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ORIGINAL PAPER

Performance of Fourth-Grade Students with Learning Disabilities on Multiplication Facts Comparing Teacher-Mediated and Technology-Mediated Interventions: A Preliminary Investigation

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Abstract Instructional applications (apps) are educational software programs that can be accessed via mobile technologies (e.g., iPad, smartphone) and used to help students acquire various academic skills, including mathematics. Although research suggests that app-based instruction (AI) can be effective, there is a paucity of research comparing AI, to teacher-directed instruction (TDI) or to a combination of instructional approaches (CI) involving both AI and TDI in tandem. In an alternating treatments design, we compared AI, TDI, and CI conditions during instruction targeting multiplication facts with six students with learning disabilities. Results were inconsistent across students, and no condition emerged as consistently better than the others. Students completed social validity rating scales, and all approaches were favored by at least one student. Our results support findings from previous research involving similar comparisons between these instructional formats in which no (or minimal) differences across conditions were detected. We conclude that there may not be a meaningful difference between the outcomes achieved using AI, TDI, or CI for many students. Results are discussed in terms of directions for the future research.

Keywords Mathematics · Leaning disabilities · Technology · iPad · Intervention

Introduction

Approximately 10 % of all school-aged students have mathematics difficulties (MD; Berch and Mazzocco 2007; Geary et al. 2007), and 5–7 % have mathematics

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learning disabilities (MLD; Geary 2011). Students with MLD often struggle with early number concepts that are foundational to the acquisition of more advanced mathematics (Aunola et al. 2004; Geary 2011; Jordan et al. 2009; National Mathematics Advisory Panel [NMAP] 2008). For example, students with LD may experience persistent deficits in the performance of skills related to number combinations (Cirino et al. 2007; Geary 2011; Gersten et al. 2005; Hanich et al. 2001), which negatively affects the acquisition of the skills needed to solve whole number computations and word problems (Fuchs et al. 2005). Because proficiency in multiplication is a prerequisite for instruction in rational numbers (e.g., fractions, ratios, and proportions) and pre-algebra (Woodward 2006), mastery of this foundational skill is paramount. However, without effective intervention, chronically low scores on mathematics assessments suggest that many students with MLD will continue to display poor mathematical achievement across time (National Assessment of Education Progress [NAEP] 2013).

Traditionally, teachers have been the primary agents for the delivery of instruction in the classroom, and research has demonstrated that systematic, explicit TDI is effective in teaching students with LD mathematics (Baker et al. 2002; Gersten et al. 2009; NMAP 2008; Stein et al. 2006). According to the NMAP (2008), teacher-mediated, explicit, strategic approach in mathematics instruction includes: (a) modeling (i.e., teacher verbalizing the steps); (b) explaining when and why it is necessary to regroup; (c) providing multiple examples and non-examples illustrating target skills; (d) sequencing examples carefully to progress from simple to more complex problems; (e) providing multiple practice opportunities; (f) immediate error correction; and (g) monitoring student progress. Previous research has established that consistent application of these strategies can lead to improvement in mathematic skills for students with LD (Swanson et al. 1999).

Although teacher-delivered instruction can be effective, efforts to improve instructional efficiency and educational outcomes via technology have a long history (e.g., Skinner 1968). Recent technological advancements coupled with rapidly declining costs have occasioned an explosion of new devices, and a number of instructional methods involving technology have been demonstrated to be effective tools in the education of a variety of student populations (e.g., Kagohara et al. 2013; Lang et al. 2014; Ramdoss et al. 2011b), including students with MLD (Hughes and Maccini 1996). The National Council for Teachers of Mathematics (NCTM 2006) has advocated the use of technology in mathematics instruction, noting that technology is vital for high-quality mathematics instruction in the 21st century.

One type of technology-mediated intervention, computer-based instruction (CBI) is a popular method for teaching mathematics to students with MLD (Bouck and Flanagan 2009; Fitzgerald et al. 2008; Vaughn and Bos 2009). CBI offers instructional content that can be used in isolation or in combination with TDI (Okolo et al. 1993; Ulman 2005). According to Watkins and Webb (1981), CBI (sometimes referred to computer-assisted instruction) is commonly delivered in the following six modes: (a) drill and practice, (b) tutorials, (c) games, (d) simulations, (e) problem solving, and (f) computer managed instruction. Research investigating these modes and other similar functions has found that CBI is a valuable approach to teaching academics (Hughes and Maccini 1996; Ramdoss et al. 2011b) and enhancing functional capabilities of students with disabilities (Bryant and Bryant 2011; Ramdoss et al. 2012a, b; Ramdoss et al. 2011a, b).

Recently, a new type of CBI that uses mobile devices (e.g., smartphones, tablets) rather than desktops or laptops has emerged. Mobile devices have a number of advantageous features: (a) the availability of inexpensive downloadable apps, (b) a touch screen that allows input without having to operate a mouse or keyboard, (c) portability due to long battery life and small screen size, (d) ability to connect to the internet, and (e) multimodality (Nirvi 2011). Moreover, these devices often include built-in accessibility options and are frequently customizable (Douglas et al. 2011). Mobile devices and educational apps seem to hold great promise for teaching students with LD important mathematics skills.

Although app-based instruction (AI; the newest iteration of CBI) has been demonstrated to be an effective teaching tool, whether or not AI enables, more efficient teaching and/or improved educational outcomes compared with TDI remain an important question. In a study involving two children with autism receiving intervention to improve communication skills, Lee et al. (in press) compared TDI with AI (i.e., iPad equipped with an educational app) using an alternating treatments design. Although time on task, challenging behavior, and response accuracy were slightly better for one participant, the differences between conditions were minimal and results for the second participant did not favor one condition over the other. The authors concluded that AI was equally effective as TDI for both students.

Bryant et al. (2014) compared word identification and reading fluency across AI, TDI, and CI conditions for four students with LD in an alternating treatment design. Results suggested that students were slightly more engaged in the AI condition, but performed marginally better on tasks related to passage fluency and word identification in the TDI condition. However, the degree of data path overlaps within the alternating treatments design led to the conclusion that both TDI and AI can improve reading performance and support high levels of engagement.

In a study involving mathematics, Wilson et al. (1996) compared the effects of CBI to TDI on the multiplication performance of four students with LD in an alternating treatments design. Students participated in 30-min intervention sessions daily. The typical daily lesson sequence consisted of a 5-min (or less) probe, a 10-min lesson (either CBI or TDI), followed by a 10-min lesson using the alternate technique. In terms of fact mastery, opportunities to respond, and success rate, results favored the TDI approach.

Howell et al. (1987) examined the effects of CBI and a combined approach (CBI plus TDI) on multiplication facts acquisition of a 16-year-old male student with LD. A series of single-case experimental designs suggested that CBI had “an initial, but transitory effect upon the number of errors and the amount of time to successfully complete multiplication problems” (Howell et al. 1987, p. 339). The student was then taught an alternative TDI strategy, “The Rule of 9s” and “then used the drill-and-practice software as a reinforcement and maintenance for any gains made” (Howell et al. 1987, p. 338). The error rate decreased following this combined approach, and the authors concluded that combining CBI and TDI may be the most beneficial.

Given the paucity of studies comparing these instructional approaches and the discrepant findings across those studies, the purpose of this current study was to replicate and extend previous research comparing AI, TDI, and CI. Specifically, this study uses an alternating treatment design to compare AI, TDI, CI when used to teach multiplication facts instruction to six fourth-grade students diagnosed with LD. Additionally, social validity data were collected to identify the students' perceptions and preferences regarding each instructional approach.

Method

Participants and Setting

Six students (four boys and two girls) attending a charter school in central Texas participated in this study. All were fourth graders identified as having LD and were receiving pullout mathematics instruction per their individualized education program (IEP; i.e., they had IEP goals in mathematics). The intervention was conducted at the participants' special education classroom. Members of the research team served as interventionists. The classroom was divided into three areas of arranged desks and chairs. The interventionists and participants were seated facing each other at each desk, and the participants' seats were arranged where they could not see other pairs if they were attending to the interventionist.

Students were selected based on their special education teacher's recommendation. To promote homogeneity within pairs, children were assigned to their two-student pair based on their pretest performance. Demographic information for the students is provided in Table 1, including achievement data in reading, mathematics, and writing, which were provided by the school.

Measures

Pretest

Before starting the intervention, the participants were tested with a researcher-designed multiplication probe [$2 \times N$ (i.e., 2×0 through 2×12) facts]. This was done to ensure that students knew their $2 \times N$ facts, a prerequisite to the lessons' [$4 \times N$ (i.e., 4×0 through 4×12) facts] and [$8 \times N$ (i.e., 8×0 through 8×12) facts] strategies, which served as a basis for the teacher-directed intervention. That is, the 4s and 8s strategies use the break-apart technique, where students break the 4s down to 2×2 and the 8s to 4×2. Thus, it was imperative for students to demonstrate competence on their 2s facts, which they did at greater than 80 % accuracy on the probe.

Dependent Variable Probes

The dependent variable for this study was digits correct in 2 min, assessed by researcher-created 2-min multiplication fact probes that were administered daily.

Table 1 Participant demographic information

Student[a]	Gender	Age (years.months)	Race/ethnicity	Grade level	Disability	Free/reduced lunch status	ELL	Mathematics	Reading	Writing
Perry	M	9.6	Hispanic	4	LD	Y	Y	92[b]	90[b]	97[b]
John	M	9.10	Hispanic	4	LD	Y	N	82[c]	71[c]	76[c]
Kelly	F	9.10	Hispanic	4	LD	N	N	76[c]	64[c]	77[c]
Sarah	F	9.5	Hispanic	4	LD	Y	N	86[b]	83[b]	100[b]
James	M	9.3	Mix Race	4	LD	Y	N	84[b]	98[b]	92[b]
Michael	M	9.10	Mix Race	4	LD	Y	N	90[b]	77[b]	12[d]

[a] Student pairings: Perry and John, Kelly and Sarah, James and Michael

[b] Woodcock-Johnson III, Standard Scores

[c] Wechsler Individual Achievement Test, Standard Scores

[d] Test of Written Language, Standard Scores

Each probe contained 70 multiplication facts of 4s and 8s (35 of each), and all items represented vertical multiplication. Researchers administered five alternate forms of the probe (A–E) to each student in counterbalanced order. Specifically, researchers administered form A to one student of each two-student pair, while another researcher administered the other student form B on the first day. The next day, each student who had been administered form A was given form B, and the other who had solved form B was given form C. The process continued until all students completed five probes. After finishing form E, the participants went back to form A and the administration order was repeated for the remainder of the study.

Social Validity Interview

A social validity interview was developed for this study. The interview format was similar to other researcher-designed questionnaires commonly used to assess social validity in intervention studies (e.g., Bryant et al. 2011a, b; Calhoon et al. 2006; Jitendra et al. 2004). The items were modified to reflect specifically the student's perceptions of the different instructional approaches that were used in the study. The following questions were asked following the intervention: (a) Which method of instruction did you like the best? (b) Why do you prefer that method? (c) What do you think about the other methods? (d) What factors made you not choose the other methods as the best? (e) Which method do you think helped you learn the most? (f) Which method do you think you were most engaged and motivated to learn the most? (g) Which method do you think you were focused on the task the most? (h) Do you have any other comments regarding the three methods of teaching that you experienced?

Alternate Forms Reliability

To determine the alternate forms reliability of the probes, forms were administered in counterbalanced order to 47 fourth and fifth graders over a 3-day period. Alternate forms reliability yielded correlation coefficients across five forms of the probes (A–E) that ranged from .84 through .94 (median = .93).

Materials

Two applications for AI and one set of TDI lessons composed the materials for this study. The third approach, CI, used both the AI and TDI materials. For AI, two mathematics iPad applications were used: Math Drills (Instant Interactive 2012) and Math Evolve (Zephyr Games 2012).

Math Drills purports to provide well-designed learning based on repeated drill-and-practice activities; the application allows students to monitor their progress. Math Drills has both review and practice modes. In the review mode, students are provided various forms of assistance and selectable cues (e.g., blocks, number lines) that help them solve multiplication facts (facts were aligned with those taught in the other approaches). The practice mode can be tailored to the ability of the individual student and allows specification for types of equations, help, sounds, colors, and so on. Math

Drills allows the user to choose types of problem generation, problem counts, answers, themes, input, arrangement (i.e., horizontal or vertical orientation of problems), review assistance, sounds, and colors. In the review mode, the questions that are missed are brought back up, so students have the chance to understand missed problems and receive another chance to understand and retry the problem.

The other application used was Math Evolve, which purports to be an engaging learning tool for practicing mathematics facts. It allows the user to choose which operations they want to practice, and customizes the difficulty level of the mathematics problems. Multiple student profiles track each student's performance to help teachers or parents improve students' mathematics learning through targeted practice. Students are supposed to solve mathematics problems to win, fighting against enemies that come along with mathematics problems. Math Evolve has two features: a story mode (a mathematics game) and a practice mode.

The TDI intervention consisted of five 30-min sessions, taught for 5 days over the 3-week period. Each lesson consisted of a Preview (providing an advance organizer), Modeled Practice (teaching the skills and engaging students during instruction), Engage Prior Knowledge Practice (practicing what was previously taught), followed by Independent Practice (solving four or five problems reflecting the day's taught facts within 4 min). At the beginning of the Independent Practice activity, the teacher provided a review statement then gave the students 4 min to complete the items. At the end of the lesson, the 2-min probe was administered.

CI was incorporated using both AI and TDI. The Engage Prior Knowledge, Practice, and the 4-min Independent Practice sections of the lesson involved the Math Drills application. Interventionists administered the Preview, Modeled Practice, Practice, and Independent Practice sections using TDI. At the end of the lesson, researchers administered the 2-min probe.

Research Design

An alternating treatments design was used to compare the effectiveness of different instructional interventions to improve multiplication skills for six students with LD who were receiving mathematics instruction in a pullout program. The three instructional formats (i.e., TDI, AI, and CI) were conducted five times each within a randomly determined sequence for a total of 15 sessions over a 3-week period.

Procedures

The 30-min intervention was implemented in mathematics class that occurred shortly after lunch 5 days per week for 15 days. Because the day of session 6 was an early release day, the intervention was delivered in the morning. The last session was postponed from a Friday to the next Monday because of a field trip. Multiplication facts of 4s were used as the instructional content in sessions 1 through 7, multiplication facts of 8s in sessions 8 through 10, and a combination of multiplication facts of 4s and 8s were used in sessions 11 through 15. Two participants (students 2 and 6) were absent twice during the intervention, resulting in two missing data points.

Three doctoral students with teaching experience served as interventionists and administered all lessons. The first author conducted a 3-h training session in the three instructional approaches. During the training, the trainer taught the interventionists how to administer the teacher-directed and combined lessons and to conduct probe assessments by strictly following the developed scripts. The training also taught the interventionists how to use the applications and practiced with them until comfortable with their use. The trainer instructed the interventionists that they were to provide no teaching, assistance, or feedback to the student during the application instruction (either alone or in the combined approach) unless the iPad or application malfunctioned.

During the AI session and the CI session when the application was used, students were told to work independently and request assistance only if the iPad or application malfunctioned, which never occurred. During TDI or CI when TDI was being implemented, interventionists checked for student understanding and provided error correction or praise as appropriate. At the end of each session, the participants received character stickers as rewards for participation. After finishing the final session, participants received a small gift as an expression of the researchers' appreciation.

Prior to the intervention, the lead author created the 3-week instructional schedule. A die was used to randomly assign an instructional approach to each pair. On each day, one pair received AI, one TDI, and one received CI. Thus, at the end of the 15-day intervention period, each pair participated, based on random assignment, in five sessions each of three instructional approaches to teach 4s and 8s multiplication facts.

With Math Drills, students began each lesson in the review mode and worked for 8 min and then worked in the practice mode. While working in review, the students were able to switch back and forth across modes at their own choosing. Prior to AI for both applications, interventionists programmed the iPad with regard to content, sounds, colors, and so forth. Students were not given the option of changing the program's settings so as to ensure that the application was consistent across all students.

For Math Evolve, the practice mode was used in the study. Enabling customization allows students/interventionists to choose exactly what types of multiplication (e.g., 4s, 8s, or both 4s and 8s together) to practice. The students' performances can be documented to show their progress. The interventionists identified the instructional content (i.e., 4s, 8s, or both 4s and 8s together) prior to each lesson. Students worked with each application for about 15 min per day of AI. Math Drills was used during the first 15 min and Math Evolve for the last 15 min. At the end of the lesson, the 2-min probe was administered.

Each probe was scored immediately after the intervention by two researchers (inter-rater agreement). If the results differed, the researchers met, examined the test protocol, and reconciled their scoring. The number of correct digits was computed.

Fidelity of Implementation

All interventionists were observed at least twice across seven sessions during the 15 days of intervention by the lead or second author to assess the quality (i.e., fidelity) of specific implementation performance indicators. During the first observation for each approach, both observers rated fidelity—perfect agreement was noted. Quality of Implementation (QoI) indicators included the degree to which the interventionist followed scripted procedures throughout the lesson sections.

Each interventionist was observed at least twice to assess indicators of adherence to the intervention. For the TDI and the CI approaches, script adherence was examined for each segment of the lesson: Engage Prior/Informal Knowledge, Modeled Practice, Practice, and Independent Practice, and Overall Fidelity. Performance in each segment was rated on a 4-point scale. A score of 1 was given if the interventionist did not follow the script at all. A score of 2 was given if the interventionist somewhat followed the script (many deviations observed). A 3 was scored if the interventionist closely followed the script (some deviations observed). Finally, a 4 was scored when the interventionist followed the script exactly. An Overall rating was also provided, ranging from 1 (poor) to 4 (excellent).

For AI, also observed twice, fidelity was assessed (using the same 4-point Likert-type system above), for the following areas: (a) the interventionist provided a review to the students on how to use the iPad and the application; (b) the interventionist let students review previous skill sets from the previous lesson (e.g., the teacher set up the application on skill sets learned in the previous session to let students practice at the beginning of the lesson); (c) the interventionist kept monitoring students' use of the iPad and their work; (d) the interventionist provided appropriate support and feedback (no teaching) when students had questions or problems (see procedures for examples of support and feedback); (e) the interventionist administered the probe and followed the written administration procedures. An Overall rating was also provided, ranging from 1 (poor) to 4 (excellent).

In all cases, scores of 3 or 4 points were awarded to each of the categories. The maximum possible fidelity score was 24 points for the TDI and the CI approaches. For AI, the maximum score was 20 points. The average fidelity rating for TDI and CI was 23.1 (96 %); for AI, the average score was 18.7 (94 %). Thus, observations across interventionists and instructional procedures showed a high degree of fidelity in the implementation of the three different instructional procedures.

Results

Figures 1 and 2 depict each student's performance on the researcher-created daily 2-min multiplication fact probes across all three conditions (TDI, AI, and CI). Table 2 provides the scores per session and the mean and standard deviations for each condition with each participant.

Perry's results are depicted in the top panel of Fig. 1. The condition with the most correct responding was the TDI condition ($M = 42$, range 37–54) followed by the CI condition ($M = 40.2$, range 23–49). The AI condition was associated with the fewest correct responses ($M = 31.2$, range 25–38). Across all conditions, a slight increasing trend is evident and the CI and TDI data paths are notably intertwined. Visual analysis suggests that TDI was consistently better than the AI

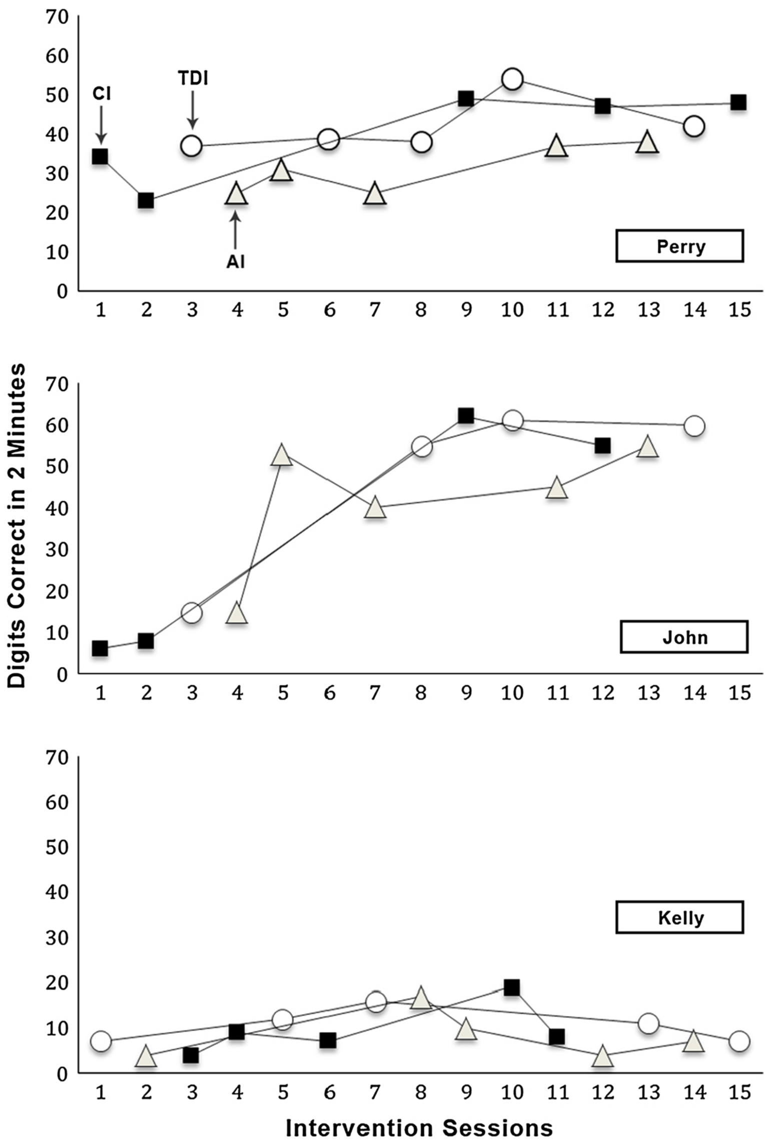

Fig. 1 Visual depiction of performance for Perry, John, and Kelly. *TDI* teacher-directed instruction, *AI* applications only instruction, *CI* combined instruction

condition, but there is a lack of divergence between the TDI and CI data paths and between the CI and AI data paths.

John's results are depicted in the second panel of Fig. 1. John demonstrated the most correct responses during the TDI condition ($M = 47.75$, range 15–60) followed by the AI condition ($M = 41.6$, range 15–55). The CI condition was associated with the fewest correct responses ($M = 32.75$, range 6–62). A rapidly

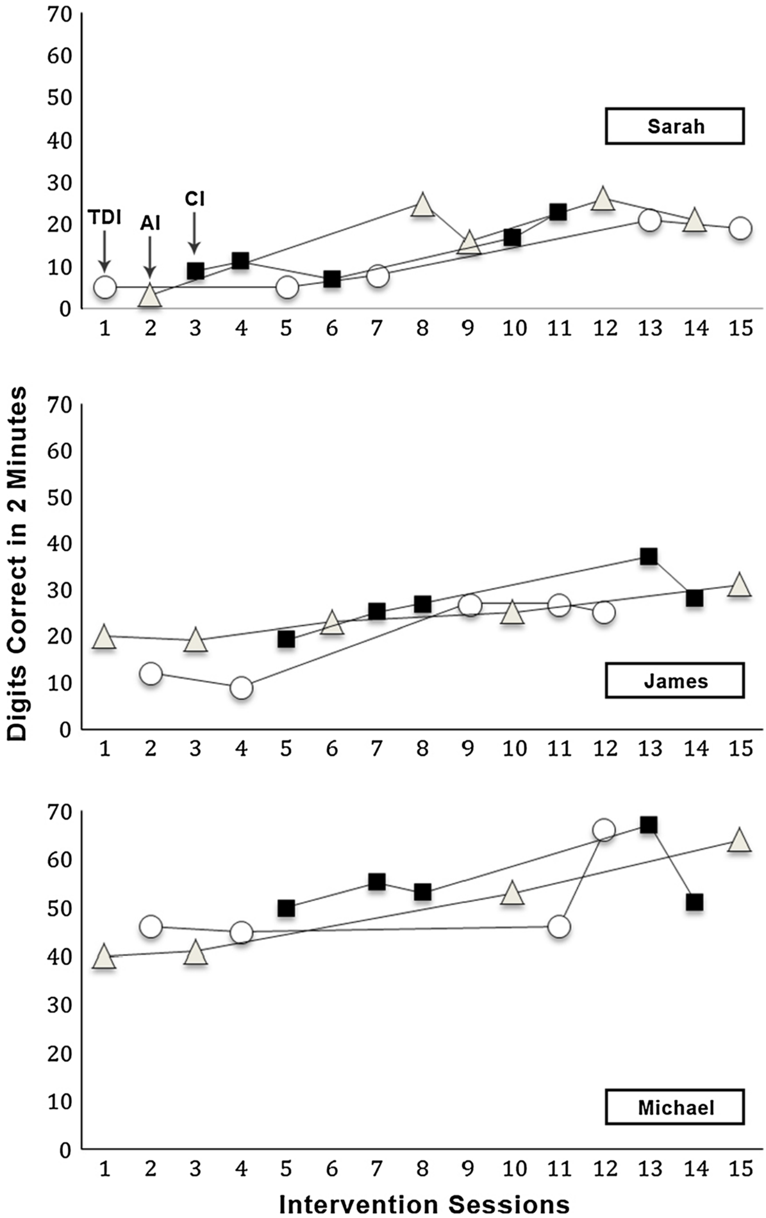

Fig. 2 Visual depiction of performance for Sarah, James, and Michael. *TDI* teacher-directed instruction, *AI* applications only instruction, *CI* combined instruction

increasing trend is evident across all conditions, and there is a high degree of overlap in the data paths for each condition.

Kelly's data are displayed in the bottom panel of Fig. 1. Kelly produced the most correct responses in the TDI condition ($M = 10.6$, range 7–16) followed by the CI

Table 2 Participant probe performance for digits correct in 2 min for intervention approaches across five sessions

Students	Intervention approaches	1	2	3	4	5	*M*	*SD*
Perry	TDI	37	39	38	54	42	42.0	6.9
	AI	25	31	25	37	38	31.2	6.2
	CI	34	23	49	47	48	40.2	11.4
John	TDI	15	NA	55	61	60	47.75	22.0
	AI	15	53	40	45	55	41.6	16.1
	CI	6	8	NA	62	55	32.75	29.9
Kelly	TDI	7	12	16	11	7	10.6	3.8
	AI	4	17	10	4	7	8.4	5.4
	CI	4	9	8	19	8	9.4	5.7
Sarah	TDI	5	5	8	21	19	11.6	7.8
	AI	3	25	16	26	21	18.2	9.4
	CI	9	11	7	17	23	14.8	5.5
James	TDI	12	9	27	27	25	20.0	8.8
	AI	20	19	23	25	31	23.6	4.8
	CI	19	25	27	37	28	27.2	6.5
Michael	TDI	46	45	NA	46	66	50.75	10.2
	AI	40	41	NA	53	64	49.5	11.3
	CI	50	55	53	67	51	55.2	6.9

TDI teacher-directed instruction, *AI* applications only instruction, *CI* combined instruction, *NA* signifies student absence

condition ($M = 9.4$, range 4–19) and then the AI condition ($M = 8.4$, range 4–17). No improvement in digits correct per 2 min was detected in any condition, and the data paths for each condition overlap entirely.

Sarah (top panel of Fig. 2) performed best in the AI condition ($M = 18.2$, range 3–26) followed by the CI ($M = 14.8$) and then the TDI conditions ($M = 11.6$, range 5–21). There is an increasing trend across all three conditions, due to overlap in data paths.

James' correct responses were highest in the CI condition ($M = 27.2$, range 19–37) and then the AI ($M = 23.6$, range 19–31) and, finally, TDI conditions ($M = 20$, range 9–27). A slight increasing trend across conditions and overlap between all data paths are observed.

Michael's scores were highest in the CI condition ($M = 55.2$, range 50–67), followed by the TDI condition ($M = 50.75$, range 445–66) and then the AI condition ($M = 49.5$ range, 40–64). All three data paths overlapped substantially, and an overall increasing trend across data paths is evident.

Social Validity Results

A social validity questionnaire was given to assess the students' perceptions and preferences regarding each instructional format (i.e., TDI, AI, CI). Four participants

(Perry, Kelly, James, and Sarah) reported that they preferred the CI condition and John and Michael identified the AI condition as most preferred. Students were then asked why the preferred the condition they selected. Perry responded, "I like the teacher and the iPad application." John, who preferred the AI, stated, "I learned more, there was clues, practice more." Kelly noted, "I liked the clues of the iPad program." Sarah offered, "I liked the teacher's teaching and using the iPad together." James noted that the CI approach was "easy to understand." And Michael stated that the AI approach was "fun."

Next, students were asked what they did not like about the conditions they did not select. Three of the students did not give a specific reason. James noted that the AI and TDI approaches were "not fun." John noted, when commenting on the TDI and CI approaches, "Other people were talking and it was disturbing." And Michael said that it was "hard to understand the strategy." When asked to identify which method helped them learn the most, five students responded with the CI approach and Sarah said the TDI approach. When asked which condition helped them stay engaged and motivated, three students (Perry, Sarah, Michael) selected the CI approach, two (John and James) the TDI approach, and one (Kelly) responded in favor of the AI approach. When asked which condition helped them to focus on the task the most, four students (Perry, John, Kelly, and Sarah) responded with the CI approach and two (James and Michael) answered, "teacher-directed."

Finally, the students were asked if they had any other comments regarding the three methods of teaching that they experienced. Perry, John, James, and Michael stated, "no;" Kelly reiterated that the iPad programs (applications) were fun; and Sarah noted, "I liked working with the teacher." Overall, students supported all three approaches. It is interesting to note that the AI received no votes from the students when they were asked which approach helped them learn the most. But in most areas, all three approaches were viewed favorably by at least one student.

Discussion

Within the past 10 years, tablets and other mobile devices have provided opportunities for people with disabilities to obtain inexpensive applications that can serve as assistive technologies (Douglas et al. 2011). There are thousands of applications that are free to the public, and others that are inexpensive, affording the opportunities for individuals to download and try the applications before using it consistently or upgrading to a larger version of the free application at a reasonable cost, many times for under $2 USD.

Among the thousands of applications currently available, many are designed to promote academic improvement in areas such as reading, writing, mathematics, and science. Early devices often lack instructional rigor and fail to include many of the elements of instruction needed by students with LD (Raskind, August, 2012, personal communication). Yet, for most students, they offer practice opportunities using colorful and appealing graphic displays and games.

Not long ago, mathematics research was far behind reading research in terms of volume of research and quality of studies (Bryant et al. 2008). Over the past

10 years, however, progress has been made in studying the prevention of early mathematics failure (e.g., Bryant et al. 2008, 2011a, b; Jordan et al. 2009), middle school algebra readiness (Stine, n.d.), and high school mathematics content (Bryant et al. 2011a, b). Research has demonstrated the effectiveness of systematic, explicit mathematics instruction (Bryant et al. 2011a, b; Baker et al. 2002; Fuchs et al. 2005; Gersten et al. 2009), and strategic instruction in mathematics (Woodward 2006).

However, there remains little research that has explored the efficacy of application programs designed for educational purposes, and even fewer comparing AI to TDI and/or CI. Thus, the purpose of this research was to (a) determine which approach (i.e., TDI, AI, or CI) best helped students with LD learn multiplication facts, and (b) gauge students' perspectives about the three instructional approaches.

In terms of comparing AI to TDI and CI, these results are inconclusive. More students scored higher on multiplication facts after TDI, but based on the average scores across all students, the CI approach was slightly better than TDI, followed by AI. However, there was a large degree of overlap in the data paths for all three conditions and all six students. Therefore, definitive conclusions regarding the instructional approach that worked best for each student is not possible. The exception is Perry, because he consistently performed better in the TDI condition than in the AI condition (no overlap in data paths). However, even for Perry, it is not possible to be certain if the CI or TDI approach was better. Overall, this study supports previous research suggesting that there may be little difference between these instructional formats (e.g., Bryant et al. 2014; Lee et al., in press).

The results for Kelly merit attention because the student did not appear to benefit from any of the three treatments. Although all six students had been identified as having MLD, it appears that Kelly's deficits may be the most resistant to intervention. Her initial scores were very low, as were Sarah's. But unlike Sarah, Kelly's scores remained low throughout the study and were notable for their decreasing trend toward the end of the intervention. Such performance is not uncommon for students with severe MLD (Bryant et al., in press), and may be the result of what Burns et al. (2006) referred to as a lack of "instructional match" (p. 402) for mathematics instruction. Even though Kelly was able to score well on the "times 2" measure, demonstrating prerequisite competence for the "times 4" and "times 8" lessons presented in this study, it could be that Kelly, more so than the others, was in the early acquisition stage of the skills being targeted and the 4s and 8s were not at an instructional match for her skill level. Unlike Perry, for instance, who appeared to be in the fluency building stage, Kelly was struggling in acquiring the "times 4" and "times 8" skills. Although these explanations seem plausible, additional research aimed at systematically identifying participant characteristics that predict response to specific instructional procedures is warranted.

In terms of student perceptions and preferences, we were somewhat surprised that students, as a whole, seemed to favor the TDI approach. Students seemed to like the interactions they had with the interventionists and the social reinforcers (i.e., praise from a human as opposed to from a computer) received during instruction. However, student preference for one instructional approach over another might be better detected with a choice-based systematic preference assessment than with a post-intervention social validity questionnaire (Verschuur et al. 2011). Further, if there truly is no difference in the outcomes achieved from technology mediated instruction (TMI) or TDI, then offering the student a choice between conditions may be even more beneficial (Lee et al., in press; Rispoli et al. 2013).

In examining the impact of our study, makers of applications for educational purposes would be well served to include the elements of effective instruction in their applications. Most applications, like many early examples of technology-mediated instruction, offer drill-and-practice exercises and include games to make the activity interesting to users. Very few that we have seen thus far in our work involve actual teaching (i.e., modeling, practice), an important instructional feature. Multiple practice opportunities are plentiful.

The results of this investigation should be interpreted as preliminary and with caution due to notable limitations. The primary limitation is the fact that the effect of all three interventions was measured in terms of performance on probes of 4s and 8s multiplication facts. Students who learn a particular skill, such as 4s and 8s multiplication, one day as a result of one instructional approach undoubtedly carry over that learning to the next day and the next instructional approach. Thus, the extent to which multiple treatments influence performance on a mathematics probe is unknown, making it difficult to adequately compare the effects of the three interventions. Future researchers should use mutually exclusive problem sets randomly assigned to each treatment condition. In addition, the researchers would have to demonstrate that each set had an equal level of difficulty. A second limitation related to the possibility of multiple treatment interference is the absence of a concurrent baseline condition.

Students with MLD typically demonstrate difficulties learning arithmetic combinations such as multiplication, which is a necessary skill for more advanced mathematics such as algebra. Teachers must spend time using effective instructional approaches that improve student performance. TDI and CI include features of evidence-based instruction for students with MLD. Although the AI approach lacks the teacher-directed aspect of instruction, from which students with MLD can benefit, the technology component is appealing for many students. Students were split with their perspectives about which approach they liked best (half selected AI and the other half selected CI), both of which included technology. Yet, in examining their perspectives about the approaches, CI and TDI both were viewed as best for helping them to learn, stay engaged, and remain motivated. Finally, the performance of Kelly and Michael was quite different. For low-responding students (i.e., Kelly), further task analysis of skills for instruction may be necessary, for higher-performing students, such as Michael, a combination of approaches may be well suited for more fluent responding while maintaining interest.

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