COVER PAGE

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RESEARCH ARTICLE

Instructors' technology experience and iPad delivered intervention implementation: a mixed methods replication study

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Abstract Instructor facilitation is an essential element in the successful implementation of technology-based interventions in authentic school settings. This manuscript reports results from two studies conducted during the development of KinderTEK, an iPad delivered kindergarten mathematics intervention, to determine the relationship between instructor-reported technology experience and intervention implementation, as measured by student use. Study results show participating instructors had a range of pre-intervention technological experience with iPads and this range corresponded with variable student use in terms of both within class variability of student use and percentage of students meeting the duration of use target. Consistent with previous research, findings also indicate that second-order technology barriers may be most influential on intervention implementation; however, the quantity of barriers reported (regardless of type) was also associated with the percentage of students meeting target durations of use in each class. Lastly, instructors who reported moderate experience with iPads and/or no barriers to technology integration demonstrated the least desirable student use patterns. Implications for technology-based intervention implementation and professional development are discussed.

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Introduction

Teachers strive to deliver specialized and individualized instruction to address the needs of all students. To differentiate instruction, educators are turning more frequently to technology-based interventions designed to increase engagement, individuate instruction, and provide efficient, embedded progress monitoring. Unfortunately, the efficacy of technology-based interventions is inconclusive and sometimes contradictory (Young et al. 2012). Inconsistent implementation may be one explanation for these ambiguous findings (MacDonald 2014; Valdez 2005). Like traditional interventions, technology-based interventions are intended for use in specific contexts under particular conditions. However, the extent to which technology-based interventions are implemented as intended remains largely unexplored. This manuscript provides an evaluation of qualitative and quantitative data generated in two studies of KinderTek (KTEK), an iPad-delivered kindergarten mathematics intervention, to determine the relationship between instructor-reported experience with technology and intervention implementation.

Supporting early mathematics development

One area in which technology-based interventions could have a significant impact is in the area of early mathematics. Longitudinal studies of mathematics achievement indicate kindergarten mathematics to be foundational to future mathematics performance (Morgan et al. 2009), and mathematics difficulties in the late elementary grades can often be traced back as early as kindergarten (Bodovski and Farkas 2007; Duncan et al. 2007; Hanich et al. 2001). Accordingly, efforts to create effective early mathematics interventions targeting the development of whole number understanding and proficiency (Jordan et al. 2012) are crucial to ensure students have a foundation on which to build an increasingly robust and complex understanding of mathematics. These targeted interventions provide intensive instruction to students whose academic achievement levels require intervention above and beyond core classroom mathematics instruction (Fuchs et al. 2012). Encouragingly, recent research reports suggest that a number of technology-based early mathematics interventions show promise for improving mathematics achievement for preschool, kindergarten, and early elementary students (Fien et al. 2016; Foster et al. 2016; Schacter et al. 2016) However, schools continue to encounter resource and time obstacles to delivering individualized, targeted intervention instruction, particularly in the area of early mathematics (Strand Cary et al. 2015).

Educational technology use

Technology-based interventions can mitigate resource and time challenges, particularly if the interventions customize instruction to individual students' needs (Taylor 2004). If devices, software, and applications are affordable and compatible with classroom contexts (Keengwe et al. 2012), such interventions are potential answers to the intervention implementation dilemma in resource-strapped contexts (U.S. Department of Education

Office of Educational Technology 2016). However, questions remain about the extent to which educational technology can reliably improve student outcomes (Slavin and Lake 2008; Young et al. 2012), and this lack of efficacy evidence is problematic.

Recent survey results suggest technology use is quite prolific in US schools (Gray et al. 2010), but not clearly linked to student gains. Most contemporary classrooms involve either teacher or student use of technology, and teachers report technology has positive effects on teaching and student engagement (DigEdu 2014). Additionally, mobile technologies such as iPads are ubiquitous in today's schools, and nearly 40 % of all 2–4 year-olds have a working knowledge of iPads and tablets (Common Sense Media 2013). Educational technology is also common in the early grades and young children are using tablet-based apps to practice early academic skills. In fact, nearly 72 % of iTunes top selling apps are geared toward preschool and elementary-aged learners (Common Sense Media 2013), and researchers report that iPads can be used to improve young children's learning (Kermani and Aldemir 2016; Ray 2015). Notably, however, fewer teachers report technology has strong effects on student achievement and learning outcomes, and teachers attribute these inconsistencies to a variety of technology-based (e.g., lack of hardware) and logistical (e.g., loss of class time) barriers (DigEdu 2014). Although students often use technology-based educational interventions independently, teachers, classroom structures, and school capacities are extremely important factors in intervention implementation.

Issues in technology-based intervention implementation

Addressing the current shortcoming of technology requires a focus on teacher facilitation and integration of technological materials (U.S. Department of Education, Office of Educational Technology 2016), which is crucial for successfully integrating technology-based interventions in authentic learning contexts (Hughes 2005). Educators' training and prior experiences with technology can affect the integration of classroom technology (Matzen and Edmunds 2007) and create barriers to successful technology-based intervention implementation, resulting in limited implementation and student use (Palak and Walls 2009). Prior research has explored the impact of multiple types and levels of barriers to technology use (Ertmer 1999). First-order barriers include general teaching and school-based demands, as well as challenges related to technological functionality, training, and support. Second-order barriers include personal fears, disinterest, and distrust.

Regardless of type, barriers to classroom technology use are surmountable. Successful classroom integration of technology-based interventions requires instructors to enact systems supporting use of the intervention. For example, proper training and modeling of student-centered technology integration has increased the likelihood of teachers successfully integrating technology in their classrooms (Matzen and Edmunds 2007). Factors such as previous experience, comfort with technology, and self-perceived barriers to technology use impact the extent to which teachers are able to integrate educational technology skillfully into traditional academic structures. Additionally, the consistent, standardized implementation of educational interventions is an important aspect of replicable research. The ability to compare the performance of treatment and control groups in development studies is dependent on a relatively high level of consistency within groups with regard to instructional exposure and treatment intensity (Durlak and DuPre 2008; McKenna et al. 2014). Thus, teacher experience with technology and barriers to technology integration are important considerations for technology-based intervention development and implementation, and the relationships between these factors and technology-based intervention implementation should be studied explicitly.

This two-study investigation explored whether instructor experience with technology, measured by iPad experience and self-reported barriers to technology integration impacted implementation, measured by time of student use of KTEK, an early mathematics intervention delivered through a system of apps that aims to assist students who struggle in math. Research questions were: (a) How does instructor experience with technology and KTEK intervention implementation vary in each study? (b) To what extent is instructor experience with technology related to the implementation of the KTEK intervention as measured by student use? (c) How are barriers to classroom technology use related to intervention implementation? and (d) To what extent are study 1 relationships replicated in study 2?

Methods

KTEK development began in the fall of 2011 and culminated with a pilot study conducted in the winter/spring of 2014. Study 1 was part of a feasibility study conducted during winter/spring of 2013 and Study 2 was part of the pilot study. All KTEK research efforts took place in one school district in the Pacific Northwest region of the United States. Approximately 17 % of the participating district's students receive special education services. Within the three participating schools, 7–27 % of the total student population is reported to be English language learners, and school-wide free–and-reduced lunch eligibility ranged from 43 to 78 % (National Center for Educational Statistics- NCES 2013). In all, KTEK was implemented in 21 classes (Study 1 = 10; Study 2 = 11), a mix of morning and afternoon half-day kindergarten classes taught by thirteen teachers and six educational assistants (EAs).

Participants: study 1

Study 1 participants included one male and five female teachers with varying levels of teaching experience and technical expertise who taught a total of ten morning and afternoon kindergarten classes. On average, Study 1 educators had more than 15 years of teaching experience and 7 years of experience at the kindergarten level. All Study 1 instructors were white. Participants implemented the intervention independently in small groups during center time in their classrooms to examine the feasibility of KTEK. Given the intervention's primary goal of supporting learning for young students who struggle with math, researchers identified five potentially at-risk students from each class. Target students ($n = 50$) were selected based on teacher recommendation, evidence of consistent attendance, and potential mathematics risk as determined by screening data collected from student performance on a brief battery of number-sense, curriculum-based measures (ASPENS; Clarke et al. 2011). The Study 1 student sample was 52 % male, 40 % Hispanic, 26 % English language learners, and 22 % received special education services. All participating students qualified for free or reduced price lunch.

Participants: study 2

Based on implementation difficulties noted in Study 1, EAs were recruited to assist with the implementation of KTEK in study 2. Thus, Study 2 participants included seven female teachers and six EAs (one male) with varying levels of educational attainment, teaching experience, and technical expertise. Study 2 instructors had over 11 years of teaching experience and approximately 4 years of experience at the kindergarten level, on average. The participants implemented the intervention in structured pull out groups outside of the classroom to examine the potential promise of KTEK for use in a tiered intervention system. Because KTEK's primary development goal was to support the learning of low performing kindergarten students, ten at-risk students from each class were identified as target students for the pilot study. As in study 1, target students were selected based on teacher recommendation, evidence of regular attendance, and screening data collected from student performance on a brief battery of number sense curriculum based measurements (Clarke et al. 2011), and then randomly assigned to condition. After attrition, the final analytic student sample for Study 2 was comprised of 45 treatment and 49 control participants. The Study 2 student sample was 58 % male, 12 % Hispanic, 6 % English language learners, and 14 % received special education services. Almost 40 % of the participating students qualified for free or reduced price lunch.

Intervention

KTEK uses the affordances of iPad technology to target whole number content outlined in the Counting & Cardinality, Operations & Algebraic Thinking, and Number & Operations in Base Ten strands of the Common Core standards (CCSSO 2014) for kindergarten. In contrast to practice apps intended solely for fluency building, the KTEK intervention system provides explicit instruction and targeted review appropriate to each student's learning needs through two iPad apps. Students use the student app individually, while the teacher app allows real-time monitoring of student use and progress. KTEK customizes learning experiences by incorporating essential instruction and key educational technology design principles (Mayer and Moreno 2003). KTEK design features that specifically target the needs of students who struggle with math include: (a) personalized instruction, scaffolding, and feedback; (b) deliberate practice to build fluency; (c) embedded formative assessment; and (d) customizable features allowing teachers to monitor and report findings (Baker et al. 2002).

In each study, instructors were provided five color-coded class iPads with headphones, and students received their own unique passcode with which they could securely access the intervention system. Instructors were asked to support target students' individual use of the KTEK intervention in small groups of five students for 15 min per day, 3 days per week, defined here as the duration of use target, in addition to regular, whole-class mathematics instruction. To increase attention and engagement, each 15-min intervention session included at least two separate learning activities. These use recommendations were developed with a consideration for the specific developmental characteristics of the target population and based on previous usability and feasibility tests of intervention session length.

Preliminary analyses of pilot study data indicated that KTEK students experienced substantively important, but not statistically significant positive effects (What Works Clearinghouse 2008) in both number line estimation (Hedge's $g = .36$) and magnitude comparison ($g = .36$), as compared to their control peers (Shanley et al. 2015). Furthermore, KTEK students who experienced success in the intervention and mastered at least 75 % of the activities they encountered demonstrated additional gains in missing number identification, oral counting, and two distal measures of number sense and early mathematics achievement (Strand Cary et al. 2014). Additionally, KTEK was generally well received by participating students; 68 % reported that they would "play KTEK at home if it was available" and the average likability rating was 1.6 on a scale from 1 to 5, with lower scores being more desirable.

Research design

A convergent parallel mixed-methods design (Creswell 2013) was used to evaluate the relationships between instructor experience with technology and the implementation of KTEK in authentic settings. In both studies, quantitative data (i.e., KTEK analytics) and qualitative data (i.e., instructor surveys and interviews) were collected and analyzed separately. Next, findings from analyses of the parallel research constructs were used in concert to address the research questions and the various types of data were examined for convergence and consistency. For example, instructor experience categorizations were verified with interview evidence and instructor reports of technology experience and intervention implementation were cross-tabulated with targeted KTEK analytics to explore relationships between experience and implementation.

This mixed methods research was conducted within the context of two distinct development studies with unique emphases. Focal concerns for Study 1 included whether (a) KTEK functioned as intended, (b) participants enjoyed using KTEK, (c) the intervention could be integrated feasibly into the school day, and (d) the apps logged the desired data accurately. Results from Study 1 were utilized as part of an iterative cycle of technology-based intervention development that included initial user testing, the feasibility study, and a pilot study interwoven with ongoing development and refinement. Prior to implementing the pilot study, development work aimed to improve the stability of the KTEK system and training materials were revised to provide targeted support to instructors with minimal technological experience. Focal concerns for Study 2 included all of those from Study 1 with the addition of a primary research question that investigated the extent to which KTEK students demonstrated mathematics achievement gains as compared to control students who used a similarly structured iPad-based literacy intervention.

Measures

The nature of the KTEK development process allowed for an authentic mixed methods approach derived from a variety of data sources. Measures included KTEK analytics (i.e., student usage data tracked by the student app), and student and instructor feedback provided through surveys and interviews.

KTEK analytics

Individual student usage data reflected the extent to which instructors adhered to the recommended schedule of use for each student (i.e., duration of use target defined as 15 min sessions, at least three times per week). Average daily duration of use per student was calculated based on total minutes of use divided by days of use. Daily duration of use values were aggregated across morning and afternoon classes to generate the percentage of students meeting duration of use targets by teacher. Because EAs worked across a range of classes, this process was applied for EAs, as well. In some cases, the percentage of students meeting duration of use targets were aggregated across instructors who reported similar levels of comfort with technology and/or barriers to technology use. These percentages were calculated by (a) combining all students taught by an instructor who reported a certain type of barrier or level of technological experience, and then (b) dividing the total number of students who met the implementation target by the total number of students.

Ranges of durations of use were also calculated for each instructor to evaluate the extent to which there were consistent minutes of use among students in a given class. To calculate the consistency of student exposure to the intervention or variability in implementation, the average range of use for each instructor was determined by subtracting the minimum average daily duration from the maximum daily duration. This value reflected the variability of student use within each instructor's class. High ranges of use indicated that some students used the intervention for many minutes on each occasion of use, while their classmates used the intervention for far fewer minutes each day. Conversely, small ranges of use indicated that instructors implemented the intervention with greater consistency and that there was less variability in the number of minutes of use each day between students.

Surveys and interviews

Instructors completed brief online surveys and participated in informal interviews (pre- and post-intervention). Surveys and interviews were comprised of 12-30 questions aimed at exploring instructors' technology expertise, use of technology in the classroom, level of satisfaction with the intervention, and observations of students' experiences with the intervention. All instructors completed all interviews and the initial surveys; with two opting out of the exit survey. Researchers coded and categorized survey responses to identify instructor technology experience themes.

Survey responses were compiled with teacher interviews to identify patterns of responses. This analytic step had two main aims: (1) form categories of levels of prior experience with iPad technology (i.e., low, medium, and high) and (2) condense pre-study technology-use barriers into two distinct categories representing both first and second-order barriers (Ertmer 1999). First-order barriers were logistic (e.g., there is not enough time to integrate technology) or tech-based (e.g., troubleshooting technological difficulties is too time consuming). Second-order barriers were internal to the instructors implementing the intervention (e.g., I am not comfortable with technology).

Results

Overall experience and implementation

Study 1

Instructors reported a range of pre-intervention experience with iPads. One instructor reported no prior experience using iPads and one instructor reported moderate levels of experience with some common iPad functions (e.g., downloading and managing apps, taking pictures, sending and receiving email, accessing the internet, etc…). The four remaining instructors reported high levels of comfort with the same common iPad functions. Additionally, five of six instructors reported at least one barrier to integrating educational technology in their classrooms; one instructor reported no barriers to technology use. See Table 1 for a complete list of barriers by type. Across all classrooms, 42 % of students met duration of use targets (i.e., the primary measure of implementation fidelity equal to 3 days per week, 15 min per day); however, student use varied. In some classrooms, nearly 60 % of student users met the duration of use target. In others, only 20 % of students met the target.

Table 1 Barriers surveyed by type

First order	Second order
I have inadequate time to learn how to use technology	I am not comfortable with technology
There is inadequate training or help offered	I am worried I will break the technology
Technology can be unreliable	I am worried that I will not be able to help the students troubleshoot
Class periods are too short	I am worried about expensive equipment in the classroom
Hardware, software, and/or apps don't work properly	I find it difficult to find useful software or apps

Study 2

Study 2 instructors also reported a range of pre-intervention experience with iPad technology. Two instructors reported no prior experience using iPads; five reported moderate levels of comfort with some common iPad functions. The six other instructors reported high levels of experience with iPad functions. Additionally, just over half of the instructors reported at least one barrier to integrating educational technology in their classrooms, while five instructors reported no barriers to technology use. Across all study 2 classrooms, 87 % of students met duration of use targets, but there was still substantial variability in the percentage of students meeting use targets across classrooms. In two instructors' groups, none of the student users met the duration of use target, while 100 % of the student users met the target for use in other study 2 instructors' groups.

Experience with iPads as an implementation factor

Study 1

The instructor with the least iPad experience provided the most consistent intervention exposure represented by the narrowest range of use among students (see Fig. 1). In contrast, instructors with moderate experience demonstrated the least consistent (i.e., most variable range) intervention exposure among students despite pre-intervention reports of some experience with iPads. Similarly students of instructors with high levels of iPad experience received less consistent intervention exposure; however, high experience instructors had more students who met duration of use targets (see Fig. 2). Both low and medium experience instructors had far fewer students meeting the duration of use target. In other words, high experience instructors had more students meet the duration of use target, but a number of their students were far below that target, as well. In the less experienced instructors' classes, there was less variability in minutes of use between students, but few students met the average duration of use target compared to students of the instructors with more iPad experience.

Study 2

Findings from Study 1 were largely confirmed in Study 2 for the instructors with ample iPad experience. That is, the high-experience instructors had slightly more variable use, but a high percentage of students who met the duration of use target. Study 2 instructors with

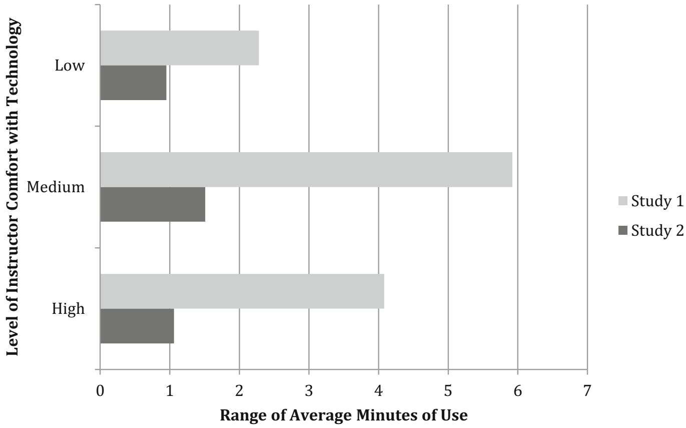

Fig. 1 Average within class variability of student use by teacher experience

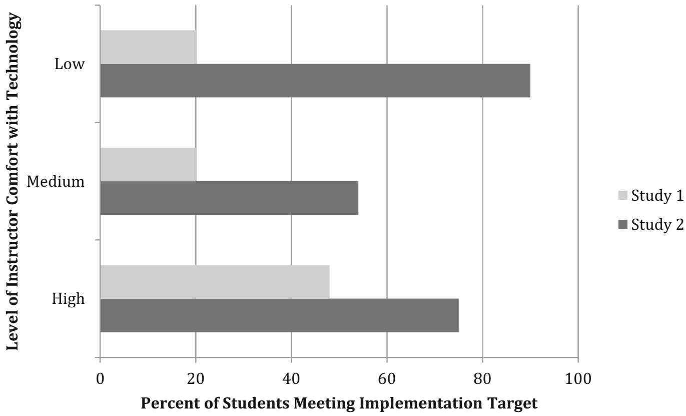

Fig. 2 Percent of students meeting duration of use target by instructor experience

little to no iPad experience were like their Study 1 counterparts in that their students received the most consistent exposure to the intervention (i.e., a small range of minimum to maximum average student use; see Fig. 1), but unlike the Study 1 instructors, the low-experience Study 2 instructors demonstrated the highest percentage of students who met the duration of use target. Potential explanations for these divergent findings are discussed below. Most notably though, medium-experience instructors again demonstrated the most variable implementation and also had the fewest students who met duration of use targets.

Barriers to technology integration

Study 1

Prior to implementing KTEK, instructors reported a range of barriers to technology use including first-order logistic or tech-based challenges and second-order internal barriers. Figure 3 displays the percent of students meeting duration of use targets by the type of barrier

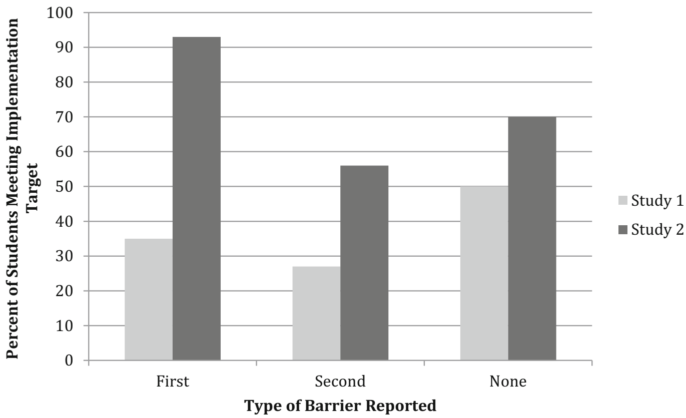

Fig. 3 Percent of students meeting duration of use target by barrier type

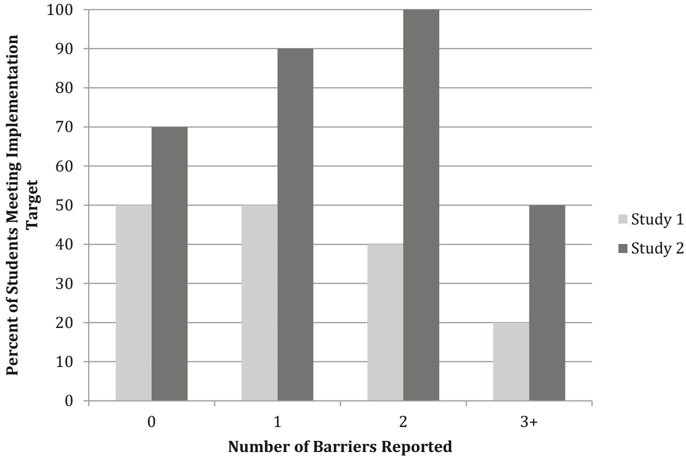

Fig. 4 Percent of students meeting duration of use target by number of barriers

each instructor reported. Consistent with previous research (Ertmer 1999), second-order barriers appeared to have the most significant negative association with average duration of use implementation metrics. Specifically, instructors who reported second-order barriers to technology use had the fewest students meeting the duration of use target. Furthermore, a comparison of the number of barriers reported by each instructor with the percentage of students meeting the duration of use target represented by Fig. 4 reveals another potentially important relationship: Study 1 instructors who reported the fewest total barriers to classroom technology use had the highest percentage of students meeting duration of use targets.

Study 2

Study 2 instructors also reported both first- and second-order barriers to technology use. As evidenced by Fig. 3, second-order barriers again appeared to be most impactful on implementation; however, instructors who reported zero barriers to integrating technology in the classroom had less desirable implementation as compared to instructors who reported simple first-order barriers. In fact, instructors who identified first-order barriers actually had the most optimal implementation of the three groups in Study 2. There were differences between Study 1 and Study 2 with regard to some of the relationships between the number of barriers reported by each instructor and the percentage of students meeting the duration of use target, as well (see Fig. 4). For example, instructors who reported one or two barriers to technology implementation had the most desirable intervention implementation with 90-100 % of their students meeting use targets in Study 2. In fact, with the exception of the instructors who reported three or more barriers to technology implementation, instructors who reported no barriers to technology integration had the fewest students meeting duration of use targets in Study 2.

Discussion

Given that instructors facilitate interactions between technology-based interventions and student users in busy classroom settings, the studies detailed here sought to investigate how instructor experience with iPad technology and barriers to technology integration impacted the implementation of an iPad-delivered kindergarten mathematics intervention. Analyses of intervention implementation by instructor technology experience found distinct—and sometimes counterintuitive—patterns in student intervention exposure. The patterns are summarized and discussed below.

Instructor experience with iPads did not always align with consistent exposure to the intervention amongst students. In fact, instructors with the least prior iPad experience implemented the intervention with the least variability evidenced by the most consistent exposure to the intervention among students in both studies. However, whereas instructors with little prior iPad experience implemented the intervention most consistently, Study 1 findings indicated that little iPad experience was associated with fewer students meeting intervention use targets. In Study 1, teachers with more pre-intervention iPad experience had higher percentages of students meeting implementation targets. In Study 2 though, the low-experience instructors demonstrated the highest percentage of students meeting duration of use targets. This improved relationship may be attributed to a combination of factors. Improved intervention system stability equated to fewer technological issues and instructors did not need to troubleshoot as often in Study 2. Additionally, instructors were given targeted training and professional development to support those with less iPad experience prior to Study 2. Finally, additional personnel (i.e., educational assistants) were employed to implement intervention sessions in the second study.

In addition to instructor iPad experience, there are other issues to consider. Specifically, the quantity of barriers reported, in addition to the type or order of barrier, may be critical implementation factors. In both studies, instructors who reported numerous barriers to technology integration and those who reported second-order barriers to technology integration demonstrated the lowest percentage of students meeting implementation targets. Notably, instructors who reported no barriers to technology integration also had less than optimal student use patterns (i.e., few students meeting implementation targets). These findings suggest professional development and ongoing teacher support aimed at both unconfident and perhaps somewhat overconfident instructors are particularly important components of technology-based intervention implementation programs.

Professional development and teacher support should have a two-fold purpose to ensure optimal technology-based intervention implementation. In addition to providing professional development about the intervention's most important features for affecting student learning (Ottenbreit-Leftwich et al. 2010), care should be taken to address teacher-perceived barriers to technology-based intervention use (Ertmer et al. 2012) and to provide ample support and experience to alleviate fears, misconceptions, and negative attitudes. Taken as a whole, the results from both Studies 1 and 2 suggest there is a need to support instructors who report some or moderate iPad experience, in addition to the naïve instructors, to identify specific implementation support mechanisms. Intervention developers and implementation support staff may also need to probe instructors who do not identify any barriers to technology implementation because it can be difficult to predict all potential barriers and there may be a tendency to oversimplify the task of implementing technology-based intervention. Troubleshooting guides and targeted trainings that prepare all instructors for potential pitfalls and provide specific strategies for overcoming seemingly insignificant barriers may be one way to support instructors who are implementing technology-based interventions. Lastly, as expected, instructors who report numerous barriers to technology use may often require more support than others to implement an intervention. In these cases, both first- and second-order barriers should be investigated, and systems of support should be initiated.

Ongoing monitoring and support are also important to track changes in instructor buy-in and confidence with technology. Observations, practitioner notes, and regular, formal professional development allow for a more accurate picture of technology-based intervention implementation and timely support provision. For instance, in study 1, an instructor with no prior iPad experience found it quite easy to integrate the iPads and implement the intervention, while other instructors noted that their students required more support than they had expected. Instructors with minimal prior educational technology integration experience might report low levels of initial buy-in, but then easily integrate the technology-based intervention into their existing classroom structures. On the other hand, high-experience instructors might experience more difficulty integrating the intervention in their classroom structures and require more support than initially anticipated. This may be a result of intervention implementation helping to shape and create a classroom-based technology schema for instructors with less iPad experience, as opposed to more experienced instructors who may struggle to find a way to integrate new technology-based interventions into their existing technology-based classroom systems. Regular monitoring and professional development that is adaptive to individual teacher needs and beliefs (Hammonds et al. 2013) will ensure that instructors receive appropriate, timely, and effective support to develop effective technology-based classroom systems.

Limitations

The studies reported here navigated two kinds of investigative challenges: (a) Synthesizing raw student analytics to appropriately characterize student's technology-based intervention experience and (b) measuring appropriate fidelity indicators of technology-based intervention implementation. First, students' differential paces of learning and individualized intervention experiences can be difficult to capture and compare. Struggling students' intervention experiences vary greatly, thus dosage variables (i.e., duration of use or progress through the app) may require the incorporation of other relevant covariates to be utilized accurately in evaluations of implementation. In this study, total minutes of use were divided by total days of use to approximate the average duration of use for each student. However, admittedly, various omitted first-order barrier variables may have affected each of these measurements. Additionally, time of exposure is only one small aspect of successful intervention implementation.

Second, conducting detailed analyses of factors affecting intervention implementation requires multi-faceted data collection in authentic contexts. This translates to extensive researcher time and resources. The present studies utilized a relatively small and demographically homogenous sample of instructors to evaluate how patterns of implementation were related to technological experience and barriers to technology integration. The results reported here suggest replicable patterns of behavior exist and knowledge of instructor experience with iPads and perceived barriers could inform professional development to support effective intervention implementation; however a larger, more diverse instructor sample is needed to improve the generalizability of these findings.

Future research

If technology is to fulfill its promise of providing the individualized instruction necessary to meet pressing academic challenges a number of key variables warrant further investigation. This study found variation in implementation based on key instructor variables including iPad experience and barriers to technology integration. Future research should focus on appropriately selecting and preparing accurate metrics of student use for analysis (from the vast array of analytic data recorded within any technology-based intervention) and recruiting a robust, diverse sample of instructors. It would also be helpful to actively incorporate implementation support and collaborate with instructors to identify specific needs, thereby impacting instructor implementation variables and subsequently, with greater fidelity of implementation, impacting student outcomes.

Harnessing the potential of educational technology requires that instructors are trained on the intended uses and most important features of technology-based interventions, and receive support to structure their classroom and use of interventions accordingly. Barriers to technology use are inevitable, thus it is essential to address specifically and mitigate first- and second-order barriers. This can be accomplished through preliminary and ongoing professional development and targeted implementation support for instructors who experience numerous barriers to classroom technology use. Deliberate support and continued focus on resolving these challenges will support the further development and refinement of technology-based interventions intended to assist with the provision of individualized instruction necessary to ensure that all students reach their full potential.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

Baker, S., Gersten, R., & Lee, D. S. (2002). A synthesis of empirical research on teaching mathematics to low-achieving students. *Elementary School Journal, 103*(1), 51–73.

Bodovski, K., & Farkas, G. (2007). Mathematics growth in early elementary school: The roles of beginning knowledge, student engagement, and instruction. *Elementary School Journal, 108*, 115–130. doi:10.1086/525550.

Clarke, B., Rolfhus, E., Dimino, J., & Gersten, R. M. (2011). *Assessing student proficiency of number sense (ASPENS)*. Longmont, CO: Cambium Learning Group, Sopris Learning.

Common Sense Media. (2013). *Zero to eight: Children's media use in America 2013*. San Francisco: Common Sense Media. Retrieved from https://www.commonsensemedia.org/research/zero-to-eight-childrens-media-use-in-america-2013.

Council of Chief State School Officers (CCSSO), National Governors Association Center for Best Practices. (2014). *Common core state standards* (*mathematics*). Washington, D.C.: National Governors Association Center for Best Practices, Council of Chief State School Officers. Retrieved from http://www.corestandards.org/Math/.

Creswell, J. W. (2013). *Research design: Qualitative, quantitative, and mixed methods approaches*. New York: Sage.

DigEdu. (2014). *Technology use in the classroom: Benefits & barriers*. Retrieved from http://digedu.com/full-report-technology-use-classroom/.

Duncan, G. J., Dowsett, C. J., Claessens, A., Magnuson, K., Huston, A. C., Klebanov, P., et al. (2007). School readiness and later achievement. *Developmental Psychology, 43*, 1428–1446. doi:10.1037/0012-1649.43.6.1428.

Durlak, J. A., & DuPre, E. P. (2008). Implementation matters: A review of research on the influence of implementation on program outcomes and the factors affecting implementation. *American Journal of Community Psychology, 41*(3–4), 327–350. doi:10.1007/s10464-008-9165-0.

Ertmer, P. A. (1999). Addressing first-and second-order barriers to change: Strategies for technology integration. *Educational Technology Research and Development, 47*(4), 47–61. doi:10.1007/BF02299597.

Ertmer, P. A., Ottenbreit-Leftwich, A. T., Sadik, O., Sendurur, E., & Sendurur, P. (2012). Teacher beliefs and technology integration practices: A critical relationship. *Computers & Education, 59*, 423–435. doi:10.1016/j.compedu.2012.02.001.

Fien, H., Doabler, C. T., Nelson, N. J., Kosty, D. B., Clarke, B., & Baker, S. K. (2016). An examination of the promise of the NumberShire level 1 gaming intervention for improving student mathematics outcomes. *Journal of Research on Educational Effectiveness*. doi:10.1080/19345747.2015.1119229.

Foster, M. E., Anthony, J. L., Clements, D. H., Sarama, J., & Williams, J. M. (2016). Improving mathematics learning of kindergarten students through computer-assisted instruction. *Journal for Research in Mathematics Education, 47*(3), 206–232. doi:10.5951/jresematheduc.47.3.0206.

Fuchs, D., Fuchs, L. S., & Compton, D. L. (2012). Smart RTI: A next-generation approach to multilevel prevention. *Exceptional Children, 78*, 263–279. doi:10.1177/001440291207800301.

Gray, L., Thomas, N., & Lewis, L. (2010*). Teachers' use of educational technology in U.S. public schools: 2009* (*NCES 2010–040*). Washington, DC: National Center for Education Statistics, Institute of Education Sciences, U.S. Department of Education.

Hammonds, L., Matherson, L. H., Wilson, E. K., & Wright, V. H. (2013). Gateway tools: Five tools to allow teachers to overcome barriers to technology integration. *Delta Kappa Gamma Bulletin, 80*(1), 36–40.

Hanich, L. B., Jordan, N. C., Kaplan, D., & Dick, J. (2001). Performance across different areas of mathematical cognition in children with learning difficulties. *Journal of Educational Psychology, 93*, 615–627. doi:10.1037/0022-0663.93.3.615.

Hughes, J. (2005). The role of teacher knowledge and learning experiences in forming technology-integrated pedagogy. *Journal of Technology and Teacher Education, 13*, 277–302.

Jordan, N. C., Glutting, J., Dyson, N., Hassinger-Das, B., & Irwin, C. (2012). Building kindergartners' number sense: A randomized controlled study. *Journal of Educational Psychology, 104*, 147–160. doi:10.1037/a0029018.

Keengwe, J., Schnellert, G., & Mills, C. (2012). Laptop initiative: Impact on instructional technology integration and student learning. *Education and Information Technologies, 17*(2), 137–146. doi:10.1007/s10639-010-9150-8.

Kermani, H., & Aldemir, J. (2016). Using iPads in the classroom to teach young children early math skills. In *Proceedings of society for information technology & teacher education international conference 2016* (pp. 1445–1449). Chesapeake, VA: Association for the Advancement of Computing in Education (AACE).

MacDonald, M. (2014, November 7). Struggle to teach students '21st century skills' when classroom technology isn't up to speed. *National Post.* Retrieved from http://news.nationalpost.com/toronto/struggle-to-teach-students-21st-century-skills-when-classroom-technology-isnt-up-to-speed.

Matzen, N. J., & Edmunds, J. A. (2007). Technology as a catalyst for change: The role of professional development. *Journal of Research on Technology in Education, 39*, 417–430. doi:10.1080/15391523.2007.10782490.

Mayer, R., & Moreno, R. (2003). Nine ways to reduce cognitive load in multimedia learning. *Educational Psychologist, 38*(1), 43–52. doi:10.1207/S15326985EP3801_6.

McKenna, J. W., Flower, A., & Ciullo, S. (2014). Measuring fidelity to improve intervention effectiveness. *Intervention in School and Clinic, 50*(1), 15–21. doi:10.1177/1053451214532348.

Morgan, P. L., Farkas, G., & Wu, Q. (2009). Five-year growth trajectories of kindergarten children with learning difficulties in mathematics. *Journal of Learning Disabilities, 42*, 306–321. doi:10.1177/0022219408331037.

National Center for Educational Statistics- NCES. (2013). *CCD common core of data*. Retrieved from http://nces.ed.gov/ccd/.

Ottenbreit-Leftwich, A. T., Glazewski, K. D., Newby, T. J., & Ertmer, P. A. (2010). Teacher value beliefs associated with using technology: Addressing professional and student needs. *Computers & Education, 55*(3), 1321–1335. doi:10.1016/j.compedu.2010.06.002.

Palak, D., & Walls, R. T. (2009). Teachers' beliefs and technology practices: A mixed-methods approach. *Journal of Research on Technology in Education, 41*, 417–441. doi:10.1080/15391523.2009.10782537.

Ray, K. (2015). Integrating iPads in the kindergarten classroom: How does technology engage students in learning? *Research and Evaluation in Literacy,* Paper 35. Retrieved from http://digitalcommons.unl.edu/cehsgpirw/35.

Schacter, J., Shih, J., Allen, C. M., DeVaul, L., Adkins, A. B., Ito, T., et al. (2016). Math Shelf: A randomized trial of a prekindergarten tablet number sense curriculum. *Early Education and Development, 27*(1), 74–88. doi:10.1080/10409289.2015.1057462.

Shanley, L., Strand Cary, M., Clarke, B., & Jungjohann, K. (2015). *KinderTEK mathematics: Evaluating the efficacy of an iPad delivered whole number intervention.* Paper presented at Council for Exceptional Children Conference, San Diego.

Slavin, R. E., & Lake, C. (2008). Effective programs in elementary mathematics: A best-evidence synthesis. *Review of Educational Research, 78*, 427–515. doi:10.3102/0034654308317473.

Strand Cary, M. Shanley, L., Clarke, B., & Sota, M. (2014). *Evaluating the KinderTEK iPad app's individualized and adaptive math instruction.* Paper presented at the 2014 International Society for Technology in Education Conference, Atlanta, GA.

Strand Cary, M., Shanley, L, & Clarke, B. (2015). *Technology-based interventions: An approach to framing the development process* (KinderTEK Technical Report 1601). Eugene, OR.

Taylor, F. P. (2004). Education technology helps unite school communities, improve academic achievement. *THE Journal (Technological Horizons In Education), 31*(10), 46–48.

U.S. Department of Education, Office of Educational Technology. (2016). *Future ready learning: Reimagining the role of technology in education.* Washington, D.C.: Author.

Valdez, G. (2005). Critical issue: Technology: A catalyst for teaching and learning in the classroom. *North Central Regional Educational Laboratory.* Retrieved on January 16, 2015 from, http://www.ncrel.org/sdrs/areas/issues/methods/technlgy/te600.htm.

What Works Clearinghouse. (2008). *What works clearinghouse evidence standards for reviewing studies.* Washington, D.C.: US Department of Education.

Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., & Yukhymenko, M. (2012). Our princess is in another castle: A review of trends in serious gaming for education. *Review of Educational Research, 82*(1), 61–89. doi:10.3102/0034654312436980.

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