Journal of Special Education Technology
2019, Vol. 34(1) 41-54

DOI: 10.1177/0162643418781298
journals.sagepub.com/home/jst
SAGE

An Exploration of Multimedia Supports for Diverse Learners During Core Math Instruction

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Abstract

In the present study, mobile technology was leveraged as a learning tool for core math instruction during a whole number multiplication and division unit. The researchers redesigned paper–pencil worksheets from the math curriculum into multimedia-enhanced, interactive math practice (the eWorkbook) accessed by students on an iPad. With this eWorkbook, which was conceptualized within a Universal Design for Learning framework, we aimed to reduce barriers and capitalize on strengths by embedding flexible scaffolds/supports, allowing for student choice, and incorporating evidence-based teaching practices. Results of this case study suggest students with and without learning disabilities can leverage multimedia to foster unique opportunities for the understanding and expression of mathematical knowledge. Additional affordances of the eWorkbook include extending the reach of teacher support while encouraging self-support. Implications for teachers and researchers are discussed.

Keywords

instructional technology, specific learning disabilities, Universal Design for Learning, mathematics, multimedia learning

As schools continue to move toward more inclusive models of special education, teachers are faced with the incredible challenge of meeting the instructional needs of every student in their classroom while adhering to rigorous learning standards. Among those students with the most intensive instructional needs are those with learning disabilities (LDs). Students with LD make up approximately 4.5% of the school-age population (U.S. Department of Education, National Center for Education Statistics, 2016), and about two thirds of these students spend 80% or more of their days in a general education setting (Cortiella & Horowitz, 2014). As a result, educators must ensure they are able to provide the intensive, targeted instruction needed by these students within general education classrooms.

LDs typically manifest in specific areas rather than across all subjects; thus, when a child is classified with LD, the classification is often specified in areas related to either reading or math (Compton, Fuchs, Fuchs, Lambert, & Hamlett, 2012). Students with mathematics LDs (MLDs) tend to demonstrate poor number sense (Geary, 2011), an overall lack of schema-based problem-solving strategies (Jitendra & Star, 2011), and while their struggles are generally related to math skills, many also have weak reading and comprehension skills, making word problems particularly difficult (Landerl, Göbel, & Moll, 2013). Additionally, given that students with MLD tend to have poor organizational skills (Cave & Brown, 2010), they may also need more support with self-instruction, self-questioning, and self-monitoring while they problem-solve (Montague, Enders, & Dietz, 2011). Fortunately, current research can direct us toward solutions that can address these barriers.

Researchers of mathematics instruction for students with MLD identify some instructional practices evidenced to improve student learning in mathematics. These practices include using explicit instruction, allowing for student verbalization of mathematical thinking, presenting visual representations, and providing heuristics to organize ideas (van Garderen, Poch, Jackson, & Roberts, 2017). Doabler and colleagues (2012) describe many of the same practices while stressing the importance of preteaching requisite skills, modeling proficient problem-solving, scaffolding instruction by slowly fading prompts/supports, and providing meaningful practice opportunities with timely feedback.

By late elementary school, these instructional practices should be incorporated to support the acquisition of procedural knowledge and skills related to multiplication and division. One way to improve students' procedural automaticity is to

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target fluency with basic multiplication facts (Fries, 2013; Lund, McLaughlin, Neyman, & Everson, 2012). Procedural automaticity can enable conceptual understanding when teachers focus on equipping students with a variety of visual representations of multiplicative problems such as arrays, area models, and multiplication tables (Gierdien, 2009; Huang, 2014). Optimally, effective instruction should also link these representations to key properties of mathematics that foster multiplicative thinking such as the distributive property (Kinzer & Stanford, 2014). In order to successfully reach the wide range of learners in their classrooms, including those with MLD, mathematics teachers may need to leverage available resources to implement these evidence-based practices.

Instructional Technology Integration

One way to incorporate the aforementioned evidence-based strategies into daily instruction is to leverage instructional technology. A recent meta-analysis of 122 peer-reviewed studies examined the impact of technology integration for elementary students and found a positive impact on student learning across subjects and settings (Chauhan, 2017). The incorporation of technology for learning is also advocated for at the local, state, and federal levels (U.S. Department of Education, 2016). Organizations such as Association of Mathematics Teacher Educators (AMTE), National Mathematics Advisory Panel (NMAP), and National Council of Teachers of Mathematics (NCTM) frame technology as a tool for learning that must be strategically implemented in a way that complements instruction (AMTE, 2015; NCTM, 2015; NMAP, 2008). Teachers may require preparation to leverage technology in this way.

Technology is increasingly incorporated into today's math curricula. For example, *Building Blocks* (Clements & Sarama, 2012) and *Accelerated Math* (Renaissance Learning, 2013), programs that include computer-based practice components, have been shown to have positive effects on the broad mathematical achievement of students. In general, computer-based components have been designed to improve declarative math knowledge (e.g., Chang, Sung, Chen, & Huang, 2008) or to provide scaffolding to support procedural and conceptual knowledge (Kim & Hannafin, 2011). As technology has become more mobile, schools continue to look for ways to integrate tablets into educational programs. Unlike desktop computers, tablets are relatively inexpensive, portable, and open new possibilities for instruction. With a class set of tablets, teachers can facilitate the synchronization and coordination of learner–learner, learner–content, and learner–instructor interactions by providing opportunities for students to use devices to engage with and respond to content activities throughout a lesson (Ting, 2013).

Despite the potential of strategic mobile technology integration to impact academic achievement, much of the mobile technology research is survey-based, and very little focuses on objectively measured academic outcomes (Wu et al., 2012). Moreover, seldom does the research examining mobile technology's impact on student learning focus specifically on students with disabilities. For example, in Wu and colleagues' (2012) meta-analysis of 164 studies on mobile technology for education, fewer than 1% of the participants were identified with a disability. In a new meta-analysis of mobile technology use for individuals with disabilities, Cumming and Draper Rodriguez (2017) found positive outcomes associated with the use of specific apps (e.g., skill practice, visual prompting, and video modeling). In another meta-analysis, Kagohara and colleagues (2013) found some objective measures were used to evaluate the impact of mobile technology in special education, though similar to the findings of Cumming and Draper Rodriguez, most studies addressed behavior/communication skills rather than academics.

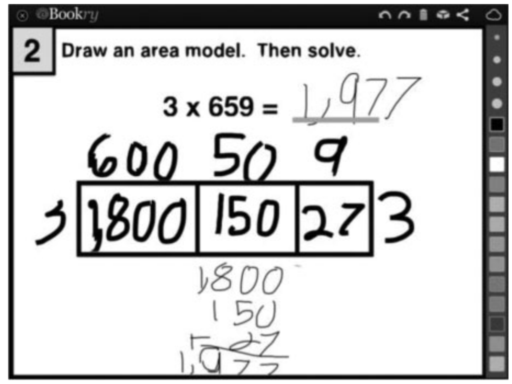
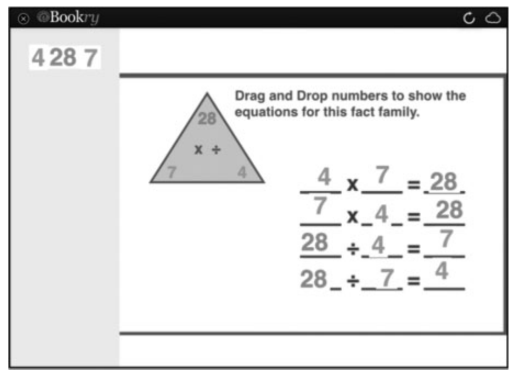
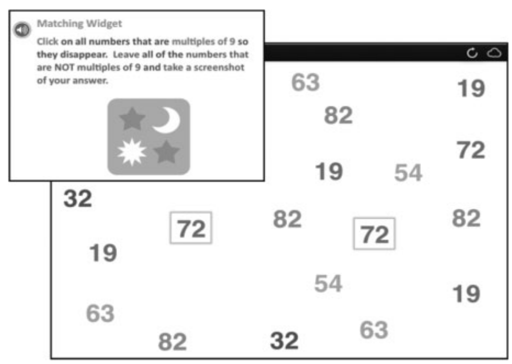
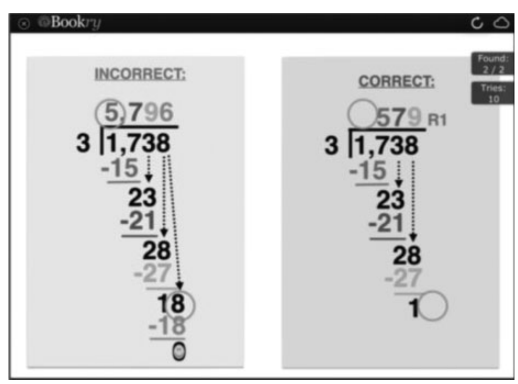
Tablets and computers are universal technologies that can provide access to the curriculum (e.g., text-to-speech, closed captioning, and alt text for images) as well as offer unique ways to present and interact with content. Due to the rich feature sets of these technologies, the tool inherently becomes intertwined with content and pedagogy. From a research standpoint, this can make it difficult to partition the impact of the technology itself. Edyburn, Rao, and Hariharan (2017) suggest it may be too shortsighted to focus on specific technology devices and applications because of how quickly they change. Instead, they suggest research on technology for diverse populations needs to first focus on the "active ingredients" in technology interventions to determine "what works, for whom, and under what conditions" (p. 369). The present study was designed to do precisely that—explore how, and under what conditions multimedia supports, when used to complement expert instruction, can support the understanding and expression of mathematical knowledge for students with and without MLD.

Rationale for Study

In response to the needs of students with MLD, the findings from empirical research, and the technology recommendations of AMTE (2015), NMAP (2008), and NCTM (2015), the principal investigator (PI) of the present study developed a mobile technology-based multimedia math workbook (the eWorkbook) using free Mac-based software (i.e., iBooks Author) and a free online widget library (i.e., Bookry—a collection of apps that can be embedded into an iBook so the user can interact with the content). The eWorkbook contained multimedia supports intended for use during the independent practice portion of the core curriculum lessons for a fourth-grade whole number multiplication and division unit (see Table 1). Additionally, the multimedia practice opportunities in the eWorkbook were carefully aligned to the objectives of the core math lessons and offered unique opportunities to engage with math content not otherwise possible without the incorporation of technology.

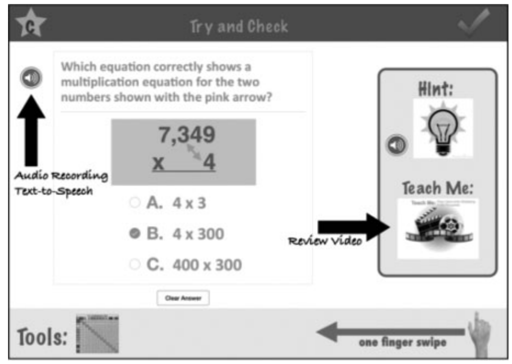
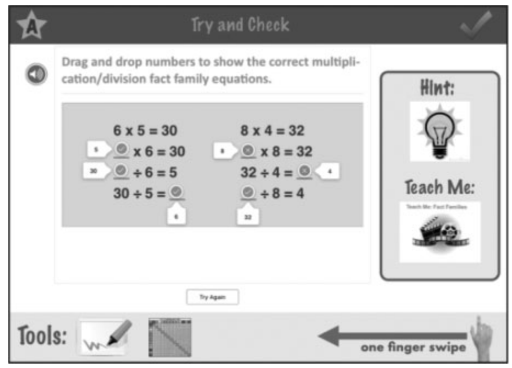
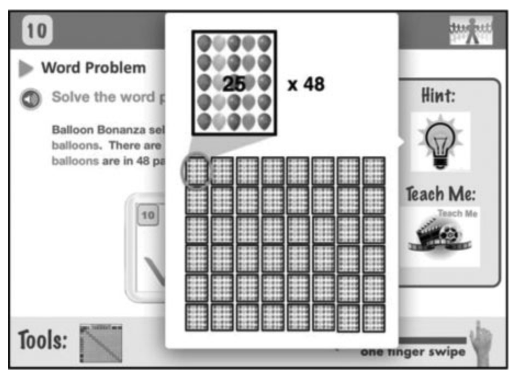
We conceptualized the eWorkbook within a Universal Design for Learning (UDL) lens. Advances in neurological research suggest that while all people possess the same three primary networks in the brain (recognition, strategic, and affective), the manner in which people engage in the learning process varies substantially. In education, this means people learn differently, so individual differences should be considered the

Table 1. eWorkbook Widgets and Sample Pages.

<table>
<tr><th>Widget and Source</th><th>Description</th><th>Sample Page</th></tr>
<tr><td>Writing (Bookry)</td><td>Allows the designer to upload backdrops to a digital writing canvas (e.g., graph paper and area model boxes) and allows users to draw on the iPad with a stylus with a customizable pen size and color. This was the primary widget used by students for solving multiplication and division problems.</td><td>
</td></tr>
<tr><td>Drag-and-Drop (Bookry)</td><td>Allows the designer to add a bank of images for users to drag-and-drop onto a customizable main canvas. This was used by students to visually model word problems and as an alternative to writing for some review concepts (e.g., fact families).</td><td>
</td></tr>
<tr><td>Matching (Bookry)</td><td>Allows the designer to add custom images that would be duplicated on the screen. The user is directed to match all like images. This widget was used in a nontraditional way for prerequisite skill review by directing users to click all multiples of specific factors.</td><td>
</td></tr>
<tr><td>Spot the difference (Bookry)</td><td>Allows the designer to upload two images and set up “correct” places for users to click that show the differences between two images. This was used in a nontraditional way to offer immediate feedback to the users who were directed to locate errors in a solved math problem.</td><td>
</td></tr>
</table>

(continued)

Table 1. (continued)

Widget and Source	Description	Sample Page
Media (iBooks Author)	Allows the designer to embed audio or video into the iBook. This was used for optional review videos and text-to-speech supports.	
Quiz (iBooks Author)	Allows the designer to embed multiple choice and matching questions that give immediate feedback to the user. This was used for prerequisite skill review.	
Pop-up (iBooks Author)	Allows the designer to embed hidden images or words that will appear when the user taps on an icon in the iBook. This was used for the optional visual hints for problem-solving.	

norm (Rose & Meyer, 2002). Providing multiple and diverse opportunities for students to engage with core content is vital to any student's learning. This idea is fundamental to the UDL framework in that it promotes a proactive approach to instructional planning where students' diverse learning needs are considered from the start. The tenets of UDL include providing multiple means of representation, expression, and engagement through flexible instruction, assessment, and materials (Rose & Meyer, 2002). While leveraging multimedia is not the only way to incorporate the tenets of UDL, modern technologies open new possibilities for doing so.

Through this exploratory study, we aimed to answer the following Research Questions: (a) How, and under what conditions, did the use of multimedia supports in the eWorkbook enhance the independent understanding and expression of whole number multiplication and division for elementary students with and without MLD? (b) How, and under what conditions, did the use of multimedia supports in the eWorkbook hinder the independent understanding and expression of whole number multiplication and division for elementary students with and without MLD? and (c) How do the teacher and students perceive the usefulness of the eWorkbook to support the independent practice of whole number operations of multiplication and division?

Method

Participants and Setting

The research site for this project was a fourth-grade classroom in an upper elementary suburban school in the Northeastern

United States. The researchers identified potential classrooms via contacts at local school districts. E-mails were sent to fourth-grade teachers, which described the study and contained a link to an initial screening survey to determine eligibility: The teacher must (a) provide services to students with disabilities in an inclusive setting, including at least five students who were performing below benchmarks in math, (b) be willing to incorporate digital technology in the classroom, and (c) use a research-based, common core-focused math curriculum. We generated a pool of eligible classrooms based on the results of the initial screening survey, and ultimately, the site was selected because it was the only site that met eligibility criteria and maintained regular communication with the researchers.

Adult participants included the classroom teacher and his teaching assistant (TA) for whom we obtained written consent to be video recorded and interviewed. Of the 23 students in the class, 19 students (10 female, 9 male) were recruited for the study because the remaining students received math instruction in a self-contained special education setting. We received parental consent and student assent from 100% of the 19 potential student participants. All fourth-grade student participants were Caucasian and ranged from 9 to 10 years old.

To sort students into subgroups for comparative purposes, we reviewed the following assessment results for each participant when available: (a) the most recent cognitive/intelligence evaluation(s), (b) the most recent academic achievement evaluation(s), (c) the most recent math progress monitoring data, and (d) recent math work samples. Rather than relying on a prior diagnosis from the school, these documents along with teacher-reported achievement anecdotes were used as part of a comprehensive evaluation of the participants (Hale et al., 2010). As per the legal definition (Individuals with Disabilities Education Act, 2004), students with a sensory or intellectual disability were excluded from participation in the MLD subgroup. Because attention or behavior difficulties often accompany MLD (Compton et al., 2012), students who also displayed poor behavior or who were diagnosed with attention deficit hyperactivity disorder were not excluded. The remaining students not eligible for the MLD subgroup were sorted into two other subgroups (Tier 1 and Tier 2) based on progress monitoring data, state assessment results, and curriculum-based assessments. The within-classroom sorting process resulted in five students assigned to the MLD subgroup (four of whom had an IEP) and seven students assigned to each of the Tier 1 and Tier 2 subgroups. The fifth participant with an IEP who also struggled with math was sorted into the Tier 2 subgroup instead of the MLD subgroup because she has a sensory impairment.

Intervention and Comparative Conditions

The primary intervention for this project was the eWorkbook, a mobile technology–based multimedia math practice tool replete with embedded supports to assist students in learning whole number operations of multiplication and division. The eWorkbook was created as a substitute for the paper–pencil worksheets (PPWs) traditionally employed during the independent practice portion of the math lessons. While PPWs have long been deployed by teachers during independent practice, their ability to offer the varied instructional and support needs of struggling learners remains limited. PPWs are relatively inflexible (i.e., once created and distributed, they are not easily or substantially modifiable), passive (i.e., unresponsive to student input), and any alterations or supports to such worksheets most often require proximal, real-time implementation from a teacher. These inherent limitations present a formidable challenge to teachers who may have many such students requiring support during the independent practice portion of their lessons.

The eWorkbook differs from traditional PPWs via the addition of scaffolded problem-solving and the incorporation of multimedia activities and supports. The eWorkbook scaffolds practice in three ways: (a) sequencing problems from simple to complex, (b) breaking multistep problems into smaller parts, and (c) adding additional practice with the component skills required for the more complex problems on the worksheet. The multimedia supports in the eWorkbook included review videos, immediate feedback practice questions, drag-and-drop activities, digital reference tables, drawing tools with multiple formatting options, and embedded pop-up hints to help guide mathematical thinking (see Table 1). The eWorkbook thus represents a substantive departure from traditional PPWs and expands both the instructional and student response opportunities during an important phase of learning.

As a part of our exploration of student learning with the eWorkbook, we also observed their work habits within two comparative conditions. The primary comparative condition was the traditional PPW that was part of the school's math curriculum—Math Expressions Common Core (Fuson, 2013). A second comparative condition, the scaffolded worksheet (SCW), was also introduced because some of the scaffolding enhancements in the eWorkbook could potentially be produced without mobile technology. The SCW contained the same additional review questions as the eWorkbook and the same organizational scaffolds (e.g., box diagrams, visual hints, and color coding of information in word problems) only without any multimedia enhancements (e.g., immediate feedback, review videos, drag-and-drop style responses, and color/formatting options for written responses) because those are, by nature, exclusive to a multimedia platform. By observing students using all three worksheet types across an entire instructional unit, we aimed to understand how and under what conditions the multimedia supports in the eWorkbook impacted the math achievement and learning habits of students with and without MLD.

Procedures

This study was conducted over 10 calendar weeks and was comprised of observation, eWorkbook training, intervention period (12 complete lessons), and student/teacher interviews at the end of the study. For the first 2 weeks, the PI observed typical math lessons to help gauge logistics for eWorkbook implementation. During this time, the classroom teacher and students received introductory training on the functionality of the eWorkbook. Students received initial training in small groups of four to six students in brief 15- to 20-min sessions as well a refresher training about halfway through the study when some new widgets were added. During the trainings, the PI demonstrated basic tasks (e.g., taking screenshots and functionality of the widgets) and followed the demonstration with time for the students to explore a sample eWorkbook on their own until all students could perform 100% of the tasks on the training checklist. During these first 2 weeks is also when the PI started creating the eWorkbooks to match the upcoming lessons. Because the classroom teacher provided the core math instruction, he was also responsible for ensuring content validity by affirming the eWorkbook contents aligned with each of the lessons.

Each day, the PI brought video cameras for recording math lessons and student interviews, as well as eight iPad Minis to deliver the eWorkbook. The teacher provided daily core math instruction (the only math instruction for the day), and students used the PPW, the SCW, or the eWorkbook to complete the independent practice problems for the lesson. Organizational materials including condition schedule and eWorkbook pouches (containing the iPad, headphones, and stylus) were utilized to facilitate efficient transition time. The PI captured digital images of all PPW and SCW work samples, and students assigned to the eWorkbook took screenshots of each task to record their work. During each intervention day, the PI completed a fidelity of treatment checklist to ensure the students were using the correct materials, all cameras were positioned, and all work samples were collected and labeled into digital folders.

Research Design

We were most interested in understanding how the utilization of multimedia supports (such as those included in the eWorkbook) might impact the learning of students with diverse academic strengths and needs. Consequently, we used a case study research strategy (Yin, 1984) to investigate how students from three different subgroups utilized the eWorkbook to practice whole number multiplication and division. In order to understand how work habits and mathematical performance potentially differ when multimedia supports are present, we administered the three worksheet types (PPW, SCW, and eWorkbook) on a randomized and balanced schedule to ensure we would observe students from all subgroups using the different worksheets across different instructional stimuli (e.g., math topic, teacher's pace, student behavior/knowledge, day of the week, and length of the lesson). Thus, on each intervention day, the schedule predetermined which student subgroup received which worksheet condition.

Quantitative data sources. As part of our exploration, we measured student accuracy across the different worksheet conditions. Each day, student worksheets or screenshots of their eWorkbook activities were graded to generate a daily accuracy score for each student. Single-step problems were scored out of 1 point and multistep problems were scored out of 4–5 points, depending on the complexity of the problem and number of steps involved. We also examined students' level of independence across worksheet conditions. The PI video recorded the classroom each intervention day and used video analysis software (Studiocode™ v.10) to calculate the percentage of time each student spent working without assistance from the teacher or the TA during the independent work period.

Qualitative data sources. To provide a more robust understanding of the eWorkbook's impact on student math achievement, the researchers examined daily work samples, video recordings of independent work sessions, field notes, and transcriptions of teacher and student interviews to carry out within-case and cross-case analysis.

Data Analysis

Given the use of both quantitative and qualitative data sources, we employed mixed methods for data analysis. Specifically, we utilized a fully mixed sequential equal status design (Leech & Onwuegbuzie, 2009), meaning both data types were collected simultaneously across multiple phases, but for the analysis, they were utilized sequentially with roughly equal emphasis. After calculating daily accuracy and independence scores using the procedures described above, we generated a daily "independent accuracy" composite score for each student to represent the intersection of their mathematical performance and their work habits. We generated this score by plotting pairs of points on a scatterplot graph (independence score on the x-axis and accuracy score on the y-axis) and measuring the linear distance from the origin to that point. We focused the qualitative analysis by primarily examining video recordings, lesson plans, field notes, and student work samples on intervention days when students who used the eWorkbook had either very high or low independent accuracy composite scores relative to the other worksheet conditions. We also looked for trends within and between student subgroups (i.e., Tier 1, Tier 2, and MLD) on these days.

Key features of building theory from case study research include a priori specification of constructs, the triangulation of multiple data sources, flexible methods/data sources, and within-case and cross-case analyses of data (Eisenhardt, 1989). For our analysis, we examined data using theoretical thematic analysis (Braun & Clarke, 2006) to search for trends in mathematical knowledge and expression and independent work habits while using the eWorkbook. With this type of analysis, our research questions and theoretical framework (UDL) helped drive the initial codes used to label work samples and anecdotal notes. Student work samples and anecdotal notes were labeled using digital spreadsheets, and videos were labeled and analyzed using video coding software (Studiocode). Similar codes were grouped together by theme in a code hierarchy (see Supplemental Online Table S1) to look for patterns within and between data sources.

Table 2. Accuracy/Independence Composite Means and Standard Deviations.

	eWorkbook		Scaffolded		Traditional	
Student Subgroup	*M*	*SD*	*M*	*SD*	*M*	*SD*
Tier 1	131.10	5.50	133.61	4.22	124.46	10.45
Tier 2	130.36	7.27	131.14	3.91	125.17	7.29
MLD	121.80	8.94	118.26	12.50	121.96	12.33
All	128.38	7.87	128.67	9.37	124.06	9.47

Note. MLD = mathematics learning disability; *SD* = standard deviation.

One doctoral scholar was recruited to double code a random sample of 25% of the student work samples for each condition as a form of interrater reliability (IRR) for the accuracy measure, which always exceeded 80% IRR. A similar process was used to double code video samples for the independence measure. Any disagreements were resolved until 100% agreement was reached. Another scholar assisted the PI in generating and refining the qualitative code hierarchy used for the qualitative analysis.

Results

We collected quantitative data about student accuracy and independence and calculated daily independent accuracy scores for each condition across subgroups as well as for each subgroup within each condition across the entire study (see Table 2). These data helped focus our qualitative analysis, as we primarily examined data from video recordings, lesson plans, field notes, and work samples on days when students who used the eWorkbook had relatively high or low independent accuracy compared to the other conditions.

Benefits of Multimedia Supports

The first research question targeted how and under what conditions the multimedia supports in the eWorkbook facilitated learning as evidenced by students' ability to express their understanding of whole number multiplication and division. The PI provided training on the features of the eWorkbook including how to use the widgets, scaffolds, accessibility features, and capture work via screenshots. Neither the PI nor the teacher provided instruction about how or when to use multimedia supports to enhance problem-solving because one of the goals of this study was to see how the students would utilize the technology on their own. We found the eWorkbook was most "effective" (i.e., higher independent accuracy composite scores relative to the other worksheet types) on the same intervention days (Day 3 and Day 9) for all three subgroups of students. Throughout the study, student scores were also the most consistent in the eWorkbook for all subgroups (see Table 2 for standard deviations). For students in the MLD subgroup, the eWorkbook was most effective on 7 (58%) of the intervention days. In fact, students from this subgroup were most independently accurate when using one of the two scaffolded conditions (eWorkbook or SCW) on 10 of the 12 intervention days (83%), which is a testament to the usefulness of those scaffolds for students with or at risk of MLD.

Lesson elements. Our qualitative analysis of effective eWorkbook days revealed several themes in lesson content or delivery. These effective days included a variety of problem types (e.g., math fact review, procedural review, conceptual representations, and word problems) and included cumulative review. On effective eWorkbook days, we observed almost all of the students across subgroups using the pop-up hints and review videos as they worked. Although two of the students still required teacher support after watching the review videos (both from the MLD subgroup), the other three students who watched review videos on the effective eWorkbook days did not ask for teacher support afterward. Additionally, on these days, we observed the teacher and TA verbally encouraging students to use the supports in the eWorkbook before asking for assistance. These lessons had no mechanical or mathematical errors in the eWorkbook nor any mismatch between teacher instruction and eWorkbook supports.

eWorkbook elements. Each day, the eWorkbook included some combination of up to five different types of widgets for problem-solving (e.g., drag-and-drop, writing, quiz, matching, and spot the differences), each possessing different affordances that supported students' expression of mathematics knowledge. Several widgets offered some form of immediate feedback (e.g., quiz and spot the differences) and were used to review prerequisite knowledge or for planning extended response questions. Students in all subgroups, particularly those in the MLD subgroup, reported enjoying different ways to review that were not available in the PPW and SCW conditions. The immediate feedback in the spot the differences widget proved particularly beneficial in helping students identify procedural errors (see example in Table 1). The widget required users to tap on the differences between two pictures and provided immediate feedback to the user by displaying either a green (correct) or red (incorrect) circle. The PI customized this widget to show images of correct and incorrect procedures for solving a division problem using the traditional algorithm. Students were asked to click on the two errors in the incorrect procedure and then write an extended response explaining those errors. All students in the study wrote extended responses during the unit, but only eight had access to the spot the difference widget because they were in the eWorkbook condition. Only four students (including two from the MLD subgroup) received full points on this question; all four had access to the immediate feedback from the widget. Four other students who used the widget, but did not get full points, failed to follow the on-screen directions and did not receive immediate feedback as a support.

Pop-up hints, review videos, and audio recordings were included in the eWorkbook to give students support options when waiting for help from the teacher or TA. In the final student interviews, 67% of students (12 of the 18 who were interviewed) reported using pop-up hints and 61% reported using the review videos as eWorkbook supports. Most students reported using the videos and hints with a hierarchical approach—first, they would try the hint and if it was not enough, they would then try the video. Only one student (from the MLD subgroup) who used the videos did not also use the hints because he said the hints did not help him. The use of media supports was common in the MLD subgroup; all but one student from this subgroup reported using the videos regularly, particularly for the word problems. Students from the Tier 1 subgroup reported and/or were observed using the review videos occasionally or not at all. The audio recordings were included as a text to speech support for any text directions or word problems. Throughout the study, 28% of the interviewed students reported used the audio recordings, including three of the five students from the MLD subgroup. One student from the MLD subgroup, who also has poor reading comprehension, reported using them for every problem. He would press the audio button just before entering the widget and then follow along with the audio recording as he read the problem. The addition of the audio recordings allowed this student to independently comprehend directions and word problems without asking for teacher assistance.

The most widely used support for expression of mathematical knowledge was altering the pen formatting in the writing widget to change the thickness or to utilize different colors. All students across subgroups altered pen settings on at least two occasions. Our analysis of the students' work, daily field notes, and video recordings of final student interviews revealed several trends in formatting, particularly related to students' use of color, to improve mathematical understanding and expression (see Online Supplemental Figure S1). Students were never given any suggestions about how manipulating colors or line width in the widget could help them. The initial findings related to the use of formatting were so interesting that we analyzed all writing widget work samples rather than just focusing on days where the eWorkbook was most effective.

All but one student used color at least once when using the writing widget with nearly 75% of them using color regularly (more than half of the time). Most students (89%) utilized color for engagement purposes—writing problems with different colors or selecting their favorite color(s). Some students also utilized color to enhance their mathematical expression. Nearly two thirds of the students used color to show procedural steps or to make the answer stand apart from their work; in fact, four of the five students in the MLD subgroup used color this way. It is important to reiterate, the idea of using color, whether for engagement purposes or to improve mathematical understanding and expression was entirely student constructed. Additionally, though students had access to colored pens, pencils, and highlighters for use on either of the PPWs, they only utilized color within the eWorkbook.

Two less common uses of color—to emphasize place value and to self-monitor—were highly effective in that they generally resulted in accurate procedures and final answers. Seven students (two from the MLD subgroup) used color to emphasize place value, which was especially helpful for these students to avoid making the error of using a regrouped number from the first step again in the second step of a two-digit by two-digit multiplication problem. Four students (one from the MLD subgroup) utilized color for self-monitoring. A student in the Tier 1 subgroup explained how she first solved a problem using the black pen, then resolved the problem in the yellow pen to ensure she got the same answer. Another student from the Tier 1 subgroup showed the PI how she matched colors with the scaffolded information in word problems to ensure she used all of the information. The student from the Tier 2 subgroup chose another color to write a rounded/estimated answer to the multiplication problem to "see if [his] answer was reasonable." Only one student from the MLD subgroup utilized color to self-monitor; she used a new color to write procedural mnemonics for long division and area model boxes for multiplication.

Drawbacks of Multimedia Supports

The second research question targeted how and under what conditions the multimedia supports in the eWorkbook hindered learning as evidenced by student challenges in expressing understanding of whole number multiplication and division. Similar to the findings for Research Question 1, elements exerting a negative influence on students' learning are grouped into two categories: aspects of the lesson or instruction that hindered learning (i.e., lesson elements) and features of the eWorkbook that students did not use successfully (i.e., eWorkbook elements). Some of the elements described below result from constraints inherent to the eWorkbook or the widgets themselves, while others emerge from a more dynamic interplay between curriculum design, instructional delivery, and student agency within an authentic classroom setting.

Lesson elements. In our examination of daily independent accuracy scores across subgroups, we found the eWorkbook was rarely the least effective condition of the day. There were 2 days (Days 4 and 10) where the eWorkbook average independent accuracy score was slightly lower (less than 1 point) than the next highest condition, so we started our qualitative analysis looking at these 2 days. Two additional days we examined were the last 2 intervention days of the study when the traditional (PPW) worksheet daily scores were higher than either of the two scaffolded conditions (the only days this occurred). On these "least effective" days, several trends emerged related to the lesson content and how students were supported by the classroom staff.

On the 4 focus days described above, the PI observed and documented the TA helping students (including two students from the MLD subgroup who typically struggled with math) before they requested any assistance. On the last 2 intervention days, the teacher frequently supported all students in the classroom, as these lessons were introductory lessons on long division. These support habits reduced the overall eWorkbook independence score for these days and may have deterred those students from using some of the embedded supports.

Additional lesson characteristics when the eWorkbook was less effective consist of the inclusion of multiple problems using nonwriting widgets, infrequent student use of embedded supports, frequent student errors in following directions, and, on the last 2 days, "new" math content. The errors related to following directions were most common when the eWorkbooks included problems with multimodal means of expression such as the matching or drag-and-drop widgets. These widget types were used unconventionally and thus required the students to read the directions carefully to execute the task accurately, which made it difficult to evaluate their true mathematical understanding. Interestingly, despite the slight decrease in accuracy and independence, days were commonly reported as student favorites because of the inclusion of nonwriting widgets. All students described the drag-and-drop and/or the matching widget as their favorite widget type when interviewed. This suggests the potential of these widgets as a means of mathematical expression if students receive enough time to practice with the tool.

eWorkbook elements. While many of the eWorkbook features appeared to foster mathematical understanding and expression, occasionally, certain aspects of eWorkbook implementation added additional barriers to mathematical understanding and expression. As much as possible, the PI attempted to address these barriers as they emerged; however, some obstacles related to the widgets and instruction could not be addressed with the resources available in the present study.

One of the goals for eWorkbook development was to match any embedded supports with the teacher's instruction. In other words, the review videos and hints only included methods and tips the teacher had used, or planned to use, in his instruction. This required regular communication between PI and teacher. On occasion, the teacher deviated from his instructional plans, used different names for multiplication and division procedures than those in the book, or used a new strategy mid-lesson (based on formative assessment of student engagement and understanding). When these changes occurred after the eWorkbook materials had been created for the lesson, there was a mismatch between instruction and practice for some questions. While these mismatches emerged from the teacher's natural teaching processes, on two occasions, this had a noticeable and negative impact on expression of mathematical understanding for students in the eWorkbook condition.

For example, on Intervention Day 6, the teacher used a different explanation for *close estimation* than was explained in the curriculum. The students using the eWorkbook for independent practice that day attempted to use the hint and video for this problem but were reportedly confused because the widget explained close estimation as it was presented in the curriculum, and this did not align with the teacher's explanation. A similar mismatch occurred on Intervention Day 12 when, according the lesson plan for the day, the students were expected to write an equation for the division word problems in addition to solving the division problem using the traditional method. Unfortunately, the teacher did not address the use of equations during his instruction. Thus, many students were confused when an in-widget scaffold reminded them to include an equation in their responses. Although this particular mismatch was not as problematic (as it only affected a small part of the word problem), it does underscore the reality that technology is most supportive when it is tightly aligned to instructional delivery.

The functionality of the widgets themselves was also, at times, a barrier to their effective use. The writing widget students regularly used for solving multiplication/division problems presented challenges to the physical act of writing with a stylus in a limited space. Over half the students (56%) reported having some difficulty with the stylus during their final student interviews. Illegible handwriting occasionally led to student errors when they misinterpreted their own writing and made it more difficult for teachers to assess student knowledge. The matching widget also presented a barrier to student expression of mathematical knowledge on occasion. Instructions for the matching widget often required students to either remove or leave all multiples of a specified number. One unchangeable aspect of the widget is its game-like design. If the students clicked all matching objects to clear the screen, a trophy would appear with the words "You Win!" The PI explained to students the goal for this widget for eWorkbooks was *not* to get the trophy but to select only the images indicated in the directions. Unfortunately, many students deleted all matching numbers (to get the trophy) when the directions had indicated to leave certain numbers visible. The latter error was more problematic because we lost any opportunity to assess the student's knowledge of multiples.

Social Validity

The final question addresses social validity. Due to the large number of students in this case study, even with the use of video, we had to rely on student reports and field notes to examine student use of specific embedded scaffolds, hints, and review videos in the eWorkbook. All students who were interviewed were able to accurately explain and demonstrate the various tools and supports available to them in the eWorkbook during their final interviews. As previously noted, students were also forthright in explaining exactly which tools and supports they used (see Online Supplemental Table S2). Students across subgroups described their challenges using specific components of the eWorkbook (e.g., writing, drag-and-drop widgets); however, their reported challenges were often described with solutions.

PI: Is there anything that's hard about using the iPad?

"HANNAH" (MLD): Some of them are, like when you do that [attempts to drag a very small item in a drag-and-drop widget], like sometimes when you move it around and try to do that it sort of messes it up a little. But then the easy thing is you can just tap it and it goes away.

When given the choice between the different options, 72% of the 18 students interviewed said they preferred the eWorkbook to either worksheet, and 17% said they preferred either the eWorkbook or the SCW. Of the four interviewed students in the MLD subgroup, three preferred the eWorkbook condition and one preferred either of the scaffolded options.

By the end of the study, all students navigated eWorkbooks with confidence and ease. When students did encounter technical difficulties, however, the PI observed students independently troubleshooting these challenges without frustration. Students' perceptions of the eWorkbook as the superior condition was evident in their descriptions.

"STACEY" (Tier 1): You have to take turns because it wouldn't be fair if someone was using the iPad every single day. And also if you kept on using the iPads it would probably make math a little bit easier and then the new worksheets and the Polar Bear [i.e., traditional] workbooks would be a little bit frustrating because the workbooks and the new worksheets are more harder.

Six students across subgroups used the word *fun* to describe math practice using the iPad. Student enjoyment of the eWorkbook was obvious by their level of engagement during the independent work period.

In his final interview, the teacher's first comment also emphasized his students' high level of engagement: "Engagement was increased significantly using the iPad—everyone was focused. I would say engagement was near 100% for the 20–30 min of independent work time each day over the course of the study." Video records of the independent work periods showed students hovering closely over their work and changing the way they were sitting in their chairs so the iPad was placed on their laps. Each day the students entered the classroom and excitedly checked the researcher's review board to see whether they were assigned to the eWorkbook condition for the day. The use of technology was clearly motivating for these students.

"NEIL" (Tier 2): Kids like electronics, and the normal worksheet and paper is not electronic, but the iPad is, which makes it easier to learn for kids . . . at least for me.

"LOKI" (Tier 2): I would definitely pick the iPad. I'm just big on tech. I'm a techy!

Discussion

For this study, we were interested in exploring how different multimedia features could support diverse learners during core math instruction. We found student use and understanding of the supports, incorporation of choice, and expert guidance from the teacher were crucial factors for student success. As suggested by evidence from the present study, technologies similar to the eWorkbook have the potential to extend the reach of a teacher's support when it enhances existing evidence-based practices and is carefully aligned with core instruction. This study offers preliminary evidence that a combination of quality instruction with optimally designed multimedia supports can serve as a critical foothold in fostering mathematical achievement for the wide range of students in today's inclusive classrooms.

Early research on technology for mathematics tended to focus on improving basic math skills rather than supporting conceptual understanding and analytical thinking (e.g., Howell, Sidorenko, & Jurica, 1987; Koscinski & Gast, 1993), particularly for students with disabilities. We are starting to see a focal shift in more recent technology research on students with and without disabilities where researchers are beginning to explore how to leverage technology to create visualizations, instructional scaffolds, and conceptual supports to teach challenging math concepts (e.g., Khouyibaba, 2010). Within the eWorkbook, students had options to independently access multimedia supports such as visual representations and review videos when practicing whole number multiplication and division. Although the students were not creating these visualizations on their own, this study demonstrates how multimedia can encourage self-support and provide options for demonstrating mathematical understanding.

Implications for Practice

Three major themes emerged related to implementation of technology for core math instruction: (a) alignment with existing evidence-based practices, (b) support habits and strategy instruction, and (c) finding a balance between guidance and student autonomy.

Evidence-based practice alignment. Researchers recommend the incorporation of explicit, systematic instruction to support students with MLD or at risk of MLD (e.g., Doabler et al., 2012). The eWorkbook was designed to enhance effective instruction in mathematics by incorporating explicit supports within an engaging multimedia tool. The PI used free software (iBooks Author) and web applications (Bookry) with the hope that teachers could eventually create their own eWorkbooks with multimedia supports that align to their instruction. Whether teachers opt to create their own multimedia or leverage existing technology tools, they should select technology with pedagogical purpose. Many educational technology tools on the market can be used to implement evidence-based practices such as providing frequent opportunities to respond, immediate feedback, video modeling, and visual organizers (Kaczorowski, 2017). Additionally, when students have access to these supports on individual devices, they can access them as needed instead of waiting for support from the teacher, particularly during small group or independent activities.

Support habits and strategy instruction. In addition to selecting tools that align with best practice, teachers need to be prepared and willing to let technology alter their support habits. The PI documented students using eWorkbook supports more when the teacher encouraged it throughout the independent work period. Students in the MLD subgroup regularly needed to be encouraged to try the built-in supports, so the teacher still played an important role in their success of using these tools. On days when the eWorkbook was least effective, we noticed some students (particularly those from the MLD subgroup) did not use, misused, or did not understand the multimedia supports provided. Although every widget's purpose and functionality was introduced to the students, neither the PI nor the teacher provided explicit instruction in how widgets such as *spot the difference*, *matching*, *media,* or *pop-up* could enhance mathematical understanding or expression. Although some students were able to utilize some of the feedback and hints provided by these widgets, many were not.

Students from the MLD subgroup seemed to have the most difficulty utilizing embedded supports, as they frequently requested teacher assistance even after trying them on their own. Students who are low achieving and those with MLD have a more difficult time paraphrasing mathematical problems and representing them visually than their average-achieving peers (Krawec, 2014), so the pop-up hints and review videos were expected to be a major affordance for these students. Unexpectedly, students with MLD had a difficult time leveraging these supports to improve their problem-solving accuracy. Using visual representations to assist with problem-solving goes beyond just looking at the images; students need to be supported in the process of leveraging visualizations (Harries & Suggate, 2006). In the present study, the teacher typically reviewed the practice problems with the whole group after the independent work session. Perhaps during these debriefing sessions, the teacher could have included a discussion about the visualizations, and during guided instruction, students might also have worked in groups to practice drawing visual representations based on word problems and writing word problems based on visual representations. These adjustments may have helped the students with MLD to more effectively leverage the available eWorkbook supports.

Another student-constructed multimedia support we discovered was their use of color strategically to self-monitor and keep track of place value. Three of the five students with MLD utilized color in the writing widget, but only one student from this subgroup used color strategically. When students used color this way, it was almost always associated with accurate and independent math practice. It may be beneficial for the teacher to provide modeling and guided practice opportunities for all students to use novel affordances of color in the context of mathematics problem-solving. To encourage student autonomy and critical thinking, teachers could also facilitate student inquiry and discussion, another evidence-based practice (Smith & Stein, 2011), about how color could be utilized as an organizational or monitoring support.

Student autonomy. Teaching with technology requires teachers to find a balance between providing structure and guidance and allowing students freedom to learn in a self-regulated way (Beishuizen, 2011). This means, at times, teachers need to be ready to shift control over to their students. When interviewed, the students reported enjoying being able to choose what supports they used. Each student confidently explained which supports were most helpful to them in the interview and did not shy away from telling the PI when a support was not useful for them. Early in the study, students would ask the PI for assistance with technology troubleshooting. Conversations with the students on the mid-study training day revealed students from all subgroups already knew how to troubleshoot most iPad-based errors (e.g., frozen screens and volume adjustment). When the PI asked the groups why they were asking for help when they knew how to fix it, the students indicated they did not know they were allowed to troubleshoot on their own. Nearly all of the students had experience with some kind of mobile technology at home and reported assisting their parents with troubleshooting. This suggests a need for teachers to allow for more student control over the technology used for learning.

Limitations and Future Directions

The results of this study were promising in terms of potential affordances of well-implemented instructional technology to support the learning of students with MLD. Several limitations, however, should be noted. First, a purposive sample was used for this research to ensure the presence of students with MLD in an inclusive classroom where the teacher was already implementing high-quality, evidence-based math instruction; therefore, the findings may not be generalizable to all settings. Additionally, the researchers, who conducted the analysis, are also the eWorkbook designers; we acknowledge a potential bias as we created the eWorkbook with the intent to enhance student learning. The identification of students for the MLD subgroup could be seen as another limitation. Exact procedures for identifying students with LD vary from district to district, so rather than relying on the school's identification of students for this subgroup, the teacher and PI worked together to evaluate students based on the federal definition of LD and research-based assessment cutoffs to identify students with or at risk of MLD. This procedure may be perceived as a limitation; however, it is common practice in MLD research.

Another limitation of this study is the short number of intervention sessions over intermittent instructional days. The second quarter in any elementary environment is filled with holiday breaks that result in shortened school weeks. Fortunately, these breaks in instruction did not appear to impact the students' knowledge of the tool, but the 12 intervention days likely did not allow optimal time for students to leverage the full potential of the eWorkbook. Despite this short intervention period, there were still 233 separate work samples included in the analysis (98 in the eWorkbook, 71 in SCW, and 64 in PPW), daily video recordings, and 19 interviews, which allowed for a data-rich investigation of the eWorkbook's impact on math achievement.

Much of the research tying technology to student achievement in mathematics focuses on accuracy as the sole achievement construct, allowing problems to be graded objectively as *correct* or *incorrect* (Seo & Bryant, 2009). In this study, we attempted to broaden the construct of math achievement by examining student engagement habits in addition to their accuracy scores to explore *how* students utilized technology to support learning in mathematics. It is important to note the researchers selected the technology for this study. In the future, to investigate more authentic uses of technology, we recommend the role of technology decision maker shifts away from the researcher and toward the teacher and even the students themselves. As demonstrated by the present study, the role of the teacher is critical in technology integration, so future research should explore ways to measure how purposeful technology integration that is linked to evidence-based instruction impacts student learning habits.

Authors' Note

Andrew Hashey is now to SUNY Buffalo State, Buffalo, NY, USA.

Declaration of Conflicting Interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: The authors of this manuscript completed this research while they were doctoral scholars at University at Buffalo. This research was supported in part by a grant from the United States Department of Education, Office of Special Education Programs, Grant Number: H325D100026.

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Supplemental Material

Supplemental material for this article is available online.

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