Boone's Meadow and other educational games afford engagement in the content so that teachers can use games to improve students' understandings beyond just practicing procedures.

More specifically related to Boone's Meadow, we also need to work with teachers to make sure they understand how to use our teacher materials. We provided all four of our case study teachers with a packet of teacher materials, but we found that the teachers did not all find these materials useful. For future iterations of our designs, we need to work alongside teachers to make sure our materials are clear and easy for teachers to use to guide discussions and gameplay time. We also need to tailor the teacher materials to help teachers differentiate and support students based on the extent of their prior knowledge relevant to the game. Ms. Vann's and Mr. Doyle's students had much more relevant prior knowledge than Ms. Lynn's and Ms. Donald's students, so the teachers interacted with students and structured gameplay very differently. Our teacher materials were not originally designed to support these different groups of students, so we need to work with teachers to improve the materials for future use. After working with Ms. Lynn's and Ms. Donald's students who had low levels of multiplicative reasoning, we made specific changes to the Boone's Meadow game to support problem solving for similar students with low levels of prior knowledge. We are in the process of analyzing and writing about those changes to the game. Overall, we are working towards improving Boone's Meadow, the Teacher Toolkit, and teacher materials to make the problems in the game more accessible to students with different levels of prior knowledge and help all students build conceptual understandings of ratio and proportion.

Conclusions

One of the most salient conclusions to be drawn from this study is that teachers use games in amazingly diverse ways, and that diversity cannot be explained by some teachers implementing the game with more fidelity than others. Instead, our observations support the idea that classrooms are complex interactive spaces, and that elements interact with and influence the behavior of other elements. As such, introducing a new element, such as a videogame, undoubtedly changed the behavior of each classroom system, but in ways that were consistent with the other existing elements of the system. Thus, what students already knew about math appeared to interact with the ways that teachers talked about math with their students in the game. Likewise, teachers' ideas about what it means to know and do mathematics interacted with the game and influenced how open problems were treated. The four teachers in this study used mathematical thinking, agency, and narrative in different ways, which appeared to influence what their students learned from playing the game. These results demonstrate that we cannot simply make good games and give them to teachers with the expectation that students will learn.

If we take as given that a classroom ecology has many factors that interact to affect student learning, then if we want teachers to be able to integrate games successfully into their classrooms and improve students' understandings of the content, we have to understand teachers' practices around gameplay. Teachers need more resources and training to help develop their practice so that they can successfully integrate games into the classroom ecology. In this study, we led a professional development session for the teachers using the game and we provided a packet of teacher materials outlining gameplay sessions and discussion questions. However, the materials were not enough to help teachers identify opportunities for deeper mathematical engagement and support the learning of all students. An important area for future research includes questions about what kinds of supports or training teachers need in order to realize the potential of digital games for learning.

This paper demonstrates the potential of problem-solving games like *Boone's Meadow* for supporting student learning, especially when teachers spend most of the gameplay time interacting with students. But it also points to the need for more detailed research on how teachers can support learning through deeper engagement in the content, and points to the need to investigate in more depth whether and how the games that we design shift the learning ecology of the classroom.

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CHAPTER II

TEACHING WITH VIDEOGAMES: HOW EXPERIENCE IMPACTS CLASSROOM INTEGRATION

This chapter is adapted from the previously published article listed here, with the permission of the publisher and my co-author, Melissa Gresalfi:

Bell, A., & Gresalfi, M. (2017). Teaching with videogames: How experience impacts classroom integration. *Technology, Knowledge, and Learning,* 22, 513–526.

Introduction

Over two decades of research have established that computers, on their own, do little or nothing to change the nature of learning (Penuel, 2006). However, the use of technology is exciting when technologies are integrated into classrooms in ways that support teachers' ideas about and knowledge of technology and the particular content area that is being taught (Mishra & Koehler, 2006). Digital games in particular have demonstrated potential for supporting student learning across disciplines (Gresalfi, 2015; Barab et al., 2007; Pareto, Arvemo, Dahl, Haake, & Gulz, 2011; Squire, 2006). The diversity of game designs makes it challenging to pinpoint exactly why games support learning. But much has been said about the potential of games to motivate and capture student attention (Dickey, 2007; Garris, Ahlers, & Driskell, 2002; Lepper & Malone, 1987), to situate disciplinary learning in realistic contexts (Barab et al., 2005; Clarke & Dede, 2009), and to offer consistent and substantive feedback about reasoning (Gresalfi, 2015; Mayer & Johnson, 2010; Nelson, 2007; Rieber, 1996).

Despite their potential, integrating digital games into instruction also creates new challenges for teachers and requires a shift in instructional practices; the new technology cannot simply be substituted for past practices. One challenge is that students usually play digital games individually and reach different points in the game at different times, making student progress a challenge to monitor and whole-class conversations difficult to structure. Additionally, teachers are often unsure about how to support students to share their thinking without the traditional artifacts of worksheets or overhead projectors. As a consequence, the mismatch between current pedagogical practice and the practices afforded (or demanded) by new technologies creates barriers to integration into classrooms (Ertmer, 2005; Straub, 2009). Integrating digital games into schools is not simply a matter of making the tools available (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012; Ertmer, Ottenbreit-Leftwich, & Tondeur, 2014; Takeuchi & Vaala, 2014). How and when games are used in relation to other instruction, the role that teachers take as they are playing the game, and how the game is integrated into the overall classroom ecology all play a role in whether and what students ultimately learn.

Indeed, research that simply examines the "efficacy" of games could miss out on the potential of games to transform the overall classroom learning ecology (Barron, 2004, 2006). While we do know teachers are using games, there are few studies about the integration of games into instruction. A recent survey of teachers (Fishman, Riconscente, Snider, Tsai, & Plass, 2014) found that 57% of survey respondents used games in their classrooms at least once a week, and over 80% say they are moderately comfortable using games in their classrooms. But teachers also reported many barriers to implementing digital games, including the challenge of finding games that connect to the school's curriculum (47% of respondents), and being unsure about how to integrate games into instruction (33%). However, what game integration looks like for these teachers and how using games affects teaching practice remains unclear. Therefore, rather than examining the fidelity of game implementation, part of the goal of the current study is to explore what teaching using videogames looks like when teachers choose how to integrate games into their classrooms.

One factor that can contribute to the integration of games in classrooms is teachers' experience with the games. More knowledge of and experience with a technological innovation contributes to successful implementation and affects teacher practice in a number of ways (Ertmer & Ottenbreit-Leftwich, 2010; Ertmer, Ottenbreit-Leftwich, & York, 2006; Mumtaz, 2000; Sheingold & Hadley, 1990). For instance, more familiarity with a technology gives teachers a sense of what to expect when using the tool in a classroom, which reduces teachers' anxieties during implementations. Experience with a technology potentially reduces the stress caused by unexpected technical issues as well. As with any new classroom technology, the more teachers use it, the more they understand how students interact with the technology and what aspects are difficult for students to understand. Knowing how students use the technology can lead to more organized and focused classroom discussions based on students' needs.

This paper will contribute to our emergent understanding of what teaching using videogames can look like, focusing on a specific example of a videogame that was designed to incorporate teacher-student interactions, rather than to replace instruction. In this context, the teacher's role is central to implementing the game successfully. The game that is the focus of this study is called *Boone's Meadow*, an interactive problem solving experience that involves using mathematical ideas of ratio and proportion, important and difficult concepts for middle school students to understand. We explore how one teacher uses the game across two years and examine how the teacher's role in supporting problem solving during gameplay changes as the teacher gains experience with the technology. Specifically, we ask:

1. How does the teacher's support of students' mathematical thinking change as the teacher gains experience with the game?
2. Who has the mathematical agency to solve problems, and does that change as the teacher gains experience with the game?
3. How do the teacher's interactions with students around the narrative of the game change as the teacher gains experience with the game?

The Game

The game students played in this study is called Boone's Meadow. The game includes a problem solving adventure that leverages concepts of ratio and proportion, and builds on a storyline from a project-based mathematics activity from the Adventures of Jasper Woodbury, called "Adventure at Boone's Meadow" (Cognition and Technology Group at Vanderbilt, 1997). We leveraged this activity for the game in part because of the history of research and development that had gone into the original project-based learning unit (Bransford et al., 2000; CTGV, 1997; Van Haneghan et al., 1992; Van Haneghan & Stofflett, 1995), suggesting its effectiveness at supporting problem solving and learning. In adapting the storyline for the richer affordances of the interactive game, we made modifications that were more consistent with game conventions, including adding more choice points and therefore different possible outcomes.

The game begins when students are told that an endangered eagle has been shot in Boone's Meadow—a place that cannot be reached by car and takes 6 hours to hike by foot. Figure 2.1 shows a picture of the map of the game world with the veterinary clinic, the gas station, and Boone's Meadow as the three main points. In exploring the problem and resources, they meet three characters who own different ultralight flying machines, which can fly at different maximum speeds, operate with different fuel efficiencies, hold different amounts of gas, and can carry different weights. Students must decide which route to take, which plane to fly, the length and time of the journey, how much gasoline will be required (and where to stop to get it), who will pilot the plane, and whether any additional cargo is necessary (or feasible) given the weight limit of the small aircraft. The problem that students are solving is rich and complex, in that they need to determine what information is relevant and necessary to solve the problem, and, once they have determined this, they must use the information in order to make a final determination of which plane and route is best, how long the trip will take, and how much gas they will need. Figure 2.2

shows the Route Planning Tool where players calculate and input their decisions. Players have two attempts to save the eagle, and they can use the second try to find a more optimal solution (taking less time, using less gas, and spending less money) or test another route.

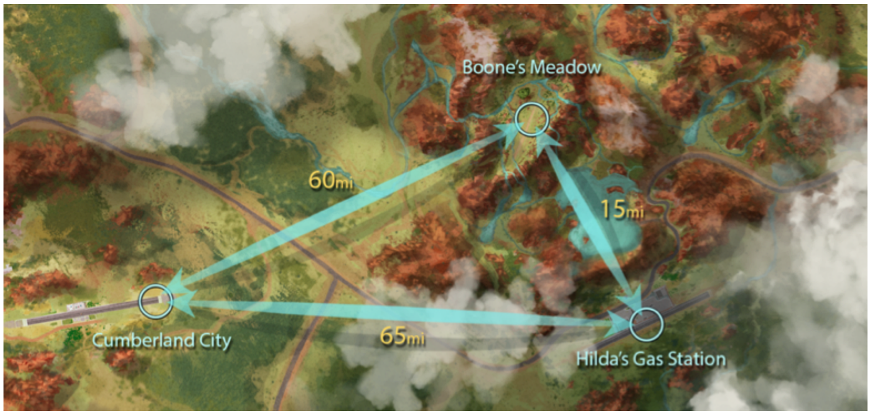
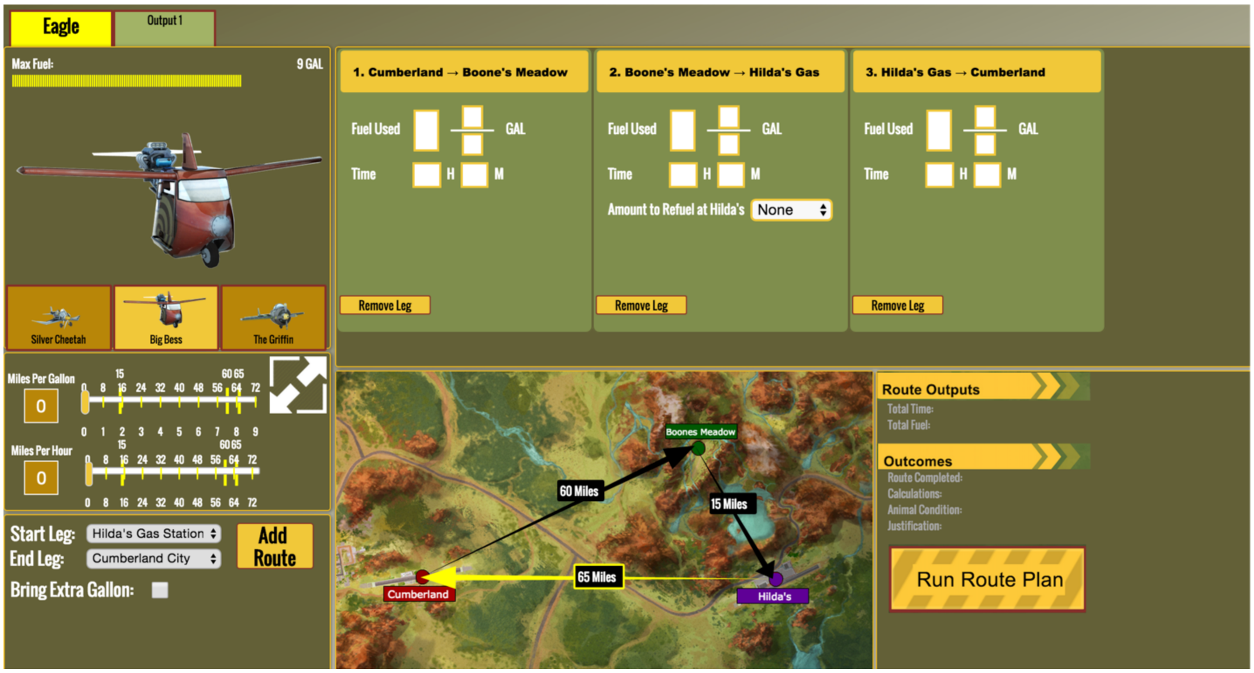


Figure 2.1: Map of the game world in Boone's Meadow.



Amount to Refuel at Hilda's: None

Start Leg: Hilda's Gas Station

End Leg: Cumberland City

Bring Extra Gallon: ☐

Figure 2.2: The Route Planning Tool where players plan and calculate how to save the eagle in Boone's Meadow.

The rationale for our design came from a commitment to seeing learning as participation in a set of practices; because our goal is to empower learners to become agentic problem solvers, we design games that create opportunities for students to see and experience the world in that way (c.f. Greeno & Gresalfi, 2008; Barab, Gresalfi, & Ingram-Goble, 2010). For example, it is one thing to be able to generate a proportional ratio (such as 1:8 = x:1); it is quite another to use that idea to figure out how much gas it would take to travel a particular distance (if your car gets 8 miles per gallon, how much gas would you use to travel one mile)? Although the calculations are the same, the activity fundamentally transforms the mathematics from a mere calculation to a legitimate problem solving task (Greeno, 1991; Boaler, 2002; Lave, Murtaugh, & de la Rocha, 1984). Thus, central to our work is designing game-based learning environments where what you know, what you do, and who you become are interrelated (Barab, Gresalfi, & Ingram-Goble, 2010).

A typical implementation of the game usually takes between 3-5 classroom periods to complete, which includes both time when students are playing the game, and times when students are discussing the game either in small groups or in whole class discussions. An implementation begins with a letter overviewing the game to the students and inviting them to play. The teacher and the students review the letter to ensure that they understand the purpose of the game. Students then move to computers to play the game. Students were allowed to talk to each other while they played, and there was often quite a bit of chatter and laughter while students played. Each day of game play usually started with a whole class discussion reviewing what students knew about the narrative of the game and a review focused on the mathematics relevant to that day's game play.

Methods

Setting/Participants

This paper focuses on Ms. Lynn (pseudonym), a 7th grade mathematics teacher who, at the time of the study, had 7 years of teaching experience. Year 1 of the study was her first time using Boone's Meadow, and she had very little experience using games of any kind in class. The middle school in which Ms. Lynn worked was ethnically diverse, served primarily a low-income community (92% free and reduced lunch), and enrolled many students who did not speak English as a first language (30% English language learners). The school is located in a medium-sized city in the Southeastern United Sates. Ms. Lynn used the game in her classroom for 4 days during the fall of years 1 and 2. In year 1, Ms. Lynn's focal class included 29 students, and in year 2, 32 students.

Ms. Lynn participated in a one-day professional development session held by the researchers the summer before she implemented the game for the first time. The PD session overviewed students thinking about ratio, what teachers wanted students to learn from the game, the problems students solve in the game, and how teachers might fit the game into their instruction.

Teachers in the PD session had an opportunity to play through the game and discuss their plans for implementation.

Ms. Lynn also received a set of teacher materials, which the research team designed. The teacher materials included pacing suggestions, such as which “missions” in the game students should complete each day, questions to guide whole class discussions before and after gameplay (involving ratio, components of the narrative, and the use of tools in the game), suggestions for thinking conceptually about ratio, and supplemental mathematics problems to discuss rates, ratio, and proportion with students. Ms. Lynn used the example problems from the teacher guide quite frequently, but she adjusted the pacing and discussions to meet her students' needs.

Data Collection

Each day during the game implementation, a camera was set up in the back of the room to capture the teacher's talk and actions. A researcher panned and zoomed the camera to follow Ms. Lynn's movements. The entire class period on game days was recorded, so even if students only played the game for 10 minutes, the entire 50 to 140 minute class period was recorded (length of classes varied because of modified schedules and time students spent traveling and settling in between classes). Although an analysis of the whole class discussions before and after gameplay time might show additional changes in the teacher's practice between years 1 and 2, for this paper we were interested in how changes in the teacher's actions during gameplay supported students' problem solving around the game. Therefore, our analyses focused specifically on individual teacher-student interactions while students were actually playing the game.

Students were also given pre- and post-tests to check their understandings of ratio and proportion. Below we detail how the assessments were developed. While data was collected on three class periods, we chose to analyze Ms. Lynn's first period class for this paper because it was the class with the highest pre to post change both years. Since research already tells us about the difficulties of using games in classrooms, we wanted to focus on the classes that demonstrated the most learning gains in order to talk about what worked successfully. We interviewed Ms. Lynn informally after the game implementations both years, and we used her responses to triangulate our findings.

Analysis

Assessments. The assessments that were used for this project were developed by a team of Mathematics Education faculty and PhD students, drawing on example items from (Lamon, 2012;

Lobato, Ellis, & Zbiek, 2010; Schwartz, Chase, Oppezzo, & Chin, 2011). The assessment was then vetted by teachers during the PD session, who offered feedback about the wording of the items and their relation to ratio and proportion as it was taught in their schools. The assessment ranged from procedural items (generate an equivalent ratio), to application items (for example, comparing relative rates), to complex problem solving items that were aligned with the problems in the game. A team of four researchers developed a system for scoring the pre- and post-tests. Most questions were scored on a scale of 0 to 2, with 0 assigned for totally incorrect or no answer, 1 assigned for correct procedures or evidence of thinking but some sort of error in the answer (either a calculational error or missing labels so it was not clear what their numbers referred to), and 2 being completely accurate. Using the pre- and posttest scores, we calculated the average pre- to post-test change for each class. Two researchers scored all assessments, and instances of uncertainty were discussed until agreement was reached. We used these results to determine focal classes for further analysis.

Videos. To answer our questions about how the teacher implemented Boone's Meadow in her classroom, we transcribed the talk from the teacher videos from the focal classes in years 1 and 2. With our research team, we watched the teacher videos several times along with the transcripts to identify major themes around how the teacher supported students' mathematical problem solving during gameplay. This helped us begin to identify codes that we could explore more deeply with each research question to determine what Ms. Lynn did differently during gameplay in years 1 and 2.

For our first research question, we asked about how the teacher supported mathematical reasoning during gameplay. To answer this question, we analyzed the talk in the interactions between the teacher and students during gameplay. The teacher's talk was coded by utterance, defined as a turn of talk (a switch in speakers) or a change in the person the teacher was addressing (if Ms. Lynn said something to student A and then said something else to student B, that was counted as two separate utterances). Drawing on Gresalfi and Barab's (2011) work, we distinguished between four different types of mathematical engagement: (1) procedural – following procedures correctly, (2) conceptual – conceptual understandings of procedures or ideas, (3) consequential – examining how the procedures used relate to the outcomes, and (4) critical – questioning why one procedure should be used over another. Four researchers coded all the transcripts, and instances of uncertainty were discussed until agreement was reached.

Our second research question asked about the agency to solve problems in the game. To answer this question, we coded the gameplay transcripts by utterance again for teacher agency or student agency. We thought about agency by asking who has the ability to decide how to approach a mathematics problem, which procedures to use, and what to do. We counted an utterance as teacher agency if the teacher gave an answer or specified a procedure to follow, meaning the teacher was the person who solved the problem. We coded an utterance as student agency if the teacher asked an open question that gave the student an opportunity to decide how to approach the problem and which procedures to use. Four researchers coded all the transcripts again, and uncertainties were discussed until we all reached agreement.

For our third research question, we asked about how the teacher interacted with students around the narrative of the game, since the narrative provided the main source of feedback for students' problem solving in the game. We looked at teacher talk during gameplay and whole class discussions and coded the teacher's utterances for narrative immersion, or when the teacher explicitly made connections to the game world in her interactions with students. We also looked for instances when the teacher interacted with students around saving or killing the eagle, since those are the major narrative outcomes of the problems in Boone's Meadow.

Findings

We first analyzed the pre- and post-test changes for Ms. Lynn's classes from both years 1 and 2. Both years showed significant pre- to post-test change, with a larger gain occurring in the first year of implementation (paired t-test, $p<0.004$ in year 1 and $p<0.04$ in year 2). Although Ms. Lynn devoted four days to the Boone's Meadow unit in both years, there was more instructional time devoted to the activities in year two, taking less time to transition between classes or talk about other school issues unrelated to the content of the game. Thus, in year 2 there was both more time for class discussions and significantly more gameplay time than seen in year 1 (see Figure 2.3).

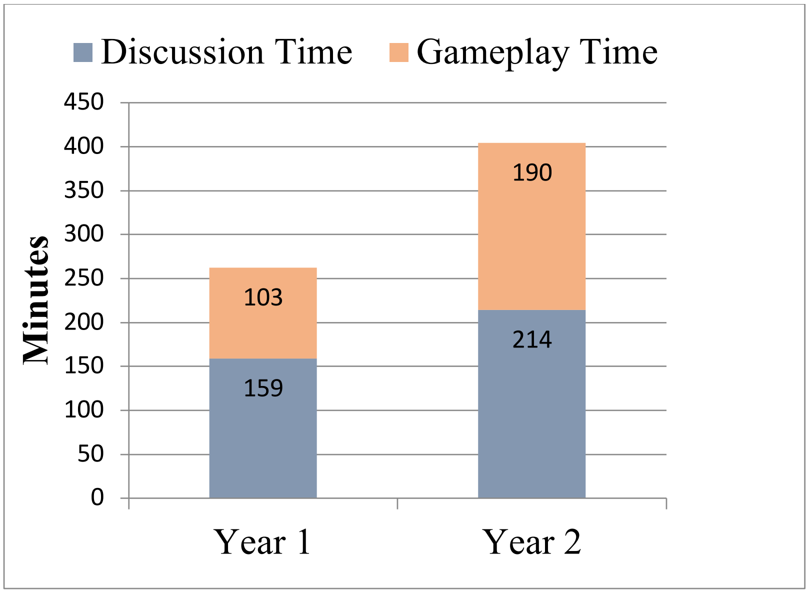


Figure 2.3: Graph of discussion versus gameplay time over all days of gameplay in years 1 and 2.

Question 1: Supporting Mathematical Thinking

Ms. Lynn's support for students' mathematical engagement shifted in years 1 and 2. In year 1, most of the mathematical talk occurred during whole class discussions, while in year 2, the mathematical talk largely happened while students were actually playing the game. In both years, Ms. Lynn did not provide many opportunities for students to engage conceptually, consequentially, or critically in the mathematics of the game, with less than 30 utterances in each of those categories. However, Ms. Lynn frequently engaged procedurally in the mathematics around the game with her students (293 of Ms. Lynn's utterances in year 1 and 306 utterances in year 2 presented opportunities for students' procedural mathematical engagement). Figure 2.4 shows the number of utterances coded as procedural engagement in years 1 and 2, separated according to whether the utterance occurred during discussion time or gameplay time. While the overall counts of utterances are similar, more of the mathematical engagement occurred during gameplay time (and less in discussion time) in year 2.

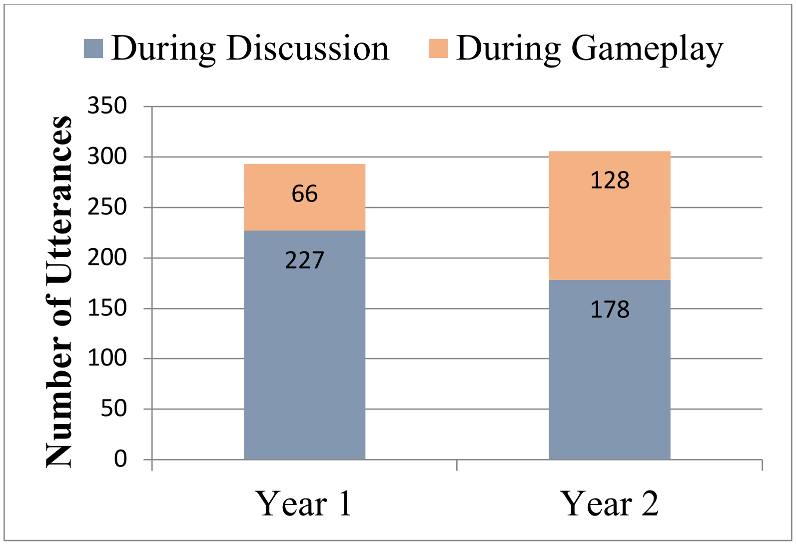


Figure 2.4: Graph of number of utterances coded as procedural engagement during discussions versus gameplay in years 1 and 2.

Question 2: Problem Solving Agency

Ms. Lynn had about the same number of mathematical problem solving utterances coded for agency in years 1 and 2 (Figure 2.5). However, she gave more problem solving agency to the students in year 2, meaning she let the students initiate the procedures they used to solve problems. When agency was distributed to the teacher, Ms. Lynn scaffolded students' mathematical thinking. Specifically, when students asked for help, Ms. Lynn responded by asking open questions that allowed students to think about their own solutions. However, if confusion continued, Ms. Lynn scaffolded students' problem solving by slowly taking back some of the agency and narrowing the question. The following exchange from year 1 exemplifies the distribution of teacher and student agency in Ms. Lynn's interactions with students during gameplay:[2]

1. Student1: Is this how fast they go? Right here?
2. Lynn: Mm hmm. Oh, and it says it right here. So first, you gotta figure out how much gas you're gonna use. Then, you're gonna figure out how much time it will take.
3. Student2: Any number I want. I just put it in.
4. Lynn: Okay. So, 65 miles.
5. Student2: Yes.
6. Lynn: And you get eight miles per gallon. So, do the calculations like we did on the math review. *[crouching behind S2, points to screen]* Okay. So, you're going 65 miles or you did, 65 miles is how, how far you're going. And, uh, I'm sorry, you're going 65 miles, not 60. Right? Yeah. You got it. ... Okay. Do you see what you're doing?

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[2] Transcription conventions use brackets and italics to record *[gestures, actions, or descriptions of what's going on]*. Ellipses indicate pauses of any length. Students are labeled as student, without a name, to keep their identities private and because Ms. Lynn is the focus of analysis.

7. Student1: This is confusing.
8. Lynn: Okay. So, you're going 60 miles. And you get seven miles per gallon. So, just like we did on our warm-up, you need to figure out how many gallons you need.
9. Student1: You gotta divide don't you?
10. Lynn: That'll work, yeah. *[seems like she's looking at what S1 does on a calculator then reads it aloud]* Seven remainder two. Don't forget your two. Don't forget your remainder two.
11. Student1: Okay.
12. Lynn: Two. Two-eighths. What does two-eighths simplify to? Seven and two-eighths? Two and eight have a common factor of *[walks to another student].*

In the exchange above, Ms. Lynn helped two students think about fuel usage and time traveled for one of the ultralights along the route the students chose. This is an example of Ms. Lynn giving students agency, then taking back some of the agency to scaffold their problem solving if students continued to struggle. In line 2, Ms. Lynn oriented the students towards calculating fuel used and time, but she did not tell them how to find the answers. She let the students think about how to solve the problem, giving agency to the students. However, the student's response of "any number I want" seemed to indicate that they needed more help thinking about the problem, so Ms. Lynn pointed out what numbers they should pay attention to and reminded them of a similar problem in a warm-up activity that morning. Ms. Lynn's responses in lines 6 and 8 specified some information students could think about to help solve the problem, but she still gave them the agency to come up with their own procedures and answers. In fact, in line 9, Student 1 suggested using the division procedure. At that point, Ms. Lynn took back some of the agency to help her students calculate precise answers in lines 10-12. During this whole exchange, Ms. Lynn scaffolded students' problem solving by first giving students the agency to solve the problems, then specifying some elements to pay attention to when students seemed confused, and finally helping students calculate precise answers using the procedure the students suggested (division).

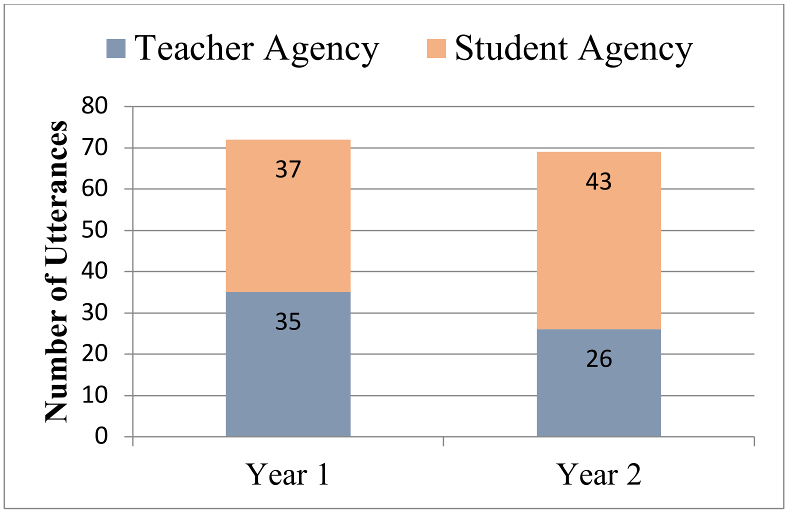

Figure 2.5: Graph of number of utterances coded as teacher or student agency during gameplay in years 1 and 2.

Question 3: Supporting Narrative Engagement

Like the mathematical thinking in question one, the amount of teacher talk supporting narrative engagement by explicitly making connections to the game world increased during gameplay time in year 2 (see Figure 2.6). These increases in math talk and game talk also reflect the overall increase in gameplay time in year 2. The number of episodes in which Ms. Lynn interacted with students around saving or killing the eagle, the major narrative outcomes of the game, also increased in year 2. In year 1, Ms. Lynn had 11 interactions with students about their outcomes during gameplay, but in year 2, Ms. Lynn had 29 interactions with students about their eagle outcomes during gameplay.

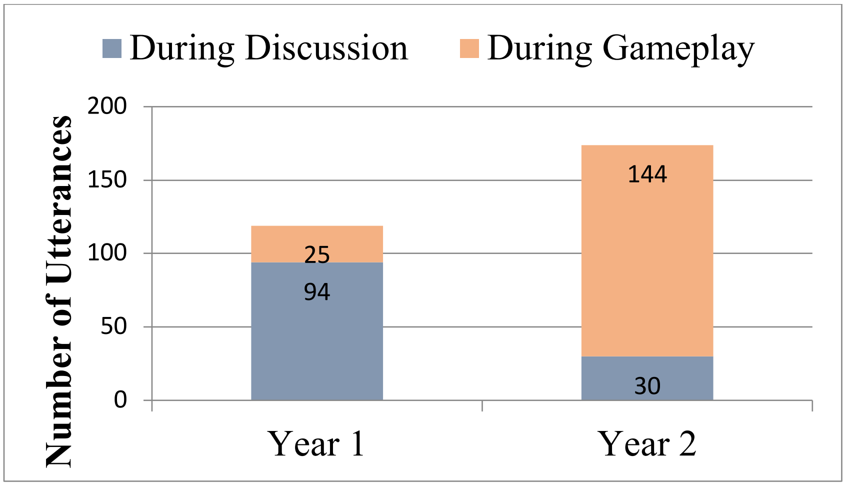

Figure 2.6: Graph of number of utterances coded as narrative immersion during discussions versus gameplay in years 1 and 2.

Discussion and Conclusions

In our discussion, we relate the findings to our interviews with Ms. Lynn about her experience implementing the game in her classroom. Our original question was about how experience implementing the digital game more than once affected teacher practice. We operationalized teacher practice by focusing on the nature of the teacher's talk about mathematics, the agency to solve problems, and the nature of the teacher's talk about the narrative of the game. We examined changes in Ms. Lynn's math and game talk during discussion and gameplay time in her first two years of implementing Boone's Meadow.

In our informal interview with Ms. Lynn after her second year of using the game in her classroom, she reported on her thoughts about the implementations. Ms. Lynn felt like the second year with the game went much better than the first year, specifically because she felt that students were much more engaged in the game and the mathematics in year 2. "Most of the days I am on the whole time. I am helping a lot, I am talking a lot, and I feel like they are not doing enough of the thinking. And I felt like that was switched, they were thinking the entire time. And that's one thing that I liked this year versus last year…they would come in and they were working and trying to understand and very rarely did they need an adult."

However, there were actually quite a few similarities between years 1 and 2 with the game. The ratio of game time to discussion time was similar for both years, but with more of each in year 2. The amount of talk the teacher devoted to mathematical engagement was almost the same across both years, with lots of procedural engagement and very little conceptual, consequential, and critical engagement in the mathematics. We found that the amount of behavioral management and talk related to technical issues also remained largely unchanged.

The biggest differences in teacher talk between years 1 and 2 can be seen in the context of the talk, that is, whether it occurred during class discussions or gameplay time. While the total amount of procedural mathematical engagement remained the same, much more of that discourse took place while students were actually playing the game in year 2. Ms. Lynn's reflection about the game experience was consistent with this finding; "I do think that them having to think through the mathematics in order to save the eagle, that made them really want to get it right…. but it's almost like [the math] is instinctively there but they didn't even process that's what was happening." This offers some insight into that change; while Ms. Lynn knew the context of the game better, having gone through it the prior year, and valued the ways that the game framed students' mathematical engagement, she also worried that they were not thinking explicitly about their mathematical work.

Ms. Lynn’s experience with the game also allowed her to give more mathematical agency to her students during year 2. She still scaffolded their problem solving when students struggled, but she allowed students to explore more of their own solutions first.

Ms. Lynn also engaged her students in much more narrative immersion during gameplay in year 2. That is, she talked more about the details of the game that framed students’ mathematical engagement. This might be due to her increased familiarity with the game, or with her increased value of the narrative, which she felt created an important context for her students’ thinking. Overall, Ms. Lynn allowed much more of the mathematical and immersive game talk to occur around students' actual gameplay experiences. We believe this shift in the context of discourse reflects Ms. Lynn's increased experience with integrating the technology into her classroom. Ms. Lynn was also able to have more interactions with her students around the major narrative outcomes of the game in year 2. The teacher was clearly more comfortable and familiar with the game during the second year, so she was able to use students' gameplay time more productively, through mathematical engagement and narrative connections.

Despite the increases in Ms. Lynn's interactions with students during her second year of using the game, the pre to post-test gain was greater in year 1 than year 2. While we do not know what caused the differences in learning gains, we conjecture this difference is due in part to the changes we made to the game in year 2. The tool where most of the mathematical problem solving occurs within the Boone's Meadow game, including planning the route, picking a plane, and calculating fuel used, time traveled, and payload, is called the Route Planning Tool. In year 1, the Route Planning Tool included a button labeled *Formula Help*, which displayed formulas for calculating fuel and time, such as "Time = Distance / Speed" and "Fuel Used = Distance / Fuel Efficiency." In year 2, the Formula Help option was removed and a new Ratio Tool was added because we found that students were focusing on memorizing the procedures of the formulas rather than developing a conceptual understanding of ratio. The introduction of the Ratio Tool allowed students to find answers to problems in the game more easily, but it also encouraged them to look for patterns rather than calculating ratios (Gresalfi & Barnes, 2016). That is, the procedural skills students developed in year 1 transferred more readily to the questions on the tests than the pattern recognition skills students focused on in year 2, which might be why we saw a higher pre to post-test gain in year 1. These results point to the need for improvements to the assessments. Specifically, for future iterations of the design, the assessments should include questions that probe for conceptual understandings of ratio along with more open-ended problem-solving items that allow students to solve ratio problems without the need for memorization of procedures.

The case we examined in this paper was unique in a number of ways. First, the students in Ms. Lynn's class, in both year 1 and year 2, were far below grade level in their mathematics achievement; most students relied on a multiplication chart to recall basic multiplication facts, and seemed to have developed very little multiplicative reasoning whatsoever. This might help to account for what seems like an inordinate amount of time spent on procedural engagement. However, in that context, it is an interesting shift that the teacher saved her procedural mathematics talk to the times when students were engaged in the game, rather than "pre-teaching" before game play commenced. This case was also unusual in the amount of commitment the teacher had to providing her students with an opportunity to engage in mathematical problem solving in this environment. This commitment could be seen in the teacher's drive to learn about the game and make sure her students were making sense of the mathematics in the game. She saw the game play as an important and unusual opportunity for her students, despite comments she received from the mathematics coordinator that the game had caused her class to fall behind: "…to me, I feel like the experience is so valuable, that it is worth the time, and we will skip something else that is less valuable."

Findings from this study highlight one of the many factors that influence teaching with videogames. In this case, experience using the game clearly impacted the teacher's ability to support mathematical thinking during the game, her ability to make connections to the narrative of the game, and her skill with giving more problem-solving agency over to the students. We know from our observations and from Ms. Lynn's interviews that students were much more engaged in year 2 and spent more time thinking carefully about the problems in the game. Integrating games into classrooms requires teachers to shift their instructional practices, which is not an easy task. These findings suggest that educational game designers should consider how to support teachers, especially as teachers may have different experience levels with the game, which affects teacher practice and ultimately, student learning. This may seem obvious, but given the present lack of research focused on teacher practice with games, we stress the need for a better understanding of how teachers actually use games in their classrooms, rather than just the number and types of games teachers use. In explanations of what and how students learn from educational games, the teacher, and the teacher's familiarity with the game, clearly plays an important role in what students learn.

Furthermore, even when teachers receive similar resources and training with a digital game, they may implement the same game very differently in their classrooms (Bell & Gresalfi, 2017). Therefore, game designers must not only include teacher materials but craft the materials to be adaptable to teachers' needs and experiences. In Ms. Lynn's first year with the game, it was helpful for her to have materials explaining how long the game would take, the pacing of the game, when to have discussions, and sample questions to ask. However, given that Ms. Lynn increased her interactions with students during gameplay time in her second year with the game, Ms. Lynn would have benefited from supplemental teacher materials providing suggestions for how to support students' engagement specifically during gameplay time rather than just during whole class discussions, such as questions to probe for conceptual, consequential, and critical mathematical engagement. We have recently added to the teacher materials, providing specific examples of different ways teachers can support mathematical engagement during one-on-one interactions with students during gameplay, which we will analyze and refine further as we continue to test iterations of the design.

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CHAPTER III

HOW FLEXIBLE DESIGNS SUPPORTED PRODUCTIVE DISCIPLINARY ENGAGEMENT IN A TEACHER PROFESSIONAL DEVELOPMENT FOR COMPUTER SCIENCE

Background and Purpose

Integrating Computing into K-12 Education

All states now recognize the importance of computing education and have adopted policies to incorporate it into the K-12 system, but only 47% of high schools in the U.S. teach computer science (CS), and even fewer middle schools offer it (Code.org, CSTA, & ECEP Alliance, 2020). At the same time, Black, Hispanic/Latinx, and Native American/Indigenous students are less likely to attend a school with computer science courses, as well as students in rural areas, students with disabilities, and English language learners (Code.org, CSTA, & ECEP Alliance, 2020). To reach more students and continue to expand access to high quality CS education, schools need more educators across grade levels trained to teach computer science.

The demand for more computing teachers in K-12 means that more teacher training is needed, but there are still very few CS teacher certification programs in the U.S. (Code.org, CSTA, & ECEP Alliance, 2020; Gal-Ezer & Stephenson, 2010). Less than 70 teachers graduated with preparation to teach CS in 2018 (Code.org, CSTA, & ECEP Alliance, 2020). Therefore, training in-service teachers from other subject areas, like mathematics, to incorporate computing into their classrooms is becoming a more popular way to bring CS into schools (Gal-Ezer & Stephenson, 2010; Grover, 2020; Yadav, 2017).

By integrating computing into existing subjects rather than offering a separate course, educators also hope to reach more students (Hu, 2011; Weintrop et al., 2016; Wilensky, Brady, & Horn, 2014). Rather than having a separate elective course that only some students have the option to take, all students could learn computer science within their already required courses. Additionally, many school schedules are too busy to add a dedicated computing class. In fact, a study examining school-wide integration of computing at the elementary level found that classroom teachers could only teach computing by integrating it into their content areas because the pre-existing curriculum was too time-consuming to introduce computing on its own (Israel et al., 2015). With this push to bring computing into all classrooms, existing teachers need training to incorporate CS into what they already teach.

Mathematics is a popular content area for technology and computer science integration because of its status as a core, required subject and its connection to other school subjects. The National Council of Teachers of Mathematics believes that mathematics is the center of any STEM program integrating science, technology, engineering, or mathematics, and that "students need a strong mathematics foundation to succeed in STEM fields," including computing (NCSM & NCTM 2018, p. 1). The majority of states now allow CS courses to count in place of mathematics for K-12 graduation requirements, highlighting the connection many policy-makers see between mathematics and computing (Orban, 2019). At the same time, researchers have begun to develop frameworks for integrating computing with mathematics, especially in the context of computational thinking (Weintrop et al., 2016; Grover, 2020). This paper contributes to research on integration by considering how mathematics teachers learn about computing while preparing to implement an interdisciplinary module connecting mathematics and CS.

Training Teachers to Integrate Computing

Although there is a push to incorporate computing into other subjects, like mathematics, there is still a lack of teacher professional development (PD) to support it. As of 2020, 18 states still did not have any funding allocated towards CS teacher professional development to support in-service teacher training (Code.org, CSTA, & ECEP Alliance, 2020). There are also many barriers that in-service teachers face when they start teaching CS, including a lack of ongoing support after PD ends, the need to learn both CS content and pedagogy, difficulty designing assessments, a sense of isolation, and lack of access to new technology (Yadav et al., 2016). These challenges point to some of the unique supports that in-service teachers from other subjects need as they incorporate CS into their classrooms.

Research on teacher PD in computing is new and ongoing. Reviews of research on computer science teacher training demonstrate that much of the existing research considers AP computer science or other high school level CS courses, and we know very little about teacher PD for middle and elementary school levels (Liu et al., 2011; Menekse, 2015; Qian et al., 2018). This work has largely focused on expanding access to PD by shortening the length of time required for PD, making training available online, and establishing ongoing teacher learning after the PD (Goode, Margolis, & Chapman, 2014; Milliken et al., 2019, Ravitz et al., 2017; Rosato et al., 2017). Additionally, most research on CS professional development has focused on evaluating teachers' content knowledge, implementation of curricula, or interests in training as measures of success (Menekse, 2015).

While this work is important for addressing some of the challenges that teachers face as they incorporate CS into their classrooms, it does not explain what happens during PD to support teacher learning - specifically, what kinds of interactions occur, norms of the learning environment, how teachers engage and how to support engagement, and what makes different kinds of teacher training productive. These details are important for understanding what makes some teacher training more successful than others, to help designers create high quality learning environments for teachers. To learn more about how to support productive and engaging in-service teaching training in CS, this study focuses on teachers' productive disciplinary engagement (PDE) as a measure of success.

Project Overview

This paper is part of a larger, multi-year project exploring the integration of computational thinking and computer science with middle school mathematics. The project focuses both on the role of activity design and its support of student learning, as well as explorations of professional development and support for in-service mathematics teachers. Our goal is to better understand what kinds of supports in-service mathematics teachers might need as they learn to incorporate computer science into their existing classrooms.

In the first year of the project, we implemented a four-day professional development for four experienced mathematics teachers with no prior knowledge in computer science. The professional development seemed successful, based on multiple indicators. First, over the four days, the teachers used many programming concepts and practices (e.g. loops, conditionals, neighbors, procedures, buttons, commenting, variables, remixing code, collaborating, using different types of agents, and more). They were able to lead a week-long programming summer camp and teach programming to students independently, using a summer camp curriculum that they personalized by developing new ideas for activities. At the end of the camp, the teachers were very positive about their experiences. Over the following academic year, two of the teachers implemented computer science activities in their classrooms during the school year, and all four teachers returned the next year to help with the next professional development and summer camp (including one teacher who returned after moving to another state). The third year of the project was limited due to the COVID-19 pandemic, but one of the teachers returned for a third time to design and lead an online summer camp, and she is now planning to implement her own training sessions for teachers that she works with.

Thus, the first year of the professional development appeared to be very productive and helped establish a strong relationship with the teachers while supporting their computer science learning. This led us to wonder, why was the first year of the PD successful, what was interesting and productive about it, and how can these findings be used to inform future PD designs for computer science education?

Overview of the Professional Development

Professional development for computer science is different from typical PD in other subjects because most teachers who participate in computer science PD have little or no prior training in CS or programming (Menekse, 2015). As such, most programs include both training for teachers to learn programming and lessons for teachers to incorporate into curricula (Liu et al., 2011), and most PD programs are targeted towards high school teachers preparing to teach stand-alone CS courses. According to a recent review of research on computer science teacher training, most studies relied on surveys or interviews to evaluate teachers' interests in the program as well as assessments to measure content knowledge (Menekse, 2015).

The professional development in this study differed from this prior research in several ways. First, the example lessons that teachers would later implement with students were intertwined with their own computer science learning, since the teachers learned programming by engaging in the activities they would later be implementing with students. Additionally, the teachers were not just given lessons to implement but participated in personalizing these lessons with the research team during professional development. Second, this training included middle school teachers rather than high school teachers, to better understand how teachers from other grade levels can incorporate CS into their existing disciplinary content. Finally, video and audio recordings were the main source of data to capture teacher participation and learning, while surveys and interviews were also used to supplement the videos and gain greater insight into teachers' thinking. These choices are further detailed below.

Professional Development Designs and Structure

While research on teacher PD in computing is quite new, by looking at research on PD in other subjects, like science and mathematics, we see some important features that support teacher learning and changes in classroom practice: a focus on content knowledge, active learning opportunities, coherence between training modules and future instructional activities, time for teachers to plan for implementation, and building a community of learners (e.g. Darling-Hammond, Hyler, & Gardner, 2017; Garet et al., 2001; Loucks-Horsley et al., 2010; Penuel et al., 2007). We drew on this prior work on quality PD designs to incorporate many of those features in the PD for this study. Specifically, we focused on engaging teachers in programming concepts and practices through short examples, exploration, and active discussions to create active learning opportunities that developed content knowledge. We gave teachers opportunities to use the same models and activities they would later implement with their students to maintain coherence between training modules and their future instructional activities. We reserved a day of PD for teachers to plan for their own implementation, giving them plenty of time to prepare before leading activities with students. Finally, we attempted to establish a community of learners by encouraging teachers to work together and with other members of the research team during the PD along with co-teaching during the implementation with their students.

NetLogo

We chose to use an agent-based modeling environment for the summer camp and PD because of its powerful representational infrastructure and its potential for creating different kinds of computational art. Single agent environments already have a strong history in computer science education, like TurtleArt (Bontá, Papert, & Silverman, 2010) and Scratch (Resnick et al., 2009). We chose to extend this to a multi-agent environment using NetLogo (Wilensky, 1999). Teachers in the PD started exploring a grid of immobile agents called *patches*, similar to the pixels of an image. Patches have Cartesian coordinates, color, and they can store variables. Next, teachers explored movable agents called *turtles*, which have color, shape, size, a heading/direction, Cartesian coordinates, can move, can store variables, can have links, and more. Commands can be given from the perspective of an observer agent (controls both patches and turtles), patches, or turtles specifically. The perspective chosen changes how the code is written and what is possible or which agents can respond.

PD Activities

On the first day of the PD, teachers were given blank NetLogo models and some instructions on how to use patches, then they had the freedom to play around and create art using patches in any way they chose. The next day, they added turtles and explored those in a similar way.

After the exploration phase in NetLogo, teachers were given pre-built models with some buttons allowing them to import images and use buttons to interact with patches and turtles. The teachers used similar pre-built models to introduce NetLogo to their students in the summer camp.

There was an online gallery space where teachers could upload their models for others to look at or download during the PD. This allowed everyone to share their work and remix or use code from each other's projects. Students in the summer camp also had a similar online gallery space to post images of their computational art.

The teachers also participated in an embodied programming activity during the PD, which was used in the summer camp (Vogelstein & Brady, 2019). The teachers and research team acted as physical patches by standing on a grid on the floor while holding colored cards to indicate patch color or turtle color. One person acted as the programmer or observer and called out a line of code, and the human patches and turtles changed their colors in response by holding up a different colored card. See Figure 3.1 for an example. Table 3.1 summarizes the NetLogo and embodied programming activities from the PD.

Figure 3.1: Participants in the embodied activity on day 2 of the PD.

Table 3.1: Overview of the PD programming activities.

	Programming Activities
Day 1	First introduction to NetLogo. Participants were given an overview of patches, explored how to change patch color, selected one or multiple patches by location or by color, made a stripe, and made new artistic creations using patches. Teachers also learned how to make buttons and how to upload projects to the shared gallery.
Day 2	Participants used a pre-built NetLogo model to import an image and edit the patch colors in different ways. They also learned how to change the size of the world/canvas and the patch size. Later in the day, participants used a blank NetLogo model to explore turtles for the first time. They started with one turtle and then added many more. They practiced making turtles move in different directions, changing the colors of turtles, and selecting turtles based on location or color. Embodied activity first introduced. Participants acted as patches in a grid and changed their color based on code called out by one person acting as the observer. They practiced changing patch color by calling on specific patches by color. They also explored colors as numbers or as words and the use of random numbers.
Day 3	Participants used another pre-built NetLogo model to import an image, sprout turtles, and continue exploring the ideas from days 1 and 2 with patches and turtles. Some also used variables to store patch color in memory to create a slideshow effect by switching between different images. To explore how turtles move, participants worked in pairs. One person acted as the programmer, and the other acted as the turtle. The programmer gave specific instructions out loud in English or pseudo-code, and the turtle acted them out. The goal was for each turtle to walk in a square, a circle, and a triangle. All participants together did another grid-based embodied activity where they acted as physical turtles in a grid. The human turtles could sprout, change color, or move.
Day 4	Participants re-examined the first pre-built NetLogo model from day 2 involving importing an image and patches, with changes based on suggestions from the teachers. For the rest of the day, the teachers worked in pairs to plan and prepare for the summer camp and edit the curriculum materials, with support from the research team. Participants re-enacted the first embodied activity (patches on a grid) with changes based on suggestions from the teachers.

Methods

Context and Participants

This study comes from a larger project investigating the integration of computer science with mathematics for middle school students. In the first year, in-service mathematics teachers participated in PD to learn programming and co-design a curriculum incorporating mathematics and programming in an art context. The teachers then implemented the curriculum in a summer camp for middle school students.

The PD was held at a private university in a southeastern U.S. city with four mathematics teachers: Sammie (6 years of teaching experience), Heather (5 years teaching of teaching experience), Matt (13 years teaching of teaching experience), and Jaida (24 years teaching of teaching experience). Pseudonyms are used to maintain anonymity. None of the teachers had prior experience learning or teaching computer science. The research team (two professors and two PhD students in a Department of Teaching and Learning, including myself) led the PD, which took place over four days. I refer to the members of the research team leading the PD throughout the paper, so I will provide their names here: Corey, Melissa (both professors), Lauren (a PhD student), and myself - Amanda (another PhD student). The PD also included two other research assistants and two undergraduate computer science students. Everyone participated in the activities of the PD, but it was designed to focus on the teachers' needs specifically. The research assistants and undergraduate CS students supported the research team with data collection, learned about the activities and curriculum for the summer camp, and supported the teachers with their questions around programming.

After the PD, the teachers co-taught a weeklong summer camp - Sammie and Heather led one classroom, and Matt and Jaida led the other classroom. The research team was there for support and data collection.

Data

We collected several different types of data during the PD, but video recordings were the primary source of data. Two cameras were set up with one on each side of the room so we could capture all the participants, with microphones on the tables to capture audio. All aspects of the PD were recorded except for lunch breaks, which often took place outside the classroom.

The entire research team contributed to field notes throughout the PD. The field notes mainly served as an overview of what happened each day, a place to capture seating charts, and notes about things that we found interesting in the moment.

When teachers arrived for the PD, they were given a questionnaire to fill out asking about their teaching experience, interest in the PD, concerns, and prior knowledge of CS. They were also given daily questionnaires that they filled out at the end of each day of the PD with more specific questions about what they learned that day.

After the summer camp, each teacher was interviewed individually by a member of the research team. The interviews were semi-structured, meaning we had a standard set of questions guiding all of them, but conversations were free to focus on what was important to each teacher. All the interviews were audio recorded.

Analytic Framework: Productive Disciplinary Engagement

The teachers in our study were novices to CS but were able to personalize the curriculum we gave them and lead a five-day CS summer camp for students, illustrating the productive outcomes from the professional development. In response, I wanted to investigate what helped make the PD productive and what helped support teacher engagement (i.e. the structures that were in place, what occurred during interactions, what resources we provided, and what problems we posed). To do so, I used the lens of productive disciplinary engagement (PDE) (Engle & Conant, 2002). The PDE framework allows this paper to illustrate: first, that teachers engaged productively in the discipline of computer science, and second, how productive engagement was supported through the enactment of the five PDE principles.

Engle and Conant (2002) define productive disciplinary engagement in learning environments by breaking down each part of the phrase. First, they suggest that engagement can be seen by analyzing students' discourse to look for how students are participating. Second, disciplinary engagement takes this a step further to specify when students are engaged in the content or practices of a discipline. Finally, disciplinary engagement is considered productive if students make some kind of intellectual progress. "What constitutes productivity depends on the discipline, the specific task and topic, and where students are when they begin addressing a problem… [S]uch productivity might involve things like recognizing a confusion, making a new connection among ideas, or designing something to satisfy a goal" (Engle & Conant, 2002, p. 403).

There are four guiding principles that Engle and Conant (2002) propose can support productive disciplinary engagement: problematizing, authority, accountability, and resources. The four principles are elaborated in the Analysis section below. The authors specify that these principles can be used as design principles to help guide decisions to support PDE in learning environments. But the principles can also be used in analysis to explain examples of engagement and to contribute to an understanding of how productive disciplinary engagement can be fostered; in fact, that is how Engle and Conant originally developed the principles.

In this case, we did not use PDE as a set of design principles; in other words, the PDE framework did not guide the way we chose to design the professional development. But in looking back at the data, we applied PDE as an analytical framework to help make sense of what happened. This framework helped identify patterns that occurred during the professional development to explain the productivity of the training and the teachers' engagement. Based on this framework, our initial wonderings about the professional development were expanded into two research questions:

1. Is there evidence that productive disciplinary engagement occurred? If so, what did PDE look like in this context?
2. How were the principles of productive disciplinary engagement (problematizing, authority, accountability, and resources) embodied?

Most studies using the PDE framework have focused on math and science contexts (e.g. Sengupta-Irving & Enyedy, 2014; Mortimer & de Araujo, 2014; Venturini & Amade-Escot, 2014; Nolen, Wetzstein, & Goodell, 2017; Schoenfeld, 2014). Most studies also focus on student engagement rather than teacher/adult learner engagement, although PDE has been explored in the context of pre-service learning in teacher education programs (Engle & Faux, 2006). PDE has also been adapted to explore productive collaboration among stakeholders, including teachers and researchers in mathematics education and curriculum development (Engle, 2006; 2008; 2010). This study builds on the history of PDE in three ways: 1. It extends the work of supporting PDE in classroom settings to include in-service teacher learning; 2. It continues the work of exploring PDE in contexts with both teachers and researchers; and 3. It builds on the history of PDE in math and science education to include computer science learning.

Analysis

I used a grounded theory approach to analysis (Strauss & Corbin, 1990) because I sought to understand what was happening in a particular context, to identify patterns of interaction, and to understand the structures of those interactions (Erickson, 1985). The data was examined in detail with multiple passes through the data to answer the two research questions. The process for each question is described in detail below.

I used qualitative research techniques to establish trustworthiness in the analysis, including prolonged engagement, persistent observation, and triangulation (Corbin & Strauss, 1990; Lincoln & Guba, 1985). I was a member of the team that designed the PD and data collection protocols, I participated in all four days of the PD, I took field notes during the PD, I was present for the entire summer camp when teachers implemented the content from the PD with students, I interviewed one of the teachers after the PD, and I sat in on the classroom of one of the teachers during the school year. I also re-watched and re-read the data multiple times, focusing on the trajectory of each teacher. Through my presence during the implementation and my repeated examination of the data afterwards, I developed a deep relationship with and knowledge of the data. I also triangulated different data sources in my analysis: videos of the PD, teacher interviews, daily written teacher questionnaires, field notes, and teacher NetLogo models. I also implemented frequent member checks with Melissa - who contributed to the design of the PD, was present for the PD and summer camp, and is one of the participants discussed in the findings - as she read and discussed the ongoing analyses with me many times. Corey, another member of the research team and a major participant discussed in this paper, also saw early versions of the ongoing analysis.

Question 1 Analysis: Is there evidence that productive disciplinary engagement occurred? If so, what did PDE look like in this context?

To answer the first question of whether PDE occurred and what it looked like, I started by writing memos of the professional development videos, pre-surveys, daily questionnaires, and post-interviews. I watched all the videos at least four times, focusing on a different teacher each time. After each time watching a video, I wrote a memo summarizing the focal teacher's interactions, engagement, what they said about computer science or computational thinking, and any episodes that seemed interesting to return to later. After watching all the videos multiple times, I read the teachers' daily surveys and added summaries of those responses to the memos for each teacher. I also listened to the individual post-interview from each teacher and added summaries of those to the memos. The surveys and interviews helped to triangulate the video memos with other sources of data. Again, all my memos focused on summarizing teachers' interactions (with each other, with the research team, and with the programming activities), the ways that they engaged or participated, their views and feelings around computer science or computational thinking, and any interesting episodes I wanted to explore in more detail later (e.g. any interactions that seemed different, seemed to change the dynamics, expressed passion or lots of emotion, or steered the conversation in a new direction).

Using the memos, I developed general descriptions of teachers' interactions and how their views of CS changed over the course of the PD. I used an open coding approach by closely examining the memos and comparing for similarities and differences while asking questions about the data (Charmaz, 2006; Strauss & Corbin, 1990). The codes fell into four major categories that came up repeatedly throughout the week for all four teachers. They also captured different ways that teachers participated during the week and changes to their definitions and views of CS. The categories included:

a) teachers' feelings towards or relationship with CS (confidence with computer science, nervousness around computer science, expressing positive affect or negative affect towards CS or CT),
b) definitions of CS or CT,
c) ways of engaging with the programming activities (through exploration, remixing, collaboration, expressing new ideas, debugging, displays of passion/emotion/excitement), and
d) mentions of students or of preparing to teach these activities to children.

The memos helped to identify that productive disciplinary engagement occurred – specifically, that all four teachers were engaged in the programming activities across the four days of PD, and teachers showed productive changes in their views or feelings of computer science. In the findings below, I use examples from the memos to argue that the teachers were productively engaged in the discipline of computer science.

Question 2 Analysis: How were the principles of productive disciplinary engagement (problematizing, authority, accountability, and resources) embodied?

After identifying that PDE occurred, I wanted to understand how it occurred, specifically, how the four principles of PDE were embodied in this context. To answer this question, I needed to focus on part of the data in more detail to look for evidence of what it meant to participate in the learning environment. From my memos and by capitalizing on my intimacy with the data, I chose to focus on day one of the PD because the first day set up the expectations and interactions for the rest of the week, establishing norms of interaction. Therefore, I took a deeper look at the interactions that occurred on the first day of professional development to document the ways in which the teachers and facilitators jointly established the characteristics of the learning environment (Cobb et al., 2001). I transcribed the videos and carefully reviewed the transcript multiple times to characterize the interactions using the four principles of PDE (problematizing, authority, accountability, resources). I identified at least one example of each of the four principles to explore in more depth, focusing particularly on when each principle was first explicitly enacted. I analyzed those moments of discourse to understand how the teachers, research team, other participants, and physical environment embodied the principles of PDE. I used an iterative and recursive process of continual analysis of the data by identifying and describing an example of one of the principles in action from the transcript, referring to other types of data to triangulate and make sense of the interaction, and repeatedly returning to edit the findings and storyline (Chun Tie, Birks, & Francis, 2019; Flick, 2019). To help guide my analysis and view of the data, I had a specific question in mind for each principle of PDE:

Problematizing: Problematizing content involves going beyond memorization and encourages students to ask questions, solve open-ended problems, and choose problems that are interesting for them. The PDE principle of problematization draws on the history of work in mathematics and science reform efforts emphasizing learning through problem solving, "doing" rather than just listening or memorizing facts, and engaging in rich, open-ended tasks (e.g. Henningsen & Stein, 1997; Hiebert et al., 1996; Lemke, 1990). To look for evidence of problematizing, I asked: were teachers encouraged to take on intellectual problems, and if so, how?

Authority: The principle of authority combines research on agency, positioning, and expertise (e.g. Cobb et al., 1997; Lampert 1990; Brown et al., 1993). It includes a mixture of giving students agency to solve problems, positioning students as stakeholders in and contributors to a learning community, and sometimes positioning students as experts. "In general, by giving students authority, we mean that the tasks, teachers, and other members of the learning community generally encourage students to be authors and producers of knowledge, with ownership over it, rather than mere consumers of it" (Engle & Conant, 2002, p. 404). Looking at the data, I asked: were teachers given authority in addressing intellectual problems? Were teachers positioned as contributors, stakeholders, or experts, and if so, how?

Accountability: Accountability means that students should be responsive to the content and practices of stakeholders in and relevant to their learning environment, like teachers, other students, and disciplinary norms. Students should be responsive to others' views, should be able to justify their work, and should explain when they violate disciplinary norms. In our professional development, was the teachers' work made accountable to others and to disciplinary norms, and if so, how?

Resources: The fourth principle, resources, supports PDE and the embodiment of the other three principles. Resources include things like having time to pursue a problem, scaffolds, models for discourse, access to experts, facilitated discussions, etc. Were the teachers provided with sufficient resources to engage productively through the other three principles? What were those resources?

With these guiding questions in mind, I present qualitative descriptions of each principle in action during the professional development. While I touch on a few small differences between the teachers, I am not focused on comparing and contrasting the teachers' experiences in this paper. Instead, I seek to illustrate that PDE occurred overall, that all four teachers were engaged productively in the discipline, and how the research team, teachers, and environment helped support PDE by embodying the four principles.

Did PDE Occur? Evidence of Productive Disciplinary Engagement

Engagement

Drawing on prior research on engagement, Engle & Conant (2002) suggest that evidence of engagement includes: when students make substantive contributions to discussions, when students' contributions coordinate or interact with each other, when there is little off-task behavior, when students' body language shows they are paying attention to each other, when students participate with emotional or passionate displays, and when students re-engage or continue to engage in an activity over a period of time. During the four days of professional development, there were very few off-task activities. Almost all off-task talk occurred during breaks, in the morning before the day started, or in the afternoon after the end of the day. Additionally, the teachers were able to engage in programming activities over extended periods of time. For instance, on the first day of the PD when Corey introduced NetLogo for the first time, all four teachers persisted in NetLogo for an hour in the morning plus one hour and 15 minutes after lunch. When Melissa tried to end the NetLogo work time in the afternoon so everyone could participate in a discussion, one teacher, Sammie exclaimed "no noo," and Jaida added in "I know, right?" Both teachers were engaged in the programming activity and wanted to keep going even longer. This level of engagement in the programming activities persisted throughout the four days of PD. On day 3, after working in NetLogo for an hour, Melissa announced that it was time for a break. In response, none of the teachers stopped working or paused what they were doing. Instead, they all continued working for about 30 more minutes in NetLogo, then Melissa again announced that it was time to take a break and have a group discussion. Again, the teachers seemed reluctant to stop what they were doing, but they slowly ceased typing on their computers and transitioned into a group discussion. The teachers were deeply focused on their work in NetLogo, both when they first learned about programming and started using NetLogo, and later in the week when they were more comfortable with NetLogo and the variety of things they could create.

In addition to the time spent programming, the teachers offered emotional displays signaling their passionate involvement in the work they were engaged in. On day 1, there were many instances when a teacher ran a piece of code successfully and the video captured them sitting back from the computer, looking back at what they created with a slight nod, smile, or arm motion (often placing their arms across their chest or on their thighs). In those moments, the teachers looked proud of what they were able to accomplish or the problem they were able to solve. For example, on day 2, the teachers worked separately on NetLogo projects, learning to use buttons and switches. Towards the end of the session, Sammie looked over at Matt's work and said, "that's really cool." In response, Matt sat back and crossed his arms, looked proud, smiled and said, "thanks." Jaida and Heather express that they would like to see the project as well, and they ask Matt to post his code to the shared website. The teachers were interested in each other's projects and were proud when they accomplished something new.

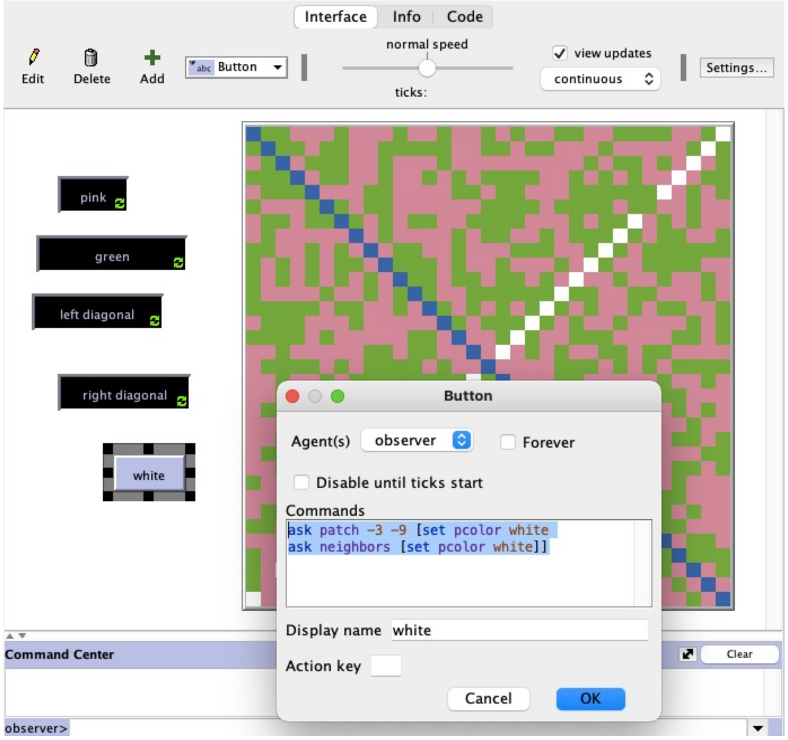
The teachers also wanted to share their programming accomplishments with each other. On day one, Matt mostly worked quietly on his own, but near the end of the day, he turned to Sammie and said, "do you want to see what I've got?" Sammie moved to sit next to him, and they observed each other's programs on their computers. These informal sharing moments happened often while teachers sat next to each other working on different projects. They illustrate that teachers were engaged in what they were doing - they cared about what they created and wanted to share it with each other.

Teachers' engagement in computer science continued after the professional development. All four of the teachers chose to return the following year for another round of PD, and two of them worked directly with the research team to implement some of the activities from the summer camp in their classrooms during the school year.

Disciplinary Engagement

The teachers very clearly engaged in computer science content and practices during the PD (Computer Science Teachers Association, 2017; 2020). By looking at the NetLogo models they created and the transcripts of talk and movement during NetLogo work time, we can see evidence of the disciplinary content that teachers engaged in.

Figure 3.2 is an example of one of the teacher's NetLogo projects during the PD, focused on patches. This teacher learned to create buttons, write code inside the buttons to add effects, and change the names of buttons. In order from top to bottom, the buttons turn all the pixels pink, turn some pixels green, turn the pixels on the right diagonal blue, turn the patches on the left diagonal white, and finally turn some patches white by selecting a patch by location and selecting neighboring patches. The image shows the code that is inside the button labeled "white."



Agent(s) observer ☐ Forever

☐ Disable until ticks start

Commands

```
ask patch -3 -9 [set pcolor white
ask neighbors [set pcolor white]]
```

Display name white

Action key

Figure 3.2: Screenshot from a NetLogo project uploaded to the Teacher Gallery Space.

Figure 3.3 is a screenshot from another teacher's NetLogo project during the PD. This project used patches and turtles. The set-up button creates turtles in the middle of the world, the set shape button changes the shape of the turtles to airplanes, the change size button makes the turtles larger, the button labeled set pcolor 97 changes the color of all the patches, the fd 10 button uses the forever functionality to make the turtles move forward until the button is pressed again, the pen down button is another forever function that puts the pen down to draw where the turtles are moving, and the die button kills (or removes) all the turtles. The screenshot shows an example of what the model looks like after running all the buttons for a short time, except the die button.

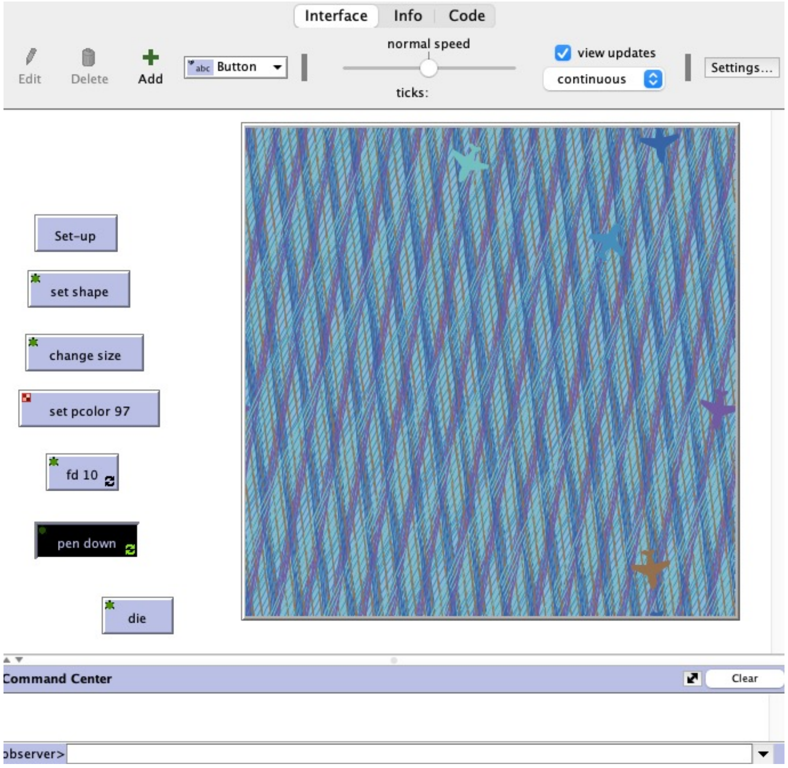
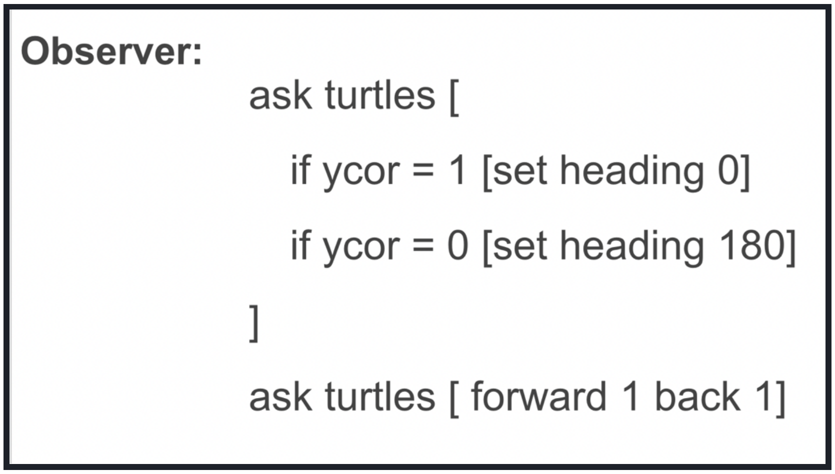


Figure 3.3: Screenshot from another NetLogo project uploaded to the Teacher Gallery Space.

Figure 3.4 is a copy of a PowerPoint slide used during one of the embodied activities in the PD. It illustrates one of the ways that turtles were used in the embodied activity. This command uses if statements to address particular turtles based on location and sets them to face opposite directions, then tells all the turtles to move forward and back. It's a complicated command that has multiple movements and if statements built into it.



```
Observer:
          ask turtles [
             if ycor = 1 [set heading 0]
             if ycor = 0 [set heading 180]
          ]
          ask turtles [ forward 1 back 1]
```

Figure 3.4: PowerPoint slide from embodied activity on day 3 of PD.

These images help to illustrate just a small portion of the programming content that teachers engaged in during the PD. It would be interesting to dig into teachers' learning and engagement in the content further, but that is out of the scope of this paper. For now, the purpose of these examples is to show that teachers did indeed engage in disciplinary content during the PD.

Productive Disciplinary Engagement

According to Engle and Conant, demonstrating productivity includes documenting some kind of change in the learners' knowledge, forms of participation, or interactions. It might involve "recognizing a confusion, making a new connection among ideas, or designing something to satisfy a goal" (Engle & Conant, 2002, p. 403). In this case, the teachers had no prior programming experience, so any programming they did or any related concepts they used demonstrated progress. We did not administer pre and post tests to assess teachers' learning, but by the end of the PD, they were able to create and edit NetLogo models using patches and turtles, and they led programming activities with students, teaching students how to use NetLogo. The teachers very clearly made intellectual progress, both in their knowledge of programming and in their practice as computer science educators.

More specifically, the daily questionnaires and discussions illustrate how the teachers' definitions of computational thinking changed during the PD. On the first day, we asked teachers to write down a definition of computational thinking. The four teachers were either unable to provide a definition or were unable to distinguish computational thinking from general problem solving. For example, Sammie wrote that she did not have a way to define computational thinking, and Matt wrote that he defined it as "the process of solving problems with numbers using different strategies." At the end of the first day, we asked teachers to again reflect on their definitions of computational thinking, and they already demonstrated a lot of progress towards developing more specific or detailed definitions. Matt wrote that it is about "taking what you know or what someone else knows and making it better," which was a much different interpretation than his early definition in the morning. Sammie mentioned that computational thinking is about efficiency and "figuring out how to make the computer do what you want, then figuring out the simplest way to do it." Sammie started the day without a definition of CT, and she ended up with a definition that's close to the one that was made popular by Jeanette Wing (2006), emphasizing abstraction and writing solutions in a way that a computer can understand and carry out. On just the first day, the teachers already demonstrated progress in their thinking about the discipline.

Matt also showed progress in his daily questionnaires about his feelings towards learning and teaching programming. Before the PD started, Matt wrote that he felt nervous to learn coding and to answer students' questions. During a group discussion, he also expressed that he was most nervous about learning to code during the PD. Out of the four teachers, Matt expressed the most apprehension around learning to code (for contrast, Sammie and Jaida both said they were excited to learn to code, and Heather said she was excited but nervous to answer students' questions). By the end of the first day learning about NetLogo patches, Matt expressed to Melissa that he was "a little excited" to learn about turtles the next day, showing a more positive outlook towards learning programming. By the end of the third day, Matt started to feel more confident. He wrote in his questionnaire that he felt "more confident helping students use turtles," and he enjoyed "using turtles to create my own image." The PD helped Matt progress from being completely nervous about coding to feeling confident in his knowledge. He was able to successfully lead a five-day computer science summer camp for students, with Jaida as his co-teacher. In fact, in Jaida's interview after the PD and summer camp, she mentioned she was happy Matt was her co-teacher for the summer camp because Matt "was stronger" in NetLogo than she was.

Heather was less vocal than the other teachers in the PD, but she still participated in all the activities and thoughtfully contributed to discussions. At the beginning of the week, she mostly worked on her own in NetLogo, but on days 3 and 4, Heather started working on projects with Sammie. Heather thought a lot about how the activities they were doing connected to mathematics. In Heather's interview after the PD and summer camp, she described her progress towards understanding the importance of computer science education: "I'd say now I know what coding is, where before that I didn't have a clear idea of this world. I think it's important where before I was like eh whatever… I didn't think it was important for my kids to be exposed to." She even mentioned a desire to incorporate programming into a monthly club she led at her school.

The four teachers progressed productively in different ways during the PD. Matt showed a lot of development in his confidence and programming knowledge, Sammie developed a definition for computational thinking and explored some features of NetLogo that other the other teachers did not, Jaida focused on understanding the structure of the different computing activities and how best to implement the activities in the summer camp, and Heather gained some perspective on the importance of computer science for all students.

While we can identify that productive disciplinary engagement occurred, we want to acknowledge that PDE did not happen in every moment throughout the professional development. There were less productive moments, like during breaks or when we had issues with technology.

But the goal here is to highlight what did work to support PDE so that we can use these findings to inform future design choices and provide further empirical data to support the development of PDE as a theory. Table 3.2 summarizes the evidence that productive disciplinary engagement occurred during professional development.

Table 3.2: Summary of evidence of PDE.

Construct	Evidence
Engagement	• Little off-task talk/activities • Teachers made substantive contributions to discussions • Teachers expressed emotional displays, suggesting passionate involvement • Teachers continued being engaged over a long period of time • The teachers chose to come back to participate in the next year of the study, and two of them implemented computer science activities during the following school year
Disciplinary Engagement	• The teachers engaged in content and practices of the computer science discipline (e.g. debugging, loops, conditionals, variables, patches, turtles, etc.)
Productivity	• The teachers made intellectual progress - since the teachers started with no knowledge of programming and they were able to create all these things and engage in disciplinary content, it shows progress • In Matt's questionnaires, he went from feeling nervous about learning to program, to feeling excited to learn more about turtles • Example of teachers' changing definitions of computational thinking • The teachers were able to implement what they learned the next week, teaching the content and activities in a summer camp with students

How were the Four Principles of PDE Embodied?

The previous section demonstrated that productive disciplinary engagement occurred. Now this section delves deeper into the professional development to describe how the interactions of the researchers, teachers, and tools supported PDE by embodying the four principles: problematizing, authority, accountability, and resources. Table 3.3 at the end of this section summarizes the findings related to the four principles.

Problematizing

Problematizing involves going beyond just memorization and encourages people to ask questions, solve open-ended problems, and choose problems that are interesting for them. When designing the curriculum and professional development, we had many discussions around what kinds of models the teachers and students should create and what content they should focus on. Ultimately, we decided to use art as the focus, with the goal of having participants learn to code to create different NetLogo models based on their personal interests. The models and activities involved manipulating patch colors in different ways, moving turtles around to animate images, and changing the sizes of patches or turtles to look like smaller and larger pixels in an image. We chose art for many reasons, including connections to the history of Logo, Scratch, and NetLogo and the idea of art as a non-stereotypical approach to learning programming, but we were particularly excited about the potential for art to afford opportunities for creativity while connecting to different students' and teachers' interests. With this decision in mind, we intentionally created opportunities for teachers to problematize in NetLogo by designing their own models and trying out what they wanted to do during the professional development.

In particular, the first day of the PD included an overview of the project and an activity in NetLogo that helped establish norms around teachers' interactions with the rest of the activities throughout the PD. About 25 minutes into the first day, Melissa described some of our goals and expectations for the activities, including an emphasis on design and exploration:

> "The activities we developed always lead with design. So we always want kids' expressive design goals to lead the activity. So it is going to happen, I guarantee, that kids are going to have questions you don't know the answers to… By the way this happens to computer scientists all the time too. It's typical to have a challenge you have to figure out how to resolve, and that's another thing we want to model too. There's always a different way to do it or a more elegant way to do something, so it is okay to say I don't know let's figure that out, and that's a legitimate part of the practice. And that's okay because we want kids to design their own things… When you look at the curriculum, you'll notice there's no direct instruction… we really want play and exploration to drive their activity." (Melissa, Day 1)

Before we started doing any activities together in the PD, Melissa's overview helped make explicit that we wanted participants to explore and play. She said there would be multiple ways of doing things or multiple possible solutions to problems, and importantly, this was relevant to the practice of doing and learning computer science.

A little while later, about an hour and 28 minutes into the first day of PD, teachers explored patches in NetLogo for the first time after Corey gave a quick overview of what patches are and what kinds of things you can do to them (e.g. change the color, refer to patches by location, change the size of the model space or the patch size). The teachers, research team, and undergraduate computer science students all worked on their own projects and talked to each other or called out when they wanted help. At one point, Sammie called out:

> *Sammie:* I have an error, didn't you say you wanted to talk about it?
> Corey: Yeah, tell us about an error. What did you get?
> *Sammie:* I wasn't listening. I mean I was just doing my own thing.
> *Corey:* Great!

Sammie's error came up when she was exploring something new on her own, and she admitted that instead of following the example Corey went through with the group, she was just doing her own thing. Corey immediately praised and validated Sammie's choice to do her own thing, continuing to establish the norm that it was okay for teachers to explore their own problems. This led to a whole group discussion in which everyone worked together to help solve Sammie's error or bug in her code. During the discussion:

> *Corey:* 5 patches set pcolor, I'm gonna do a different color, blue. So n-of and then a number says I'm gonna choose 5 of them. So ask n-of patches set pcolor blue gives me. Alright. So we've already gone off book. And this is gonna happen. As soon as someone has an idea, we're gonna go off book. Notice when I did that there was a difference between the observer and the patches and when I wanted to talk to all patches I had two options. Well we didn't show the other option. The observer could ask if I wanted to say all the patches, I could just say ask patches, right not one of patches just ask the patches to set pcolor yellow. And this is the same as talking directly to the patches. So if you imagine what I did, here's my observer, I said yo observer could you tell all the patches to turn yellow and then the observer tells asks the patches to turn yellow. Or I could use my special form to text message line to talk to the patches.
> *Sammie:* So when you're in the observer - sorry do you, is it okay if I ask questions?
> *Corey:* It's great if you ask questions.

By bringing Sammie's problem to the group for discussion, Corey validated Sammie's act of exploration and showed that everyone could contribute to solving problems (this also relates to the PDE principle of authority, explored in the next section below). Corey normalized the idea of going "off book" and problematizing the activities. Corey also called out the fact that asking questions was an appropriate and valuable form of interaction in this learning environment.

These early interactions helped set the tone for the rest of the PD, letting teachers know that we wanted them to problematize by exploring different problems based on their interests and questions. Throughout the PD, Corey and Melissa continued to encourage teachers to try things out, explore, and play around with the PD activities and the summer camp curriculum.

Authority

We intentionally created opportunities for teachers to design their own models and try out what they wanted to do during the professional development, as the *Problematizing* section describes. The above example from the first NetLogo activity illustrates that Corey gave teachers the authority to help define what they wanted to learn and do during the PD. The norms for interaction established during this first NetLogo activity carried through the rest of the professional development. When new models or concepts were introduced, the teachers were given the authority to do what they wanted in NetLogo, with the research team there to help answer questions or provide guidance. The teachers also had an active role in defining, addressing, and resolving problems that came up, and they were encouraged to share errors or bugs with the group.

Along with the authority that teachers had over their NetLogo models, the teachers were also positioned as experts on teaching and their students' needs. The first 20 minutes of the first day of PD started with a short discussion of the teachers' pre-questionnaire responses and an overview of the grant. During this introduction, Melissa and Corey made a series of statements that helped to position the teachers as knowledgeable contributors and as models for other teachers. Melissa mentioned that one of our goals was to learn more about "what kinds of supports math teachers in particular need, ask for, want that would make it likely that they'd do this in school?" This question pointed out early on that we wanted feedback from these teachers so that we could learn from them to better support other teachers. Corey reinforced this by adding, "it really is important to use yourself as an instrument for this, so anytime you feel excited or nervous about it you want to keep a record of it. Again as Melissa said, part of the goal here is to think about how this work could spread to your colleagues and you are our best measure of what is going to be the challenge there and what is going to be needed so you're not speaking just for yourselves." Melissa also specified that "we're interested in thinking and reasoning. For you, resources you request, challenges, your perception of overlapping mathematics. You are way more connected to the mathematics you're teaching in your classroom." This statement positioned the teachers as experts on the mathematics content relevant to their classrooms and pointed out that we expected them to actively make connections between computer science and mathematics.

Additionally, the teachers were positioned as stakeholders in their learning. They were not just participating in the professional development to learn some coding. All four teachers knew they would be actively teaching the material themselves in the week after the training. They wanted to succeed as teachers, and they wanted their students to have a positive learning experience, so the teachers had an obvious stake in the development of the activities and the decision-making around the plans for the summer camp. The research team led whole group discussions after each NetLogo activity and embodied activity to hear teachers' feedback about the activity, what was difficult, what worked well, what they would change, and we implemented those changes in the written summer camp curriculum. Teachers practiced the embodied activity multiple times with changes we made based on their feedback. Additionally, teachers spent most of the time on the last PD day working together to plan, adjust, and edit the summer camp curriculum for their students.

Accountability

There was a shared online gallery space where teachers could post their work, see each other's work, and download other's projects to remix or copy bits of code. The PD facilitators often reminded and encouraged teachers to share their work in the gallery space. Teachers were also given opportunities to present their work to the group. Through both the shared gallery space and presentations, each teacher's work was made visible and accountable to others.

Corey also waited to introduce the online gallery space until after teachers had spent a little time creating in NetLogo and talking with the people sitting next to them about their work. After Corey explained patches in NetLogo and guided the group through a few examples with patch colors, he gave the teachers space to explore on their own. After only a few minutes, Corey said, "alright now check with your neighbor, what they did and that they got it." He quickly encouraged the teachers to talk to each other and share their work. This early normalization of sharing and collaborating created a need for teachers to make their work visible to each other.

When Corey brought everyone together for a group discussion a few minutes later, he finally introduced the gallery space, which made it easier for teachers to collaborate and view each other's code from anywhere in the room. Corey also encouraged teachers to look at each other's NetLogo models, download them, and remix them:

> "The last thing is uh we mentioned sharing. So right now you guys were elbow partner sharing. But what if you found something awesome and wanted to share it with the world. That's what's going on in this part of the screen where you can post to what we call a gallery…[Corey explains how to post to the gallery.] You guys can go to those galleries, see what I did and then download my model so you can play. So the idea is they find something cool, they share it, they start remixing." (Corey, Day 1)

From this introduction, the teachers knew that others would be remixing and looking at their code for the rest of the week. They could also look at Corey's code or work from any of the PD facilitators. The gallery created a space where teachers' work was accountable to Corey, the research team, and to their peers. But it also created a space where Corey's code, the computer science undergraduate students' code, and everyone on the research team's code was accountable to the teachers because everyone could see and reuse each other's work.

In addition to being accountable to each other and to the research team, the teachers were also accountable to their future students. Since the teachers knew they would soon be teaching the content to their students, there was an underlying focus on developing as much expertise as possible during the PD. For example, when the PD started, Heather expressed that she "was most nervous about encountering student questions that I don't know how to answer." Matt was also nervous to learn how to code and wanted to master the content as much as possible to be able to help his students. In his post interview, Matt reported that he didn't know the computer science content as well as he is used to knowing the mathematics content he teaches, but he felt prepared enough to help the students who were new to programming. In Jaida's post interview, she mentioned she was happy to work with Matt because he knew more of the programming content than she did. Clearly, the goal of developing the knowledge to support their students helped keep the teachers accountable for their learning in the PD.

Resources

The findings from the other three principles demonstrate some of the many resources that supported PDE. Since there were so many resources throughout the four days of professional development, I find it helpful to separate these resources into three categories: digital resources, human resources, and physical resources.

Digital resources included tools like NetLogo, the shared gallery space, Google, pre-built models, and the NetLogo color chart. NetLogo provided a resource for teachers to do and practice coding. Most of the activities for the week were centered around this resource. Decisions for what to teach, what examples to use, the vocabulary that was used (e.g. agents, turtles, patches, etc.), and what types of things to help teachers create were all based on the choice to use NetLogo as the programming platform. NetLogo itself comes with some pre-built models that teachers used as a starting place for exploring programming concepts and creating their models. The research team also added to the menu of pre-built models by creating some of our own for teachers to use. These models served as an important tool for teachers to see what was possible in NetLogo and as a resource for remixing or reusing code. The shared online gallery space was another digital resource for teachers to share their projects, which sparked discussions and further remixing or reusing of code. Google served as a resource for teachers to easily find and download images to use in their models. The research team also occasionally used Google to search for how to code something that we or one of the teachers wanted to make in NetLogo. Finally, teachers frequently used the NetLogo color chart to change their patches or turtles to specific colors. The color chart is built into NetLogo, and it matches different colors with a specific number that can be used to refer to each color in code.

Some of the human resources included the research team and undergraduate assistants, the teachers' existing mathematics knowledge and teaching experience, and knowledge of the English language. The research team designed and facilitated the PD, while the undergraduate assistants used their computer science knowledge to create example models in NetLogo and provide extra support for the teachers. Since these were experienced teachers, we intentionally drew on their existing mathematics knowledge by making connections to topics they already cover in their mathematics classrooms and their knowledge of teaching by asking them to contribute to the development of the curriculum. At the same time, teachers' knowledge of the English language helped them make sense of the new coding and NetLogo terms they learned. We especially drew on their language skills in the embodied activity, where teachers practiced translating simple English commands into pseudocode and finally into NetLogo code.

The physical resources involved the physical space we shared, NetLogo reference sheets, computers, and the grid for the embodied activity space. Being together in a physical space, around a large table, allowed the teachers to easily talk to their neighbors, have side conversations or multiple conversations at the same time, engage in group discussions, and physically move around to work with different people. Returning to the same shared physical space every day of the PD also allowed us to create a familiar and comfortable environment and a place where people could leave items overnight. The room was large enough so that we could sit on one side of the room with our computers, have a table with food and snacks in another part of the room, and have space to set up the embodied activity. The embodied activity space (the gridlines on the floor), and the physical pieces of colored paper that were used in the activity, gave us the ability to enact that activity so teachers could embody and practice what their students would later be doing. Of course, the laptops allowed the teachers to code and use NetLogo. Providing the teachers with small laptops instead of desktops also afforded the ability for teachers to easily pick up their computers and move around the room to work with different people. As one more example of a physical resource, we provided NetLogo reference sheets to everyone in the room: physical pieces of paper that listed some example pieces of code to model common NetLogo syntax (e.g. how to write a loop or a conditional statement in NetLogo, or how to refer to a specific patch).

Table 3.3: Summary of the four principles of PDE and how they were embodied.

Principle	Examples of how this principle was enacted in this context
Problematizing	• The research team encouraged the teachers to try things out by exploring and playing around in NetLogo in a variety of different ways
Authority	• The PD facilitators gave teachers the authority to do what they wanted in NetLogo, with the research team for support • The teachers were positioned as contributors and were encouraged to suggest changes to the PD and curriculum • The teachers had an active role in defining, addressing, and resolving problems that came up; they were encouraged to share their errors or bugs and suggest ways to fix them • Teachers were positioned as stakeholders: they were going to be teaching the material, so they had an obvious stake in the development of the activities and the decision-making
Accountability	• The teachers were often told to share their work in the shared gallery space, look at each other's work, and present their work to the group, making it accountable and visible to others • The teachers focused on developing expertise in the content to be able to answer students' questions
Resources	• Digital resources: NetLogo, the shared gallery space, Google, pre-built models, and the NetLogo color chart • Human resources: the research team and CS undergrads, teachers' existing mathematics knowledge, knowledge of the English language (when making sense of code / pseudocode in the embodied activities) • Physical resources: Physical room, computers, NetLogo reference sheets, grid for embodied activity space

Teacher Feedback and Continued Participation

To understand the impact of PDE on teachers' learning and development in computer science, it is important to mention some of the feedback we got from teachers in post-interviews after the training and summer camp. Each teacher was interviewed individually by a member of the research team, using a semi-structured interview protocol to cover a set of questions, with flexibility to follow the conversation where appropriate.

In the post interviews, the teachers offered some feedback to help improve the training. Matt and Jaida both expressed that a longer professional development session would be helpful to give them more time to learn the material. The teachers also wanted a clearer separation between acting as students learning the material and acting as teachers developing the curriculum. Jaida and Heather expressed that more opportunities to practice teaching during the PD would be helpful, or even some videos to see examples of how the activities can be implemented in different classrooms.

In Heather's post-interview, she explained that attending the PD transformed her views of coding and its use in the classroom:

> "It's hard for me to imagine in my 4th grade class what that looks like, but I'd say now I know what coding is, where before that, I didn't have a clear idea of this world. I think it's important, where before I was like eh whatever… I didn't think it was important for my kids to be exposed to… I think sort of seeing them light up with the power of creating something that was interesting to them is a really big takeaway." (Heather, post-interview after the PD and summer camp)

Sammie also expressed similar growth in her views on computing in the classroom:

> "At first I had no idea what we were going to do… But I see the value in it now. I think it's important for everyone to create… the importance of seeing I can create something with nothing. You have a computer, you're only limited by your ideas. And then the fact that this is a skill that could be really useful to me… I think it's far more empowering than I ever thought it to be. I feel like there's a lot of life lessons in it and I did not expect that." (Sammie, post-interview after the PD and summer camp)

The teachers expressed both nervousness and excitement on the first day, but after just four days of training, they were able to teach students and lead their first computer science lessons. We can see evidence that the teachers valued their experience if we look beyond that first summer to see how they carried that knowledge into their classrooms and in future years. For example, two teachers implemented material they learned from the PD in their classrooms during the school year - one teacher started an after-school computer science club and another led computer science Fridays in a mathematics class. They both invited our research team to help support their work during the school year. Additionally, all four teachers chose to return the following summer to participate in another CS professional development and to lead another computer science summer camp. One of those returning teachers even traveled from outside the state to participate. During the second summer following this study, the COVID-19 pandemic changed our plans of running a third round of PD. But one teacher returned a third time to create and lead her own virtual computer science summer camp, with support from the research team. Her relationship with the research team transformed over time as she took on more of a leadership role in designing and implementing her own lessons. As we reflected on the first year of the PD and summer camp in this study, we were excited to see that the first year of training carried through the school year and beyond for these four teachers leading to continued participation and the development of different teacher-researcher relationships. Members of the research team plan to explore these stories in more depth in other papers.

Discussion

In this study, I explored a professional development involving four middle school mathematics teachers learning computer science. Very few pre-service computer science teacher training programs exist, so most educators teach other subjects first, then later learn to teach computer science as a standalone subject or to integrate CS into their classrooms. Many schools and districts are rushing to incorporate computer science into their schools, so more professional development programs are needed to train existing teachers in computer science (Code.org, CSTA, & ECEP Alliance, 2020). Mathematics in particular is a popular subject for integrating computer science in K-12 schools. This paper contributes to the growth of professional development for in-service teachers, particularly experienced mathematics educators, by exploring how to support teachers' productive engagement in computer science PD.

I used productive disciplinary engagement as the framework for analysis in this paper, to show that teachers engaged productively in computer science and how the interactions and resources of the learning environment supported that engagement. In particular, the designs emphasized different kinds of flexibility in response to teachers' interactions. This flexibility was embodied through the four principles of productive disciplinary engagement, even though we did not intentionally draw on the PDE framework in our initial designs. "Addressing authentic problems and tasks requires the teacher and students to work with open, flexible and tentative plans and goals that might not be clear from the outset, and need reconfiguring also along the way (Rajala et al., 2013). This flexibility is at a core of PDE framework" (Kumpulainen, 2014, p. 218), and it matched our goal of encouraging teachers to personalize both their training and curriculum by responding flexibly to their ideas. Since this goal was a central part of our designs, it likely led to the successful examples of PDE that occurred.

The analysis also illustrated that flexibility can be embodied in several ways: in the design of activities, in the specific content covered, in the ways problems are presented to teachers, and in the resources provided. Here, I consider these different versions of flexibility as design features that can support productive disciplinary engagement with experienced teachers during computer science professional development. Table 3.4 summarizes these design features and provides brief explanations and examples of what they look like in practice.

Table 3.4: Features of flexible professional development designs and examples.

PD Design Feature	Examples in Practice
Flexibility in the design of activities, with a focus on valuing teacher expertise	The facilitators and research team made changes to PD and summer camp activities based on teachers' input, questions, and reactions to what they were learning. There were times when teachers offered ideas for changing an activity we did together in the PD, the team worked to make those changes, then we practiced the activity again later in the week with the teachers. Since the teachers were practicing and learning activities they would later lead with students, our flexibility with the activity designs was very important. While the research team designed the activities for both the PD and summer camp ahead of time, we considered the teachers co-designers of the activities during the PD. We valued their expertise as teachers and wanted them to contribute their knowledge of what kinds of activities work best with students, what would be challenging for students, what would be fun, etc.
Flexibility in the specific content covered, while redistributing authority to teachers	We had a plan for the week with an idea of what we thought would be interesting to teachers and projects they would like to create in NetLogo. However, there were many times during the PD when one or more teachers did not follow our suggested ideas and instead explored new content or asked new questions. For instance, we were not planning to talk about using variables to store patch colors, but when several teachers insisted that they wanted some sort of "undo" button, we created the button and discussed the concepts behind it with the teachers. This idea of an undo button, which was unplanned, became an important part of students' NetLogo models in the summer camp. In contrast, we could have told teachers that they needed to follow our instructions and only work on the types of projects we originally planned. But instead of ignoring teachers' bids for new content or ideas, we helped them figure out how to write the code, integrated their ideas into group discussions, or created example models to support them. In other words, the teachers had authority to contribute to their learning in important ways.
Flexibility in the way problems are presented to teachers, emphasizing open-ended problems	We purposefully presented open-ended problems for teachers to solve throughout the PD, by presenting them with NetLogo models or ideas they could build off of in any way that interested them. The facilitators and others in the room were there for support.
Providing appropriate resources when needed	The resources we provided (online gallery, printed code sheets, pre-build NetLogo models, etc.) and the just-in-time nature of the resources helped support teachers' engagement by scaffolding their learning.

It appears from the examples of how PDE occurred that the teachers in this PD often didn't listen to the facilitators or research team. The fact that teachers did not do exactly what they were told could, on the surface, seem detrimental to their learning. It is also possible teachers in other contexts could engage in similar behaviors in unproductive ways. So what made the interactions productive in this case? The shared respect and authority amongst everyone in the room seemed an important factor in this professional development. These teachers valued the computer science expertise of others in the room, and the facilitators valued the pedagogical and mathematical expertise of the teachers. Teachers were aware the facilitators had more computer science knowledge, and they often relied on facilitators for support with their learning. At the same time, they actively pushed against the prescribed lessons. But rather than dismissing the facilitators' expertise, the teachers made bids for what they wanted to learn and relied on the facilitators for help. Corey and Melissa responded by encouraging teachers to ask questions, talk about their mistakes, and solve new problems. In this way, authority was distributed amongst the teachers, research team/facilitators, and other participants. Additionally, it is important to remember that these teachers knew they were responsible for leading the same activities with students, so they wanted to master the content as much as possible. This level of built-in accountability probably helped keep teachers engaged productively in the content.

Productive disciplinary engagement was a useful framework for exploring how and why this professional development case seemed successful. However, PDE is typically used to make sense of student learning rather than adult learning. PDE has been used in some studies of prospective or pre-service teachers (Engle & Faux, 2006), but still rarely with in-service and more experienced teachers. It is worth noting that the features of the design that supported PDE in this context might not work with younger learners or learners without some relevant expertise to bring into the learning environment. For instance, even though these teachers were new to computer science, the fact that they had expertise with teaching, the needs of middle school students, and mathematics education allowed us to enact the first two design features listed above: valuing teacher expertise and redistributing authority. If these were students or first-year teachers, they would have needed more support with building a curriculum and understanding how to implement activities with students. Additionally, since this was a summer camp environment, we did not have specific standards that we needed to meet or follow, so we had some flexibility in the content that we could cover based on what interested the teachers. In a formal school environment with students, that flexibility in content might be difficult to achieve while balancing any standardized learning requirements. In other words, the flexible design features discussed in this paper supported productive disciplinary engagement during computer science professional development for in-service teachers, but it is important to remember that those features might not support PDE with other types of learners or contexts. It would be interesting to continue this work by comparing how these teachers implemented the summer camp curriculum with students and whether and how they were able to support productive disciplinary engagement with their students.

Conclusion

The activities and interactions during the professional development in this study embodied the four principles of PDE by emphasizing problematization, learners' authority and expertise, accountability, and the resources to support those principles. In just four days of professional development, in-service mathematics teachers with no prior programming experience were able to engage productively in the discipline of computer science, successfully implement a computer science curriculum with students, and become computer science advocates for other teachers during the school year and in future summers.

This study illustrates the power of productive disciplinary engagement for in-service teacher learning in computer science. It also provides an example of how the four principles of PDE can be embodied in a teacher professional development context and points to the importance of designing for flexibility and teacher expertise, authority, and choice. We hope that future work with this project will explore individual teacher's experience over multiple years of the project in-depth to better understand how teachers develop as computer science educators and advocates and what supports they need. Future work should also continue exploring how the principles of PDE are embodied in different teacher learning contexts to better understand how professional development designers and providers can support PDE for teachers learning computer science across various tools, resources, and curricula.

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