Title
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Journal
Journal of Computer Assisted Learning, 34(1)

ISSN
0266-4909

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Publication Date
2018-02-01

DOI
10.1111/jcal.12209

Peer reviewed

Received: 24 September 2016 | Revised: 29 June 2017 | Accepted: 16 July 2017
DOI: 10.1111/jcal.12209

WILEY Journal of Computer Assisted Learning

ORIGINAL ARTICLE

How teachers integrate a math computer game: Professional development use, teaching practices, and student achievement

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Funding information
Division of Graduate Education of the National Science Foundation, Grant/Award Number: DGE-1321846; Institute of Education Sciences, Grant/Award Number: R305A090527

Abstract

As more attention is placed on designing digital educational games to align with schools′ academic aims (e.g., Common Core), questions arise regarding how professional development (PD) may support teachers′ using games for instruction and how such integration might impact students′ achievement. This study seeks to (a) understand how teachers use PD resources (e.g., technology personnel and game-use workshops) for integration; (b) determine how teachers integrate games into their instruction; and (c) examine how those teaching practices are associated with student achievement. This mixed method study used survey and interview responses from elementary school teachers (n = 863) with access to PD resources for implementing a math game intervention and standardized math-test scores from their second- through sixth-grade students (n = 10,715). Findings showed few teachers sought PD assistance for integration, but many desired such support. Some reported using integrative practices (i.e., referencing game and using game-generated progress reports) to identify struggling students, whereas several found integration challenging. Teachers′ reordering of game objectives to align with lessons and viewing of game-based PD videos were associated with increased student math achievement in our OLS-analysis. However, this result was no longer statistically significant within a school fixed-effects model, suggesting school differences may influence how strongly teachers′ practices are associated with student achievement.

KEYWORDS

educational games, elementary education, math learning, professional development

1 | INTRODUCTION

Digital games have been designed and used as supplemental tools for learning in classrooms. Some games were designed solely for entertainment and later used for educational purposes, whereas other games were designed with the specific intent to teach material through drill, practice, and rewards (Shelton & Scoresby, 2011). Recently, researchers have placed more attention on designing educational games to align with teachers′ targeted content, which may assist teachers′ integration of games into their curriculum (e.g., Shelton & Scoresby, 2011). Research has shown that the uniquely interactive properties of educational computer games can improve student learning and engagement (Annetta, Minogue, Holmes, & Cheng, 2009; Tuzun, Yilmaz-Soylu, Karakus, Inal, & Kizilkaya, 2009). For example, some games can adapt to students′ differing abilities and provide progress reports for teachers to gauge students′ understanding of the material, providing teachers with feedback on areas where students need additional support. These recent technological advances have led to the design of educational games that are no longer created to accompany teaching but instead are intended to be integrated into teachers′ practices and curricula (MIND Research Institute, 2013a, 2013b). This raises new challenges for teachers, namely, how to align these tools with their curricula to benefit students. However, little is known about how to best support teachers when implementing educational games within classroom instruction, rather than using them as stand-alone tool for reinforcing skills.

Though most educational computer games supplement, not supplant, teachers′ effective integration of computer games and class instruction can help students become more engaged and increase their content learning (Wouters & Oostendrop, 2013). By using instructional support, such as reflecting on computer game content to demonstrate how it aligns with class lessons, providing supplemental tasks for further reflection, and modelling how a specific problem is solved, teachers can help students get the most out of their in-game experiences (Wouters & Oostendrop, 2013). Though integrating computer games with class instruction can be challenging (Demirbilek & Tamar, 2010), professional development (PD) programs strive to make integration easier and more efficient (Koehler, Mishra, & Yahya, 2007). These PD resources can include instructional workshops for building teachers′ understanding of new educational software, one-on-one guidance for improving efficient use of class time, and easy access to gaming-support personnel for further questions.

This study aims to contribute to the limited body of literature on how to support teachers through PD resources and computer game tools. More specifically, we ask (a) whether teachers report using PD support to integrate a math computer game with their teaching practices; (b) what reasons they report for using game features in their teaching; and (c) how their use of game-based resources is associated with students′ math achievement. We investigate these questions in the context of a digital math game intervention, Spatial Temporal Math (ST Math®; MIND Research Institute, 2013a, 2013b), because research shows that computer technology can be particularly useful for increasing math achievement (Li & Ma, 2010). ST Math was designed to integrate with teachers′ classroom instruction, advance students′ spatial understanding of math, and provide a suite of PD resources for supporting implementation. Knowing whether teachers use computer game features (e.g., reports of students′ game progression and tools for organizing game modules to overlap with class modules) to integrate game content with class content, as intended, may help future PD programs tailor their resources to best support teachers′ game implementation.

2 | INTEGRATING TECHNOLOGY IN CLASSROOMS: PD, TEACHING PRACTICES, AND STUDENT ACHIEVEMENT

Though minimally studied, research suggests that effectively integrating a math game with class instruction can be a complex and challenging task (Chen, 2008; Demirbilek & Tamar, 2010; Hew & Brush, 2007). Years of research on classroom integration of technology may shed light on how PD can be used to support teachers implementing technology, why integrating class curriculum with technology is not easy, and how teachers who utilize PD may better support the academic achievement of their students.

2.1 | PD

Generally, PD programs to support technology integration are structured to deepen teachers′ understanding of course content, and extend and improve their teaching practices (Ko, Wallhead, & Ward, 2006). Eastwood and Sadler (2013) found that providing biotechnology teachers with integrative teaching materials (i.e., pre-made lecture slides, activity instructions, and class discussion questions) led them to view class content from new perspectives and helped them facilitate collaborative activities that overlapped games with class content. The PD support of fellow educators and technological staff can assist teachers based on their individual needs (Deglau & O′Sullivan, 2006) and help them discover the most efficient and effective ways to integrate computer game content with classroom instruction (Ketelhut & Schifter, 2011).

The impact PD has on teacher implementation of digital math games has been minimally researched. However, focus group responses from middle school math teachers using a computer-based math game suggest that PD should be designed to help teachers gain a deeper understanding of the game being implemented and how to link game-based teaching practices to the content of the class (Evans, Nino, Deater-Deckard, & Change, 2015). This suggests that to best adapt PD resources to teachers′ needs when implementing educational computer games, developers of PD programs need to know both how teachers use the resources provided and how these resources and the game fit within the context of their classroom instruction.

2.2 | Integrative teaching practices in classrooms

Technology-based integrative teaching practices are defined herein as the use of technology for student exploration, teacher-driven design and supportive assistance, active use of computers for problem solving, and comfortable use of the computer-based platform for targeted learning outcomes (Moersch, 1995). Recently, some educational computer games have been programmed with in-game extensions designed to ease teacher use and advance student play, which could help teachers integrate game content with class instruction (e.g., MIND Research Institute, 2013a, 2013b). For example, the ability to restructure game content to align with predetermined course curriculum could help a teacher reference game content during class lectures and activities. When teachers incorporate integrative practices in their classroom, such as modelling problem solving in the game and helping students reflect on content, students are better able to learn educationally relevant information within games. For example, Wouters and Oostendrop′s (2013) meta-analysis of 27 studies comparing the use of educational computer games with and without integrative teaching instruction showed that coupling integrative instruction with the games can improve students′ learning experiences. A deeper understanding of how these types of tools work may help teachers effectively integrate computer games into their classes (Shuldman, 2004).

Teachers integrate educational computer games within classes to varying degrees. Some teachers, particularly those who like and are experienced with technology, may explore and experiment with computer-based programs (Ertmer, Ottenbreit-Leftwich, Sadik, Sendurur, & Sendurur, 2012). In contrast, teachers with negative perceptions of or little experience with technology may resist altering their teaching practices (Ertmer et al., 2012; Rakes, Fields, & Cox, 2006). Regardless of teachers′ past experiences using technology, studies find consistent integration of course curriculum and computer game content to be quite challenging (Demirbilek & Tamar, 2010).

Research has identified some of the challenges that teachers encounter integrating technology-based activities into teaching practices, including time constraints to learn and use new technology, limited access to technical support, and, in some cases, conflict with school institutions that do not value educational technology (Hew & Brush, 2007). When applied to educational games, each of these potential “barriers” may inhibit teachers′ abilities to learn, utilize, and integrate educational computer games. For example, math teachers have reported that they struggled finding enough time to cover class material and integrate computer game time (Demirbilek & Tamar, 2010), especially under pressures to improve students′ test scores (Chen, 2008). Additionally, a randomized control trial of a math game intervention showed that even when the game was strongly aligned with the math curriculum, teachers still rarely used integrative teaching practices (Rutherford et al., 2014). It seems that integrating computer games can be taxing for teachers, requiring extensive time to learn the technology and alter curricula (Demirbilek & Tamar, 2010), but strong integration is imperative for achieving desired student learning outcomes (Wouters & Oostendrop, 2013). This raises the question, how do teachers use game-based PD to alter teaching practices to help students understand the content?

2.3 | Linking PD to student outcomes

Prior research examines the link between PD, teaching practices, and student learning and has provided frameworks for studying and designing effective PD resources (e.g., Birman, Desimone, Porter, & Garet, 2000). Fishman, Marx, Best, and Tal (2003) proposed that PD can shape teachers′ knowledge, beliefs, and attitudes about the class content and pedagogical practices, influencing teachers′ facilitation practices, and ultimately leading to the targeted goal of impacting students′ academic performance. Student performance may then modify teachers′ existing knowledge, beliefs, and attitudes (Fishman et al., 2003). This model can also be applied to educational game-based PD and its potential impact on student outcomes. For example, one study (Rutherford, Long, & Farkas, 2017) examined the association between teachers′ value for a PD designed and provided by the developers of a math game and their self-efficacy for implementing the math game into their classroom. Structural equation modelling analyses showed that teachers who indicated the PD was useful also had higher reports of self-efficacy for using the math game. Furthermore, there was a positive, although small, statistically significant association between teachers′ self-efficacy for using the math game and student achievement. The impact of PD resources may influence teachers′ knowledge and beliefs about using educational games for teaching, which may drive the way they facilitate classes and impact students′ learning experiences.

3 | CURRENT STUDY

This study was designed to help future developers of PD to improve their design by identifying ways that encourage and guide teachers′ use of integrative teaching practices to create more effective learning environments for students (Wouters & Oostendrop, 2013). This study extends previous literature by addressing how elementary school teachers use PD resources and computer game features to assist with game integration, and identifies how those self-reported teaching practices are associated with students′ math achievement scores. The following research questions are examined:

RQ1. Do teachers report using PD support to integrate a math computer game with their teaching practices?

RQ2. For what reasons do teachers report using game features in their teaching practices?

RQ3. How is teachers′ use of game features associated with students′ math achievement?

4 | RESEARCH DESIGN

This mixed-method study is an extension of a randomized control trial that investigated the effectiveness of the Spatial Temporal Math (ST Math) computer game intervention, created by the MIND Research Institute (MIND), as implemented in 52 Southern California schools starting in 2008 (see Rutherford et al., 2014). ST Math was designed to teach mathematics concepts to elementary-aged students using visual manipulations while providing in-game features that support teachers during instruction. Within ST Math, students solve math puzzles (i.e., pictorial representation of how many pie-pieces equal the fraction given) to remove obstacles blocking the progress of the ST Math penguin, Jiji (MIND Research Institute, 2013a, 2013b). Although the narrative remains the same, the complexity and difficulty of math puzzles increases throughout the year and at every grade level to align with Common Core standards. This study was designed to see how teachers utilize PD support for better integrating the math game into their class instruction. Interviews were conducted with 12 teachers from three schools with and three schools without increased student achievement scores after implementing ST Math. After identifying patterns in responses across teacher interviews, a survey was created to understand if the complete pool of teachers (n = 863) had experiences similar to those interviewed. Interview and survey responses from teachers were then used to identify associations between teachers′ practices and students′ state-based, standardized math test scores.

4.1 | Participants

Participants (n = 863 survey; n = 12 interview) taught pre-kindergarten through 6th grade, with most (80% of sample) having taught for 10 years or more. All teachers who participated in this study had teacher-based support available through MIND. Most (81%) teachers participated in a 1-hr introduction PD workshop before the school year began, which primarily focused on the game′s interface. This teacher training, additional workshops, and resources were marketed as "PD resources" and are identified as such for the duration of this paper. Teachers could also attend additional workshops to learn the mathematical models underlying the game and integrative practices. Student-level analyses focus on students within 2nd–6th grade (n = 10,610) who were predominantly Latino/Hispanic (Hispanic = 86.9%; Asian = 5.5%; White = 4.8%; Other = 2.9%) and eligible for the federal free/reduced lunch programme (89%).

4.2 | Data collection

4.2.1 | Teacher interviews

To gain a deep understanding of teachers′ practices and experiences with ST Math, the research team selected six schools from the 52 study schools to participate in interviews, three with 3rd grade-level student gains in standardized California Standards Test (CST) math scores after using the math game and three schools without such gains. Once these six schools were identified, two 3rd grade teachers from each school were selected and asked to participate in interviews. In this evaluation, 3rd grade teachers had the most variance in their experience with ST Math. Due to staggered enrollment from early to later grades, 3rd grade teachers had 1 to 5 years of ST Math use. The randomized control trial was designed to investigate how variations in experience with the math game influenced teacher use and student gains. Thus, selecting third grade teachers to interview offered the greatest opportunity to discuss the varied experiences with the program. Of the 12 teachers who agreed to participate, 11 were 3rd grade teachers and one was a 2nd grade teacher who taught 3rd grade the year before.

The two teachers from each school were asked to participate together in a 30–60 min, semistructured interview held at their school, with two research team members and two to three staff members from MIND Research Institute. Interviews included questions prepared in advance and those that arose from the natural flow of conversation. Teachers were asked questions such as "How do you think the math game has impacted your mathematics teaching?" and "What do you think we should know about your experiences integrating the game into your math teaching?" These questions were then used to assess teachers′ patterns in accessing PD resources, benefits and challenges of game implementation, and use of the math game during class.

4.2.2 | Teacher surveys

The research team e-mailed an online survey developed from the teacher interview responses to teachers in the 52 participating schools. This e-mail described the scope, time, and voluntary nature of the study. Teachers had 6 weeks to complete the survey; the regional school district provided codes linking teachers with their students. There was a 73% response rate on the survey.

The survey items included open- and close-ended questions (Likert scales and multiple choice) about avenues of seeking assistance to understand the game, use of math game tools, demographic history (e.g., number years of teaching), and past use of computer-based technologies. In this study, we analysed responses to one survey question that asked: "For what purposes do you use the tools in the math game? (Check all that apply)." This prompt was followed by a list of 11 teacher-based game tools that teachers may have used for class instruction (see Table 1). Teachers were asked to indicate whether they used those tools by checking the box ("yes, that applies to me") or leaving it blank. Missing data (unchecked boxes) were treated as meaningful, because a blank box indicated that the associated items did not apply to teachers.

4.2.3 | Student measures

As per usual protocol, school districts collected students′ test scores yearly from 2008 to 2013, to measure student achievement in math. The scaled math CST scores from 2012 and 2013 were used for this study to provide standardized estimates of any potential changes in students′ math achievement before and after teacher-based variables were measured. Along with the CST data, the districts also provided demographic information, such as birthdates, language proficiency, ethnicity, and gender. We used this demographic information as control variables in the student achievement analyses.

TABLE 1 Teachers′ reported use of game-based PD resources. For what purposes do you use the tools in the math game? (Check all that apply.)

Label	Frequency[a]	Percentage (%)
Viewing class reports	772	89
Checking on students with issues	624	72
Managing classes	556	64
Re-training students on password	471	55
Reordering objectives	371	42
Test driving games	331	38
Viewing RTI[b] reports	194	22
Accessing classroom resources	126	22
Accessing manuals and guides	76	9
Using whiteboard mode[c]	55	10
Viewing PD videos	27	3

Note. PD = professional development; RTI = response to intervention.

[a]Frequencies represent the number of teachers who checked "yes" on their survey.

[b]RTI reports are individual progress reports of how each student is doing at each level of the math game.

[c]Whiteboard mode is a tool that teachers can use to project the math game on the interactive class whiteboard.

4.3 | Data analysis

4.3.1 | Qualitative analyses

To answer RQ1 and RQ2 regarding teacher use of PD resources and math game tools, interviews with teachers were audio recorded and later transcribed. After reading through interview transcripts, we identified common themes that emerged from these teacher responses. Using a bottom-up processing method (Strauss & Corbin, 1994), emergent themes were then used as the basic coding framework. The coding framework was created to identify the types of PD resources teachers did or did not utilize, the ways teachers did or did not integrate the math computer game, and how the math game influenced teachers′ perceptions and practices of math instruction. After revising the coding framework, all six interview sessions were coded, identifying common themes across teachers′ responses.

4.3.2 | Quantitative analyses

To provide a broader understanding of teachers′ support seeking practices and how they used the computer game with class content, we used survey data from all participating teachers (n = 863) to further address RQ1 and RQ3. For RQ1, we calculated frequencies of how many teachers used math game features for the various purposes shown in Table 1.

To answer RQ3, concerning the association between teaching practices and changes in students′ achievement scores, we dichotomized each teaching practice, indicating whether it was used (1) or not (0). To identify how each teaching practice was associated with changes in students′ (n = 10,610) achievement scores from 2012 to 2013, regression analyses were used including each dichotomous predictor variable together in the regression. Because all teacher surveys and student demographics were collected before 2012, CST change scores (students′ 2012 CST scaled score subtracted from their 2013 CST scaled score) were used to understand whether students had any gains or losses in math achievement after the teaching practice variables were measured (Allison, 1990). PD and teacher practices are likely to be correlated with school; therefore, it is possible that unobserved between-school differences may drive associations between teacher practices and student achievement. We estimated a second model using school fixed effects to illustrate how teaching practices were associated with student achievement within schools, controlling for observable and unobservable characteristics that might exist between schools (Clarke, Crawford, Steele, & Vignoles, 2010). Both our fixed effect and non-fixed effect models included Huber-White standard error adjustments at the classroom level, to account for nesting of students within classes. The following model for each individual student was analysed:

$$\begin{aligned} \Delta\, Students' \; CST \; math \; scores &= b_0 + b_1 Teachers' \; practices \\ &\quad + b_2 Students' \; demographics \\ &\quad + b_3 Class + e. \end{aligned}$$

As shown above, the dependent variable was change in students′ CST math scaled scores (from 2012 to 2013). It was also possible to simply use 2013 CST scores as the dependent variable and control for 2012 CST scores, and doing so produced similar results as those displayed in Table 2. However, this study specifically sought to determine how teaching practices affected changes in student achievement. Therefore, using CST change scores, a dependent variable that measured potential change in math achievement during the time-frame when teachers used the teaching practices, was best suited for these analyses (Allison, 1990). The key independent variables were the individual math game teaching tools that teachers had the option of using during that school year, denoted as b_1*Teachers′ practices* to represent all 11 teaching practices within one variable. The b_2*Students′ demographics* variable controlled for student ethnicity, grade level, gender, low-income (eligibility for free reduced lunch program), and whether they were English language learners. These variables were included in regression models to demonstrate the association between achievement and teaching practices after controlling for these characteristics, and with school fixed effects—denoted as b_3*Class*, which is a proxy for a series of dummy variables for all schools except one. Last, b_0 is a constant and e is a student-level error term.

5 | RESULTS

5.1 | Teacher use of PD support for game integration

RQ1 focused on whether teachers used PD support to integrate the game with their teaching practices. We identified three themes from the 12 teachers′ interview responses: Teachers had (a) little awareness of PD resources, (b) strong desire for more PD support for integration, and (c) rarely sought PD support.

5.1.1 | Awareness of PD resources

Nine of the 12 teachers stated that they only participated in the initial PD workshop held at the beginning of game implementation. Several teachers claimed that the workshop helped them log into the game, but rarely addressed game integration practices. Even though MIND personnel were assigned and available to assist each school, several teachers were not in contact with them, and some shared that they were not aware those resources existed. Furthermore, some teachers were unaware of certain math game tools (e.g., reordering objectives or test driving games) or could not access them, leaving these teachers unable to assist students who needed help during computer lab sessions. A couple of teachers shared that they had to learn different game puzzles when assisting struggling students during computer lab sessions. For example, one teacher described:

> *I didn′t know what [the students] were doing because I haven′t been playing the games, so I ask them, "what is the point of the game, what are you supposed to be doing?" Some could kind of tell me, some are like "I have no idea."*

Situations such as this caused teachers to feel uneasy using the game, prompting them to comment on how they wished they had additional PD support.

5.1.2 | Desire for PD support

All teachers felt that they would strongly benefit from PD sessions that provided the opportunity to play the game with experienced personnel, which would enable them to learn strategies for helping students and integrating the game. As some students progressed to advanced levels, teachers were unaware of the game′s purpose and underlying mathematics. Thus, teachers felt unable to assist struggling students. Also, teachers expressed challenges aligning the game with their curriculum. When asked what type of PD support they desired, one teacher explained:

> *It would be nice to know how to integrate it into our classroom teaching … because, it doesn′t transfer—that′s ST Math, this is our classroom. And it doesn′t blend.*

The math game and in-class lessons were sometimes perceived as two separate entities, rather than blended forms of teaching the same content.

5.1.3 | Seeking PD support

Teachers expressed a strong desire for PD support to help understand how to use game features and integrate the game into their instruction, but most (eight) of the teachers had not sought such support prior to their interview. Many teachers did not initiate contact with PD support to help integrate the math game with class content, possibly because they did not know whom to contact for support or that this type of support was available. Thus, several of the teachers mentioned approaching colleagues for support, rather than IT staff or MIND personnel. Interviews suggest that the teachers had limited exposure to

TABLE 2 Regressions of standardized California Standards Test (CST) change score on teaching practices

	OLS regression with class clustering	School fixed effects with class clustering
Teacher practices	CST 2012–2013 change score	CST 2012–2013 change score
Managing classes	−0.06 (0.05)	−0.07 (0.05)
Reordering objectives	**0.12*** (0.05)	0.09 (0.05)
Viewing class reports	0.12 (0.07)	0.09 (0.07)
Viewing RTI reports	−0.05 (0.05)	−0.02 (0.05)
Checking on students with issues	−0.10 (0.06)	−0.10 (0.06)
Test driving games	−0.03 (0.05)	−0.07 (0.05)
Using whiteboard mode	0.01 (0.09)	−0.01 (0.08)
Retraining students on passwords	0.06 (0.05)	0.06 (0.05)
Accessing manuals and guides	−0.03 (0.08)	−0.02 (0.08)
Viewing PD videos	**0.30*** (0.12)	0.25 (0.14)
Accessing classroom resources	0.01 (0.07)	0.04 (0.06)
Grade level (grade 2 as reference group)		
Grade 3	**−1.24*** (0.56)	−0.95 (0.59)
Grade 4	**−1.51**** (0.56)	**−1.23*** (0.59)
Grade 5	**−1.48**** (0.56)	**−1.18*** (0.59)
Grade 6	**−1.88**** (0.57)	**−1.56*** (0.61)
Ethnicity (Whites as reference group)		
Asian	0.09 (0.07)	0.11 (0.07)
Hispanic	−0.11 (0.06)	−0.04 (0.05)
Other	−0.09 (0.08)	−0.06 (0.07)
Additional controls		
Male	−0.01 (0.02)	−0.01 (0.02)
English language learners	**0.08**** (0.03)	**0.08**** (0.03)
Low income	−0.03 (0.04)	−0.03 (0.04)
CST math score 2012		
Constant	−0.06 (0.07)	**1.44*** (0.56)
N	10,715	10,610
R-squared	0.012	0.034

Note. The "Other" group under Ethnicity includes American Indian/Alaska Native, Black/African American, Filipino, Native Hawaiian, Samoan, and Other Pacific Islander.

**p* < .05;

***p* < .01;

****p* < .001.

Bold values are statistically significant.

PD that would support integration of the software with their existing curriculum.

5.2 | Connecting game features with teaching practice

Our analysis for RQ2 draws from interview and survey data to understand how teachers integrated the math game into their instruction. To begin, we analysed the interviews and six themes emerged: (a) *referenced the game during class lessons*, (b) *used visual aids*, (c) *reordered computer game objectives*, (d) *test drove games*, (e) *identified struggling students*, and (f) *changed their teaching perspectives*.

5.2.1 | Referenced the math game during class lessons

Six teachers stated that they referenced the math game during class lessons to help students recall previous game content saying, "Oh because, [do you] see [here]? Do you remember when we did this in ST Math?" Three teachers said that they only mentioned the game during class to allow students to make their own connections, rather than doing step-by-step demonstrations of how the game content overlapped with class.

5.2.2 | Used visual aids

External visual aids were used to help students better understand the math computer game, and game visual aids were used to help students better understand class lessons. For example, several teachers stated that they used images from the game during class and lab sessions to demonstrate how to move through puzzles within the game, connecting the game with the class content. Additionally, two teachers used personally created or textbook math visual aids to help struggling students understand the math game content.

5.2.3 | Reordered game objectives

Four teachers used teacher-based math game tools to reorder learning objectives within the game to align game content with class content. Others left the order of game objectives untouched (six) or could not reorder objectives due to school district restrictions (two). Those who did reorder objectives did so to "integrate game content with what was being taught at that time." Teachers were occasionally surprised to hear certain integrative teaching tools existed, whereas others were aware of the tools but had no time to integrate the game into their lessons. One teacher struggled over how much content was needed to fit into a year, stating, "… sometimes it feels like, gosh, I don't have enough time for this particular math topic … I have to be really careful in terms of my use of time or I have to be very specific on which lessons I'm going to remove …" Thus, there was both uneven awareness and application among the teachers of ways they could reorganize the math games to better meet their needs.

5.2.4 | Test drove games

To learn more about the puzzles within the math game, four teachers reported playing the game outside of class. This extra time testing out the game gave teachers material to demonstrate on the overhead projector in class, also making it easier to assist struggling students one-on-one during labs.

5.2.5 | Identified struggling students

Teachers found the game useful for identifying struggling students. For example, individual students' response to intervention reports and class progress reports were automatically generated by the game, allowing teachers to review and identify students' mathematical strengths and weaknesses after each computer lab session. Teachers stated that the reports helped them pinpoint students who did not ask for help by showing them which areas students continuously struggled with in the game. Additionally, the game requires students to complete certain puzzles to progress further in the game. A red flag appears on the screen after several failed attempts or after a student clicks the flag to request assistance. Teachers stated that these features helped initiate conversations with students who were struggling with the content, especially students who were uncomfortable raising their hand in class.

5.2.6 | Changing teaching perspectives

A couple teachers claimed that the game helped them understand and describe the math concepts to students. One teacher stated: "ST Math helped me … explain it a little bit better just because I visually saw it." However, not all participating teachers shared this sentiment. One teacher specifically claimed that the game had no impact on the way he/she described math concepts to students.

These interview findings suggest that the PD opportunities that teachers participated in provided limited support for how to use various game features while teaching and that teachers varied in their use of game features, with overall low use of features MIND provided for classroom integration. To investigate if these themes were prevalent across a broader group of teachers, we analysed the teacher surveys (n = 863). Frequencies (see Table 1) describe the prevalence of teachers' use of game tools.

It appears that most teachers used game features to view reports of how the class (i.e., students collectively) was progressing through the game, to check on struggling students during computer lab sessions, and to manage class sessions. It was less common for teachers to use game features for viewing PD videos or using whiteboard mode, an interactive projector that allowed teachers to project the math game on the board.

5.3 | Teacher game use and student outcomes

Finally, RQ3 asked how teachers' use of math game features was associated with student math achievement. Model 1 within Table 2 displays results from the individual student-level regression; Model 2 displays results from the school fixed effects regression.

Looking both between and within schools together (Model 1), two teaching practices were associated with larger student CST change scores. As shown by the standardized effect sizes (betas), having teachers use the math game to reorder game objectives was positively associated with increases in students' CST math scores (B = 0.12, SE = 0.05, p < .05). Additionally, having a teacher who used the math game to view PD videos was a statistically significant predictor of increases in math CST scores (B = 0.30, SE = .12, p < .05). However, these associations were reduced in size and failed to attain statistical significance after the application of school fixed-effects in Model 2.

6 | DISCUSSION

6.1 | Teacher use of PD support

Teachers′ responses suggest that consistent dialogue between teachers and PD support may be key to strengthening teachers′ knowledge of the game tools available to them. Other research finds Web-based PD platforms to be effective when coupled with face-to-face PD interactions, yet it is the consistency of support that makes sustaining impacts on teachers′ practices (Ketelhut & Schifter, 2011). Many teachers in this study attended the introduction PD workshop to learn about the math game and how to access technical support, but most did not maintain consistent contact with PD resources. Yet teachers desired PD demonstrations of integrative teaching practices. Although those types of PD resources exist (Koehler et al., 2007), the communication line between supporting PD staff and teachers seemed weak. Strengthening and maintaining contact between teachers and PD personnel may be key for increasing teachers′ use of integrative teaching practices (Ketelhut & Schifter, 2011) and developing effective computer game-based learning environments (Wouters & Oostendrop, 2013).

6.2 | Teacher use of computer game features and their associations with student achievement

Teachers reported varied use of game features for instruction. Some teachers verbally and visually referenced the math game during class, reminding students that the game aligned with class lessons, potentially bringing students′ attention to the relevant math content. Additionally, teachers used the game to identify and reach out to struggling students, potentially helping them improve. Similar to findings from Eastwood and Sadler′s (2013) case studies, some teachers in this study who interacted with the game during or outside of class developed new perspectives and strategies for describing math problems to students. Fewer than half of the teachers used the integrative teaching practice of reordering game objectives to align with class lessons, which could improve students′ recognition of underlying connections between game concepts and class instruction (Wouters & Oostendrop, 2013). Ultimately, it appears that a stronger, consistent connection between PD support and teachers may help teachers feel more informed and better prepared to use the various teacher-based tools within the game, helping them to better integrate game content with class instruction.

Findings indicated that two teaching practices had a positive statistically significant association with increases in student math achievement. The OLS-regression output indicated that using the math game to reorder game objectives and the viewing of PD videos were associated with increased student math achievement scores. Taking the time to align course and game content can give students the in-depth practice that they need to truly grasp the math material (Demirbilek & Tamar, 2010), and those teachers who indicated using this practice had students whose change scores were one tenth of a standard deviation higher than students of teachers who did not. An effect three times as large was found for those who indicated watching the math game PD videos. Given that many teachers reported only receiving the initial PD, those who watched the videos may be a unique group—indeed only 3% of teachers reported this practice.

It should be noted that the inclusion of school fixed effects eliminated any statistically significant associations between teacher practices and student achievement change. This suggests that, within these data, unobservable differences between schools likely impacted the way teachers′ practices affected students′ achievement. Evidence from the literature supports this proposition, noting that school leaders, context, teacher collaboration, and local supports influence the impact of PD and implementation of educational technology (Anderson & Dexter, 2005; Penuel, Fishman, Yamaguchi, & Gallagher, 2007).

Well-designed PD support has the potential to assist teachers with using game-based tools in a way that positively impacts student achievement. Both individual and school fixed-effects regression models indicated that many of the teaching practices examined did not have a statistically significant association with students′ achievement. Perhaps stronger PD support for understanding and utilizing the tools and resources available could increase the impact each practice could have on students′ achievement. Even game-based PD resources, such as test driving games, viewing students′ in-game progress reports, and using the whiteboard mode may have produced stronger effects on students′ achievement in the OLS and school fixed-effects models if teachers were made more aware of such resources and were able to form and maintain an active line of communication to PD personnel. Researchers (e.g., Kratochwill, Volpiansky, Clements, & Ball, 2007) suggest that PD programs providing multiple workshops and activities to support schools′ needs for sustainable implementation of interventions may best emphasize the links between teachers′ practice and student outcomes. Given the lack of engagement among our study teachers in repeated or consistent ST Math PD, this integration seems unlikely to be achieved.

6.3 | Limitations

Our main limitations rest with the sample and measures. Relying on teacher self-report may miss important variance in actual implementation that can better explain both integration between ST Math and teacher practices and their connection to student achievement. As noted, our sample was largely made up of teachers with 10 or more years of teaching experience; results regarding technology integration might vary according to teaching experience (Baek, 2008). With less expertise, novice teachers might be less inclined to integrate technology (Rakes et al., 2006) or perhaps be more accustomed to technology use and integration (Ertmer et al., 2012). Also, because only third-grade teachers were interviewed, it is possible that teachers of different grade levels may have different perceptions, especially because math content and students′ ages vary across grades. Furthermore, our results may be driven by omitted teaching variables not captured by this study′s survey. For example, the effect of reordering game objectives may be due to confounding factors such as extensive math knowledge or technology competence (Mishra & Koehler, 2006).

Last, because the student-level analyses required students′ CST scores from 2012 to 2013, along with teacher survey responses, the sample size decreased from 11,889 to 10,610 students as more predictor variables were added. Chi-squared difference tests comparing included and excluded student participants show that those included in the study were more likely to be Hispanic ($p < .001$) or eligible for free/reduced lunch ($p < .001$) and less likely to be an English language learner ($p = .001$), White ($p = .02$), or from other ethnicities ($p = .01$). These differences may influence the generalizability of our results.

7 | CONCLUSION

Prior research has found that educational computer games can positively impact student learning (Annetta et al., 2009). This study aimed to better understand how PD could support teachers in using educational computer games and how the use of these resources is associated with changes in student achievement. We found that teachers' integrated use of the math computer game was associated with improved student achievement. Overall, findings also suggest that teachers recognize a need for greater resources and this need was not completely met by the PD resources provided and/or utilized. Moreover, although math game companies market their teacher-based resources as "PD," the support that teachers chose to participate in herein seemed to be more aligned with "teacher training." Although similar, teacher training is focused on building teaching skills, whereas PD resources are to support teachers' professional growth. In addition to technical support, it is important to emphasize resources that help teachers to understand course content and pedagogical practices—this may be key to improving their confidence and competence while teaching students (Mishra & Koehler, 2006). PD that shows teachers how computer games can be integrated into and supportive of classroom practices may ultimately benefit student learning and overcome the negative perception that educational technologies are distractions from school instruction (see Demirbilek & Tamar, 2010). Future research should strive to identify successful forms of PD support, perhaps utilizing resources that accommodate busy teacher schedules, such as blending online and in-person resources (Ketelhut & Schifter, 2011). Identifying resources that teachers find both easy to use and relevant to their teaching may be key to technology integration and, ultimately, increased student learning.

ACKNOWLEDGEMENTS

National Science Foundation's Graduate Research Fellowship Program is funded by their Division of Graduate Education of the National Science Foundation (Grant DGE-1321846). Any opinion, findings, and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation. This research was also supported in part by grants from the Institute of Education Sciences (Grant R305A090527).

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How to cite this article: Callaghan MN, Long JJ, van Es EA, Reich SM, Rutherford T. How teachers integrate a math computer game: Professional development use, teaching practices, and student achievement. *J Comput Assist Learn*. 2017. https://doi.org/10.1111/jcal.12209