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Using Video Modeling, Explicit Instruction, and Augmented Reality to Teach Mathematics to Students With Disabilities

Jared R. Morris, PhD[1], Elizabeth M. Hughes, PhD[2], James D. Stocker, PhD[3], and Emelie S. Davis, BS[1]

Abstract

Students with exceptionalities who do not make adequate progress with core instruction in mathematics require more intensive research-based interventions such as explicit instruction or video modeling to address instructional needs. This study examined the effects of combining point-of-view video modeling, explicit instruction, and augmented reality to teach mathematics to students with disabilities. The researchers employed a multiple baseline across skills, single-subject research design to evaluate the effects of the intervention on student performance across four mathematics skills. Two eighth grade students identified as having a disability impacting mathematics, one with autism spectrum disorder and one with a specific learning disability, participated in the study. Visual analysis determined a functional relationship between the dependent and independent variables. Tau-U result for the intervention phase was 1.0 across all four skills for each participant. Participants demonstrated high levels of maintenance, and with one exception, students were able to apply the skills to word problems without additional training. Limitations and implications for future research and practice are discussed.

Keywords

video modeling, augmented reality, explicit instruction, educational technology, effective instruction, mathematics instruction, mathematics disability

Competent performance in mathematics is widely recognized as a necessity for participation in the 21st-century economy. In addition to predicting whether students pursue post-secondary education, it has been linked to increased employment opportunities, higher wages, and improved quality of life (Adelman, 2006; Lee, 2012; National Mathematics Advisory Panel [NMAP], 2008). Yet many students have difficulty learning mathematics, especially students with exceptionalities.

For many students, a decline in mathematics performance occurs in middle school and continues to worsen through high school (National Assessment of Educational Progress [NAEP], 2019). Students with exceptionalities struggle far more than students without exceptionalities, warranting additional concern. Less than 10% of eighth grade students with exceptionalities performed at or above proficiency (NAEP, 2019). By the time these students graduate from high school, only 4% are proficient in mathematics (NAEP, 2019). Thus, educators must address targeted learning needs of students with exceptionalities, such as mathematics disabilities (MD).

Geary (2004) estimated that approximately 5% to 8% of students have MD, which equates to approximately 2.5 to 4 million students attending public and private schools according to recent public school enrollment (National Center for Educational Statistics, 2018). Students with MDs often require more intensive intervention than core instruction (Fuchs et al., 2017; Powell & Fuchs, 2015). Although a number of strategies are used to teach mathematics to students with MD, research indicates explicit and systematic instruction as the most effective pedagogical practice (Baker et al., 2002; Dennis et al., 2016; Doabler et al., 2014; Gersten et al., 2009; Kroensbergen & Van Luit, 2003; Shin & Bryant, 2015). Components of explicit instruction (EI)

[1]Brigham Young University, Provo, UT, USA
[2]The Pennsylvania State University, University Park, USA
[3]University of North Carolina, Wilmington, USA

Corresponding Author:
Jared R. Morris, Brigham Young University, 340B MCKB, Provo, UT 84602, USA.
Email: jared.morris@byu.edu

include scaffolded instruction, clear and concise language, active student engagement, frequent feedback, and purposeful practice techniques (Archer & Hughes, 2011; C. A. Hughes et al., 2017). A typical explicit lesson progresses through a sequential structure beginning with the lesson's opening (i.e., gain attention, state the goal of the lesson, discuss relevance, review prerequisite skills), followed by the lesson's body (i.e., model, guided practice, check for understanding), and concluding with the lesson's closure (i.e., review, next lesson preview, independent practice).

Despite research on the positive effects of EI (Archer & Hughes, 2011), a recent synthesis of observational research asserts that teachers have difficulty applying the core components of EI during mathematics instruction (McKenna et al., 2015). For instance, as students with MD present varied levels of understanding of topics and acquire or refine skills at different learning rates from classmates, teachers often omit guided practice and checking for understanding when leading instruction. The problem is compounded as many mathematics textbooks do not include the necessary quantity of teacher demonstrations and practice opportunities for students to build proficiency (Bryant et al., 2008; Doabler, Cary, et al., 2012a; Doabler, Fien, et al., 2012b). Thus, teachers may struggle providing the proper form, individualization, and intensity of instruction for students who are acquiring the skills at a different pace from their peers.

One alternative to live teacher-led instruction is video-based instruction (VBI; Kellems & Edwards, 2016). VBI can assist teachers in meeting the diverse instructional needs of their students. VBI provides pre-recorded instructional lessons that students can access via personalized technological devices. VBI can include different types of instructional components, allowing educators to utilize evidence-based practices within a technology-based delivery system. Similar to live instruction, VBI affords learners the benefit of observational learning, but unlike live instruction, the learner controls the pace of instruction by being able to pause, play, and watch instruction again to fit personal needs (E. M. Hughes & Yakubova, 2019).

VBI is a term that encompasses several styles of video presentation (E. M. Hughes & Yakubova, 2016). Video modeling (VM) depicts a person (model) performing the desired behavior. Self-video modeling (SVM) is similar to VM except that the model is the individual for whom the video is intended. Video prompting (VP), designed to be watched in intervals, depicts a multistep process or behavior. Point-of-view video modeling (POV-VM) shows a video filmed from a first-person point of view. VBI may also include hybrids of the video styles (e.g., VP and POV-VM). A sound base of research supports the use of VBI to teach mathematics to students with various exceptionalities (e.g., Burton et al., 2013; Yakubova et al., 2015, 2016) and specific learning disabilities (SLD; E. M. Hughes, 2019).

Another form of technology with increasing prevalence for use with academic interventions is augmented reality (AR; Wu et al., 2013). AR integrates digital information with the real world (Akçayır & Akçayır, 2017) and is most often utilized in one of two ways: location-based applications and marker-based applications. Location-based AR uses global positioning satellites and real-life objects, where image- or marker-based AR incorporates markers into printed material to provide access to additional digital resources (Hung et al., 2017; Hwang et al., 2018). Researchers found that AR increases student motivation (Bujak et al., 2013) because it has an active component with the potential and novelty to gain students' attention in an intervention.

This study incorporated marker-based AR technology to provide a platform for presenting self-directed, explicit mathematics instruction. The research is an intervention that assessed the effectiveness of an intervention featuring AR, VBI, and EI to increase targeted mathematics performance for students with MD. More specifically, we evaluated the effects of POV-VM featuring EI instruction accessed by students via an AR app on the mathematical performance for students requiring more intensive intervention in mathematics. Combining VBI, EI, and AR in this study addressed a need to provide intensive intervention for students with MD. The following research questions guided this study:

RQ1. How does an intervention using POV-VM, EI, and AR affect the performance of targeted mathematics skills by students with MD?
RQ2. How does the VBI intervention affect the maintenance of targeted mathematics skills for students with MD?
RQ3. How does the VBI intervention affect transfer of discrete mathematics skills to applied word problems for students with MD?
RQ4. How do participants rate the social validity of the intervention?

Method

Setting and Participants

The study took place at a small public charter middle school located in the northeastern United States that served students in fifth through eighth grades. According to the school website, approximately 90% of the student population was White and just over 22% qualified for special education. Students received special education services in inclusive and resource room settings. The researchers recruited students indicated by the special education teacher to have demonstrated gaps in mathematics knowledge with the potential to benefit from additional intensive mathematics

Table 1. Summary of Participant Demographics and Test Results.

Demographic	Katherine	Carolyn
Age	15	14
Gender	F	F
Disability	ASD	LD
Broad mathematics	71[a]	60[a]
Brief intellectual ability	75[b]	43[b]
Short-term working memory	56[b]	48[b]
Number facility	56[b]	42[b]
Oral vocabulary	90[b]	66[b]
Visualization	90[b]	57[b]

Note. F = Female, LD = learning disability, ASD = autism spectrum disorder.
[a]Standard Score, Woodcock-Johnson IV Tests of Achievement (Schrank et al., 2014).
[b]Standard Score, Woodcock-Johnson IV Test of Cognitive Abilities (Schrank et al., 2014).

interventions on targeted skills. The special education teacher identified two students from her combined seventh and eighth grade mathematics class based on professional observation and past performance measures. Guardians for the selected participants consented, and both students assented to participate in the study. Both students qualified for special education services and had individualized education program (IEP) goals for mathematics. The intervention took place during mathematics instruction time in a special education resource room. All research was conducted in accordance with the participating university's institutional review board. Permission and consent were collected for each of the participants.

Katherine (pseudonym) received special education services under the primary identification of autism spectrum disorder (ASD), with a cooccurring diagnosis of attention-deficit/hyperactivity disorder (ADHD). She received academic supports for mathematics and reading. She was 15 years old at the time of the study. Scores from the Woodcock-Johnson IV Tests of Cognitive Abilities (Schrank et al., 2014) indicated that Katherine classified as *low* on the brief intellectual ability cluster and *very low* on short-term working memory and number facility. Her scores for oral vocabulary and visualization were in the *average* range. Her scores on the Woodcock-Johnson IV Tests of Achievement (Schrank et al., 2014) in broad mathematics measures were documented as *low* (see Table 1).

Carolyn (pseudonym) received special education services for a SLD. She demonstrated challenges with language skills and short-term working memory and was receiving academic supports in mathematics and reading. She was 14 years old when the study was conducted. She was a White eighth grade student whose scores from the Woodcock-Johnson IV Test of Cognitive Abilities (Schrank et al., 2014) classified as *very low* on the brief intellectual ability cluster, short-term working memory, and number facility. Her scores for oral vocabulary were *very low.* Her scores on the Woodcock-Johnson IV Tests of Achievement (Schrank et al., 2014) in broad mathematics measures were documented as *very low* (see Table 1).

Independent Variables

The independent variable featured EI instruction delivered using POV-VM, accessed through an AR mobile application. Each POV-VM sequence explicitly taught one skill. Prior to the intervention phase, the participants were administered a benchmark assessment that included grade-level and near grade-level mathematics skills. The special education instructor provided the researchers with autonomy to select the skills for the intervention. Four skills for which both students demonstrated low performance and required intensive intervention. The skills identified for the intervention were (a) adding fractions with common denominators, (b) calculating perimeter, (c) calculating the range of a set of numbers, and (d) calculating the mean of a set of numbers. The participants had received instruction on these skills prior to the intervention; however, the special education teacher, who provided all of the students' math instruction, did not provide instruction on the selected skills during any of the stages of the intervention.

POV-VM for each skill included the same core instructional components and followed the same sequence. The intervention was accessed via AR app. Video lessons were recorded in the point-of-view perspective. Two videos were prepared for each skill: the first containing the lesson opening and the model; the second providing the guided practice, the check, and the close components. For clarity, the intervention is described sequentially.

Prior to beginning the intervention, an account was created at https://studio.hpreveal.com, followed by the preparation of two "auras" for each skill, one for each video. An aura is the behind-scenes settings and functions for the AR platform. Each aura required that an image be uploaded and tested for compatibility to act as a "trigger" for each instructional video. The HP Reveal app on an iPad used the iPad's camera to scan for that image. When the trigger was detected, the video, which had previously been connected to that image online at the HP Reveal studio, began to play. Settings had been configured in the online HP Reveal studio so that when each image was scanned by the iPad, it "triggered" an instructional video to begin. Other settings were utilized to ensure that the video would begin in full-screen mode and that when the video ended the app would automatically return to search mode to be prepared for scanning the next trigger image.

At the beginning of each intervention session, the participants received an instructional packet, an iPad,

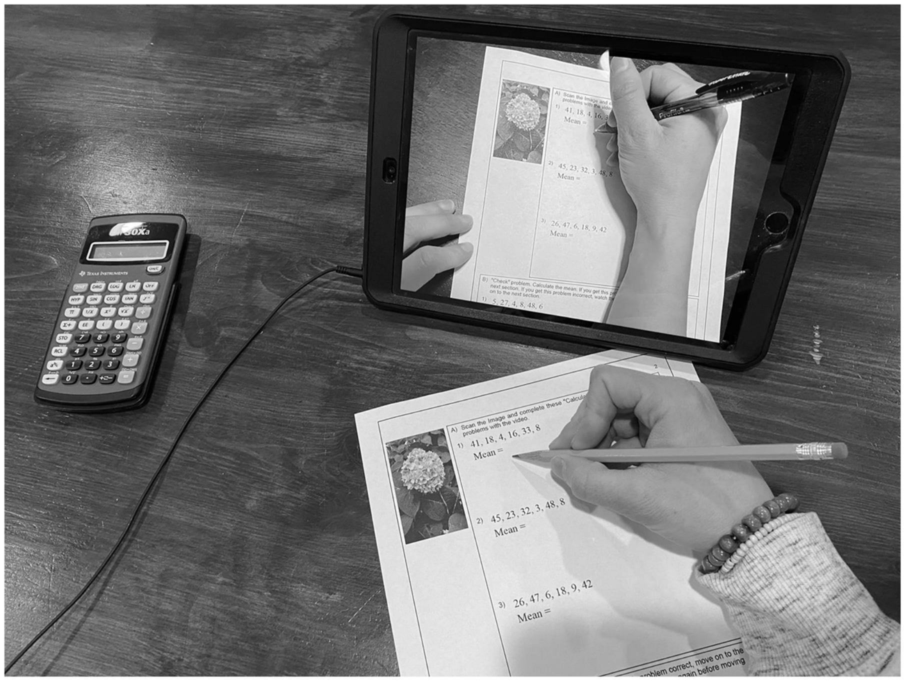

Figure 1. Image of student working along with the guided practice video model.

headphones, a calculator, and two pencils. The worksheets in the instructional packet were created using Math Resource Studio 6 by Schoolhouse Technologies® (Version 6.1.6.2). Each packet contained four pages, a cover page, a page for the opening and model, a page for the guided practice and check, and an independent practice page. The cover page communicated instructions for how to complete the packet. The participant was to scan all embedded images with the iPad and watch the accompanying instructional video (see Figure 1). The directions outlined procedures for the check stage, to solve a problem independently. Students whose answer corresponded with the correct answer displayed on the video were to continue to the guided practice pages; those whose answers did not match were to watch the model and guided practice videos again, with encouragement to do their best and show all their work. The instructions were read by the first author to the participants at the beginning of each session to mitigate any reading difficulty.

The next page, created for the lesson opening and teacher model, contained an image and brief instructions reminding students to scan the image and watch the video. The image on this page triggered a video containing the lesson's introduction and a teacher model for the intervention skills. Each model video began with a greeting to gain the students' attention, a statement of the lessons goal, and a brief review of prerequisite skills or vocabulary relevant to the math skill being taught, for example, brief explanations of the vocabulary denominator, numerator, and common were reviewed as prerequisite skills in the adding fractions with common denominators introduction portion of the video.

During the video model, the students were instructed to keep their pencils down and to watch and listen to the instruction. Three to six examples were provided, and the instructor presented a visual and verbal demonstration of the steps of performing the skill along with cognitive modeling, sometimes referred to as "thinking aloud." In cognitive modeling, the teacher vocalizes thought processes or internal dialogue (Archer & Hughes, 2011; Denney, 1975) that may not otherwise be apparent.

The third page consisted of two sections, an upper section that contained a trigger image and three guided practice problems, and a lower section that had a check problem. For the upper section, the participants scanned the image and completed the guided practice problems along with the video. The students were instructed to follow along with the video and complete the practice problems as the video instructed. The guided practice video followed a systematic fading of prompts (Archer & Hughes, 2011); initially providing intense scaffolding by telling students explicitly how to do each step of the skill, then fading to asking them how to do each step, and eventually simply reminding them to follow the steps or procedures.

The check stage of the lesson required that each student demonstrate her ability to accurately perform the skill that was taught. Each student was required to perform the skill at the required minimum level of accuracy (e.g., 90%) without guidance or prompting. The final component of the lesson, the close, quickly reviewed the skill and then provided an opportunity for independent practice. All of these stages were employed in the video lessons for each of the four skills. The remaining pages in the worksheet packet contained the dependent variable probe.

Dependent Variables

The dependent variables were permanent product performance measures. Each targeted mathematics skill had a separate performance measure consisting of five problems. Problems used to create the baseline and intervention mathematics probes were randomized using the problem generator in Math Resource Studio 6 (Schoolhouse Technologies [ST], 2018). Data were scored for percentage of accuracy, which was defined as the number of correct responses divided by the number of correct responses plus the number of incorrect responses multiplied by 100.

Data Collection Procedures

Experimental research design. This study utilized a concurrent multiple baseline across skills experimental design to measure the effectiveness of VBI, EI, and AR to teach mathematics and to determine the experimental effects including whether a functional relation was present (Gast et al., 2018). Baseline data were collected from each participant across four different mathematics skills. After the participants had had five consecutive stable baseline data points, the intervention was implemented with two skills and then in a staggered fashion for the two remaining skills. The intervention was in place for each student until she achieved mastery criterion, which was predetermined to be five sequential points with a mean of 95% correct or higher. At that point, the intervention was discontinued for that skill. Baseline only sessions lasted approximately 15 min while sessions that included both baseline and intervention sessions averaged between 30 and 45 min. Students participated in the intervention sessions 2 to 4 times a week. There were six baseline sessions without intervention, six sessions were baseline and intervention sessions, 14 sessions where students were in a combination of intervention or maintenance, and there was one session to evaluate the students' ability to transfer the mathematics skills to word problems for all four skills that lasted about 30 min.

In addition to the intervention, students receive 1 hr of mathematics instruction per day from their special education teacher. The school curriculum aligns with CCSS-M and the school uses a variety of resources (e.g., IXL.com) and integrated cross-curricular projects to teach mathematics.

Baseline. Baseline data collection took place in a quiet classroom in the school. Participants met with the interventionalist in a one-on-one setting. During each session, the interventionalist sat across from the student and gave the student an assessment packet that consisted of one page for each skill with five different mathematics problems per page. No additional instruction or feedback was given. Participants were given unlimited time to complete the assessment. All assessments were completed within 15 min. The participants were thanked for their work and returned to their classroom at the completion of the assessment. Baseline sessions continued until the baseline data reached stability for a minimum of four consecutive sessions. Three data points were collected with the first and second skills in intervention, while three additional baseline data points were collected for the other two skills. Then the intervention was implemented in a staggered manner for the third and fourth skills.

Intervention. When the intervention began, students were given (a) an instructional packet, (b) an Apple iPad Air 2 with a hinged keyboard case that would hold the iPad vertically in landscape orientation when opened, (c) a headset, and (d) a workbook packet. The directions on the cover page were read to the participants, and they were directed to begin. The participants used their iPad to scan the first image, which started the first instructional video, the introduction and model. These videos varied in length from 2 to 9 min. The first page in the instruction packet did not require students to complete any equations. When the video concluded, the participants turned the page, scanned the next image, and practiced the skill along with the video—the guided practice stage. These videos were between 3 and 10 min. Following the guided practice portion, the participants completed a check problem. To check for understanding, the instructor paused for approximately 30 to 60 s to allow the participants to complete the problem. The instructor then worked out the problem and displayed the answer. The written instructions for the check section told students how to proceed with the section, and the instructor in the video verbally reiterated the instructions. The instructions directed the participant to solve the problem and compare her answer with the worked-out answer displayed in the video. If a participant did not correctly answer the check problem, the instructor on the verbal and written instructions directed the student to re-watch the model and guided practice videos and rework the guided practice problems before attempting another check problem. This was completed before going on to the next page with independent unprompted practice problems. If the participants completed the check problem correctly, they were instructed to continue to the next page that contained five opportunities to independently practice the skill. The remaining baseline worksheets followed.

Maintenance and transfer. Response maintenance probes were given at 1-week intervals after intervention cessation. These probes were identical in difficulty and mode of presentation to the sheets used to collect data in the intervention phase. No instruction or review was given on a skill during the maintenance interval.

Student participants were evaluated to see if they were able to transfer the discrete mathematics skills to word problems. No programming or instruction was provided to prepare the participants for this assessment. A set of word problems assessment, containing five questions for each skill, was administered near the conclusion of the study in the same setting as the intervention but after intervention and maintenance phases. Example problems from each of the mathematics skills included in the assessment are as follows:

a. Sophie's cup was 1/5 full of water. If she added 3/5 of a cup more, how much total water did she have?
b. Tara was building a shed. She plans on having the shed be 5 feet by 6 feet. What is the perimeter of her shed?
c. Andrew has five cats. His cats weigh 6 pounds, 8 pounds, 15 pounds, 12 pounds, and 7 pounds. What is the range of their weight?
d. Cam collected 6 shells from the beach. Molly collected 8 shells. Megan collected 5 shells. Jamal collected 5 shells. Mia collected 6 shells. What was the average number of shells collected?

Fidelity and Interobserver Agreement

Fidelity was measured for 31% of the total sessions (eight of 26 sessions) across baseline (33%; baseline only), intervention (27%; a combination of intervention only and intervention with baseline), and maintenance (50%) phases. Both participants were present for all the sessions where fidelity was assessed. Prior to assisting as a rater in the intervention, the second rater, a doctoral candidate, was provided with a copy of a fidelity checklist designed to measure the fidelity of the structure and process of the intervention. The checklist evaluated if the interventionist did the following: handed out: (a) an intervention worksheet to each participant, (b) two sharpened pencils, (c) a calculator, (d) an iPad, and (e) headphones. The fidelity checklist further evaluated if the interventionist read the instructions on the first page of the instructional packet to the participants and whether or not the participants needed help scanning one or more images. In addition, the checklist evaluated whether the interventionist helped the students solve the problems in any way or prompt the student's answers (this item was reverse coded), and evaluated whether the participant worked through the instructional packet from front to back and watched the videos on every page when applicable.

The second rater observed the implementation of the intervention and used the checklist to verify that the intervention was implemented with fidelity. Fidelity was measured using a point system, (0 = *behavior was not observed*, 1 = *behavior was observed with high level of implementation*). Fidelity was calculated by totaling the points at the end of the session and dividing that number by the number of total questions. The treatment integrity results were >99% (Carolyn and Katherine). The question on the fidelity checklist concerning whether or not the students were provided help scanning the pictures, was excluded from the fidelity results because this question related more to social validity. Both participants scanned the images independently 98% of the time (Katherin = 100%, Carolyn = 97%).

Interrater reliability was conducted on 30% of all permanent product data (e.g., baseline, intervention, maintenance, and the word problem probe). Scoring sheets were created automatically using Math Studio Resource Studio 6 that contained the answers for all dependent variable, maintenance, and word problem worksheets. All results were scored by the first author. The second author was the second evaluator of the scoring accuracy. Interobserver agreement between the first and second raters was >99%.

Finally, the difficulty of the mathematics problems was reviewed by an external reviewer across baseline, intervention, and maintenance to verify that the problem difficulty did not vary between phases. The reviewer found no significant difference in problem difficulty after reviewing 100% of the data.

Social Validity

Viability and acceptability are important indicators of the social validity of an intervention as components in determining the quality of single-subject research (Horner et al., 2005). Questionnaires were administered to the participants by the special education teacher after the intervention to evaluate their experience. The questionnaire was modeled from Vasquez and Slocum (2012) and contained nine statements with 6-point Likert-type response choices (e.g., 1 = *Strongly disagree*; 2 = *Disagree*; 3 = *Somewhat disagree*; 4 = *Somewhat agree*; 5 = *Agree*; 6 = *Strongly agree*). The questionnaire was designed to evaluate the participants' perspectives about the goals, procedures, and outcomes of the intervention. The questionnaire was anonymous to encourage open and honest reporting.

Data Analysis

The results were analyzed using visual analysis evaluate for experimental control, intervention effect, and functional relation. For visual analysis, the trend, level, variability, and immediacy of effect were evaluated (Cooper et al., 2020). We also reported overlap of baseline and intervention phase data and consistencies in data patterns. Trend, level, and variability evaluate data patterns within phases, while immediate of effect evaluates data patterns between phases. Trend of the data evaluates its stability over time. Level indicated level of data along Y axis. The variability of data is reported as the data range. Immediacy reported change in level in the data at or near the time when the intervention was implemented.

In addition to visual analysis, Tau-*U* was calculated. Tau-*U* is a combination of four indices that use regressive statistics to account for (a) improvement overall, (b) improvement of non-overlapping data, (c) improvement considering trend intervention, and (d) control for baseline trend (Parker et al., 2011). Tau-*U* was calculated on the between-phase difference of the baseline and intervention phases using an online calculator (Vannest et al., 2011). The first step in using this calculator is to evaluate the phase contrast of the baseline. The baseline did not need to be corrected for. Next, the Tau-*U* calculator compares the baseline and intervention phases contrast for each tier of the intervention across each student. In addition, the combined for a weighted mean Tau-*U* for each participant across each skill was calculated for an overall Tau-*U*. Tau-*U* can be interpreted for intervention effect as follows: *small* < 0.20, *moderate* $= 0.20$ to 0.60, *large* = 0.60 to 0.80, and *very large* > 0.80 (Vannest & Ninci, 2015). However, Tau-*U* is not an estimate of magnitude (Moeyaert et al., 2018) and interpretations should be contextualized based on the study and not as strict benchmarks (Vannest & Ninci, 2015).

Results

This intervention, using POV-VM, EI, and AR, resulted in increased mathematics performance. The results are illustrated in Figures 2 and 3. Key features found that each skill began with a stable low baseline with no trend, an immediate change in level with the implementation of the intervention, and a steady high or increasing trend during the intervention (see Table 2 for more information). Trends were determined using the Tukey trend method (Tukey et al., 1985). Tau-*U* was calculated at 1.0 across all intervention phases, maintenance phases, and participants, resulting in an overall, combined, and weighted Tau-*U* score for the intervention of 1.0.

Carolyn

Adding fractions with common denominators. The first skill addressed adding fractions with common denominators. In the baseline phase, Carolyn had a stable low score with a mean of 0%, which increased immediately upon implementation of the intervention. During the intervention phase, the mean was calculated at 97.1% correct, resulting in a 97.1% increase from baseline to intervention. The mean percentage correct for maintenance was 90%. Word problem assessment was calculated at 100%.

Calculating the perimeter. The second skill addressed calculating the perimeter. Again, Carolyn had a low and stable baseline with a mean score of 0%, with an immediate increase upon intervention. The mean for the intervention phase was 95% correct, resulting in a 95% increase from baseline to intervention. The maintenance mean percentage correct was 100%. Word problem assessment was calculated at 80%.

Calculating the range. On the third skill, calculating the range of a set of numbers, Carolyn's pattern was consistent with the other skills, with a baseline mean score of 0% and an immediate increase when the intervention was introduced. Her mean correct response was at 90% during the intervention phase, and her mean percentage correct for maintenance was 100%. Performance on the Word problem measure was 80%.

Calculating the mean. The fourth skill required Carolyn to calculate the mean of a set of numbers. Again she had a baseline mean score of 0% and an immediate increase at intervention implementation. The mean was calculated at 86.7% correct during the intervention phase, resulting in an 86.7% increase from baseline to intervention. Her mean percentage correct for maintenance was 100%. Word problem assessment for calculating the mean was 0%.

Katherine

Adding fractions with common denominators. In the baseline phase of adding fractions with common denominators, Katherine had a stable and low score with a mean of 0%, with an immediate increase upon implementation of the intervention. During the intervention phase, the mean was calculated at 100% correct, resulting in a 100% increase from baseline to intervention. The mean percentage correct for maintenance was 100%. Word problem assessment was calculated at 100%.

Calculating the perimeter. Calculating the perimeter had similar results for Katherine: a low stable baseline with a mean score of 0%, followed by an immediate increase when the intervention began. During the intervention phase, the mean was calculated at 97.8% correct, resulting in a 97.8% increase from baseline to intervention. The mean percentage correct for maintenance was 100%. Word problem measure yielded 100% accuracy.

Calculating the range. When asked to calculate the range of a set of numbers, the third skill, Katherine's baseline mean score again was 0%. She had an immediate increase upon implementation of the intervention, with a mean calculated at 90.9% correct during the intervention phase, resulting in a 90.9% increase from baseline to intervention. The mean percentage correct for maintenance was 100%. Word problem assessment was calculated at 80% correct.

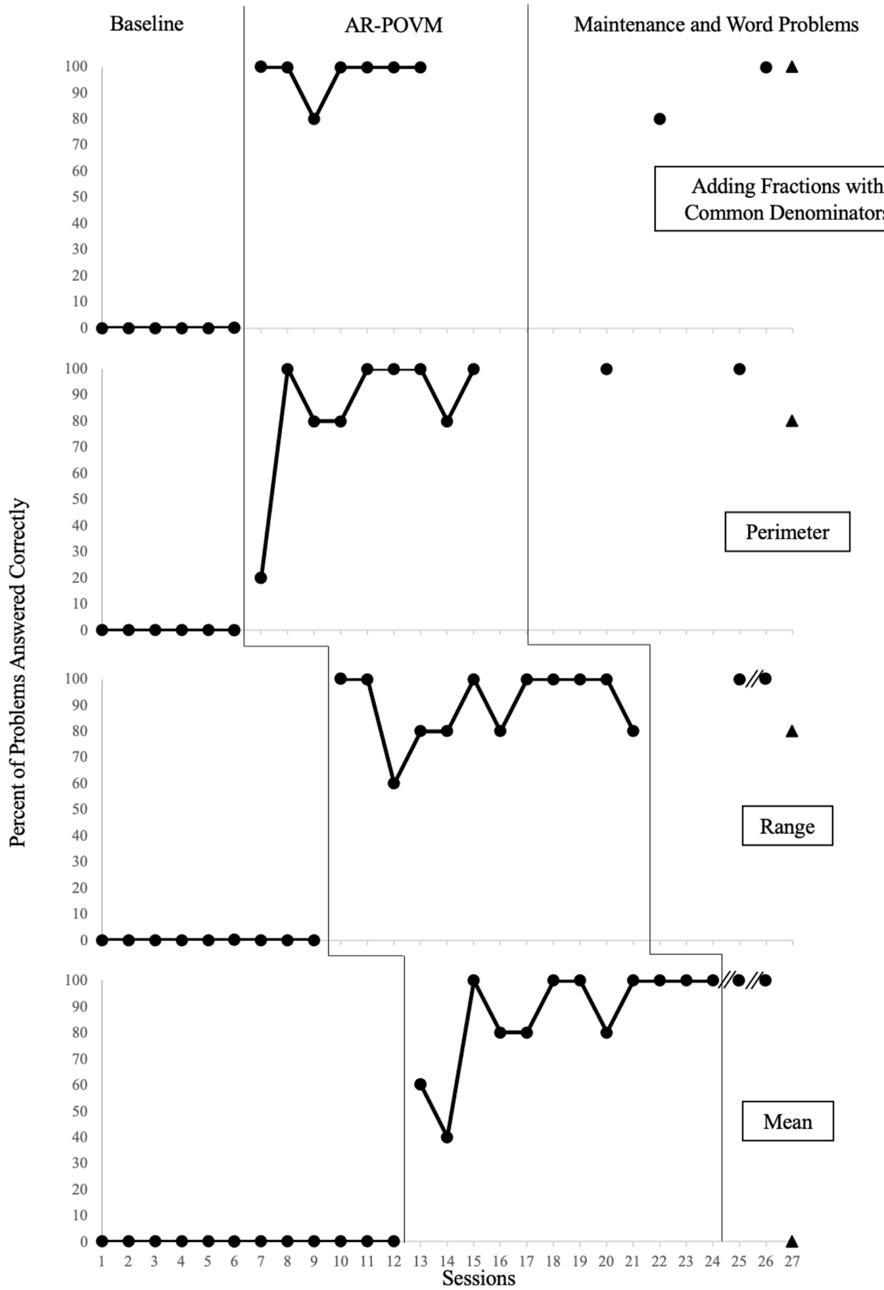

Figure 2. Percentage of response accuracy across fraction addition with unlike denominators, calculating the perimeter, calculating the range, and calculating the mean for Carolyn.
Note. // = sessions more than 5 days apart. ▲ = Word problem data point. AR-POVM = augmented reality point-of-view video modeling.

Calculating the mean. The fourth skill, which required Katherine to calculate the mean of a set of numbers, showed another baseline mean score of 0%. Again, her score showed an immediate increase when the intervention occurred, with a mean calculated at 73.3% correct during the intervention phase—a 73.3% increase from baseline to intervention. The mean percentage correct for maintenance was 100%. The word problem assessment for this skill was 80%.

Social Validity Questionnaire

The results from the social validity questionnaire showed that the participants were positive toward the intervention

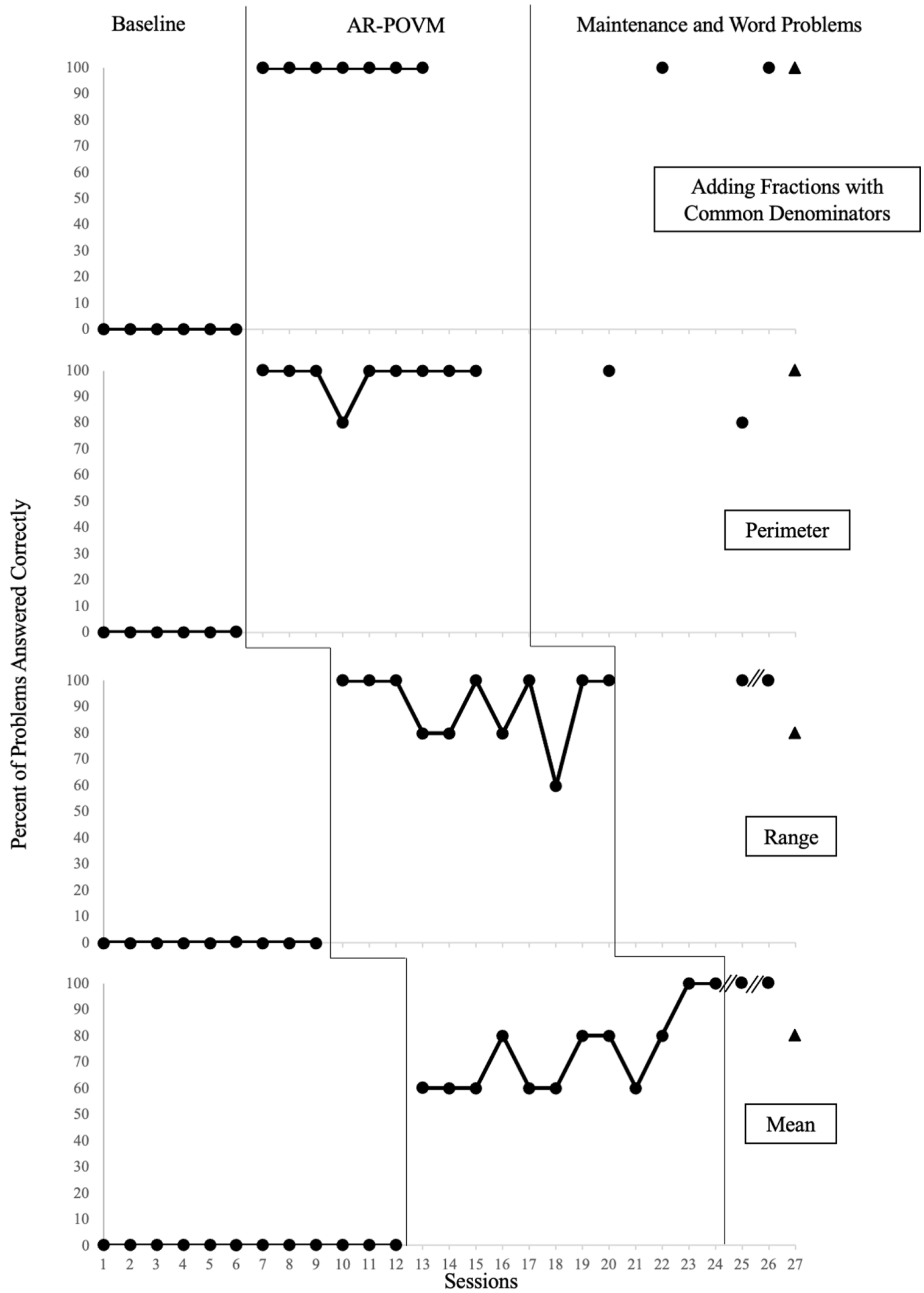

Figure 3. Percentage of response accuracy across fraction addition with unlike denominators, calculating the perimeter, calculating the range, and calculating the mean for Katherine.
Note. // = sessions more than 5 days apart. ▲ = Word problem data point. AR-POVM = augmented reality point-of-view video modeling.

as an effective way to learn mathematics (M = 6). Both participants strongly agreed that they enjoyed learning mathematics skills from the videos on the iPad (M = 6). Both indicated that progress was shown and explained (M = 5.5) that it was easy to use the iPad to learn mathematics (M = 5.5) and it was easy to hear the instructor (M = 6). They indicated a high preference for practicing with the video (guided practice; M = 6). Both students communicated that their mathematics skills improved (M = 6). Katherine slightly marked down the length of the video (rating = 5), while Carolyn had a higher preference for video length (rating = 6). Both students strongly agreed that they

Table 2. Summary of Visual Analysis.

	Within phases								
	Baseline			Intervention			Between phases		
Participant and Mathematics Skill	Level (mean%)	Trend (Tukey)	Variability (range)	Level (mean%)	Trend (Tukey)	Variability (range)	Immediacy	Overlap	Consistency
Caroline									High
Adding fractions with common denominators	0	No trend	0	97.1	No trend	80–100	Immediate	0	
Perimeter	0	No trend	0	95	No trend	20–100	Immediate	0	
Range	0	No trend	0	90.0	No trend	60–100	Immediate	0	
Mean	0	No trend	0	86.7	Increase	40–100	Immediate	0	
Katherine									Very High
Adding fractions with common denominators	0	No trend	0	100	No trend	100–100	Immediate	0	
Perimeter	0	No trend	0	97.8	No trend	80–100	Immediate	0	
Range	0	No trend	0	90.9	No trend	60–100	Immediate	0	
Mean	0	No trend	0	73.3	Increase	60–100	Immediate	0	

Note. We used the method of evaluating the trend in our visual analysis from Tukey (1985).

would like to learn more math skills using the intervention ($M = 6$).

Discussion

The current study extends the research base supporting the use of EI in mathematics interventions delivered digitally to increase performance and maintenance of mathematics skills for students with MD. Specifically, this study evaluated POV-VM and EI accessed through AR technologies to teach targeted mathematics skills. This study contributes to the literature in several ways, including (a) extending VBI research to students with MD, (b) incorporating digital delivery of EI with students controlling the pace of instruction, and (c) exploring use of AR technologies in mathematics intervention research.

For many students with MD, core instruction in mathematics is not sufficient to address knowledge gaps and adequately accelerate learning. Therefore, more intensive intervention must be provided for students who fail to make adequate progress (Fuchs et al., 2017). Digital applications/VBI such as POV-VM show promise for individualizing instruction when a teacher is unavailable to provide one-on-one support. The first research question evaluated the effects of using a POV-VM, EI, and AR in which students accessed an AR app targeting mathematics skills for students with exceptionalities. The intervention was effective for both students across all four skills, as indicated by the percentage increase on performance measures.

The instructional components of POV-VM were explicit, and findings continue to validate the emerging research that POV-VM can be an effective digital tool for teaching mathematics to students with exceptionalities (e.g., Burton et al., 2013; E. M. Hughes, 2019; Yakubova et al., 2015; Yakubova et al., 2016). Unlike traditional EI where the modeling and guided practice are teacher-led, POV-VM allows students to self-manage learning through an AR and a virtual prerecorded teacher-led model. Students who self-manage their learning often exhibit increased focus, incentive, and independence (McDougall, 1998; Reid et al., 2005). Self-management also allows students to regulate feedback where individuals methodically assess and evaluate their own work (Mace et al., 2001; Pintrich, 2000). During the guided instruction portion of POV-VM, the teacher followed a sequence for reducing the prompting and supports, sometimes referred to as the TAR sequence (Archer & Hughes, 2011). Perhaps the guided practice as presented in the POV-VM lends itself to plausibility that students benefited from the practice and recorded feedback in the TAR sequence, supporting Hattie and Timperley's (2007) emphasis on effective feedback.

Individual variability requires adaption for different learning rates. Because instructional materials included in POV-VM were appropriately leveled and sequenced, students were able to progress independently without teacher mediation and unhindered by other students. The video instruction also provided meta-cognitive support (i.e., think-aloud) as the model discussed the concepts and procedures of the skills. Furthermore, POV-VM allowed learners to modulate the pace of instruction. Students were able to watch the video again (in full or portions) when seeking clarity and additional reinforcement. As a result, the students transitioned between the stages of learning (i.e., modeling, guided practice, independent practice) and reached the pre-established mastery criterion. In practice, an educator can assess the quality of the final product to monitor progress, provide mediated feedback, and appropriately match leveled materials.

Some variability was evident in the rate of mastery by which the participants reached criterion from skill to skill. Calculating the range and calculating the mean were clearly the most challenging for both participants. They were able to reach criterion in an average of 13 sessions for multistep skills. Calculating the mean requires three steps: counting how many numbers are in the set, adding all the numbers together, and dividing by the number of numbers in the set. This performance task required greater cognitive demand than the other three skills which only required one or two steps.

Initial acquisition is essential to develop skills for long-term maintenance. Students need maintenance of skills to progress to further mathematical skills and concepts, as many mathematics skills build upon each other. The second research question addressed the effects of the intervention in maintaining targeted mathematics skills. Without exception, the participants maintained the skills.

Participants in this intervention were provided with a novel assessment near the conclusion of the study to evaluate their ability to transfer the skills targeted in the intervention to word problems. Overall, across both participants and the four skills, the students were able to transfer the discrete mathematics skills to word problems. One exception was that Carolyn overgeneralized one step on calculating the mean word problem assessment resulting in incorrect scores for each of the problems. She did all the other steps correctly for that skill.

The final research question addressed the social validity of the intervention. Considering the social significance and consumer evaluation of the intervention promotes the use and sustainability of the intervention when bridging research to practice. It is important for researchers must evaluate the participants' perspectives of the intervention. Both participants rated the intervention as positive and beneficial, and they expressed interest in it. The feasibility of the intervention and interest from the participants to continue using similar interventions complement the suggestions set forth by Horner et al. (2005) pertaining to social validity in special education intervention research. Following a session near the end of the intervention, one participant was asked how things were going; she commented, "I'm feeling smarter!"

As part of a post hoc analysis, the authors analyzed participants' errors to learn about the underlying causes (Radatz, 1979) to inform instructional decisions and intervention iteration. Many of the errors made by participants throughout the intervention indicated that they had learned the steps correctly and quickly, rarely making errors in the process but often making transfer errors or simple calculation mistakes. Future research may look at additional behavioral supports, such as providing a graphic organizer for multistep mathematics problems to reduce the cognitive load and increase the speed of acquisition. Adding behavioral supports aligns with work from other researchers (e.g., E. M. Hughes, 2019; King et al., 2014), who used VBI to support mathematics acquisition of new skills for students with MD.

Limitations and Implications

Four limitations within this study should be mentioned. The first limitation was the method of implementing the check stage. Because the intervention's design automated much of the instruction, the check stage had the potential to be less effective than it could have been because even if the student did not quite have the understanding to correctly solve the problems, the correct answer was presented on the video within about 60 s. However, situating this simple intervention within advanced technologies would allow future researchers to evaluate delivery of the intervention in a platform with greater control.

The second limitation is that generalization data was not collected. The researchers did provide students with novel word problem assessments for each of the four skills near the conclusion of the study to evaluate if they would able to transfer the mathematics skills in meaningful ways. This assessment was not given during the baseline or intervention phase, which further limits the generalizability of the findings.

Third, only two maintenance probes were given to each participant. Because it is recommended that a minimum of three data points be collected in each phase (Kratochwill et al., 2013), the maintenance results should be interpreted cautiously.

Finally, reporting Tau-*U* is a limitation. Reporting Tau-*U* is a limitation because the chances of error can be greater in Tau-*U* calculation and interpretation than with visual analysis (Tarlow, 2017). For this reason and others, some researchers recommend that it not be used for evaluation of single-subject research (Moeyaert et al., 2018; Tarlow, 2017).

Implications for research. Future research should look at participants with other disabilities and at students without disabilities, (e.g., those with only mathematics difficulties). In addition, broadening the scope of skills taught into other mathematics areas and other content areas, as well as other settings, would help to establish generalization of the intervention. Future research should provide sufficient maintenance probes. Also, research, where the participant's primary instructor served as the interventionist, would be beneficial.

Implications for practice. A strength of this intervention is that it utilized relatively common technology that can be easily accessed by individuals with a wide range of technology experience. This adds to the potential for social validity of VBI to support intensifying interventions for students who need additional supports; however, this study did not evaluate the perspectives of the teacher on the practicality of the intervention because the first author implemented it during the study. Future research should evaluate teacher implementation of VBI to differentiate instruction and meet targeted needs of students in a tiered intervention system. This would also allow researchers to more accurately assess the social validity and sustainability of the intervention. VBI has the empirical support and utility to be a beneficial resource for teachers as an alternative way to provide direct EI. In tiered systems where intensive interventions are required to address gaps with requisite mathematics skills, VBI may allow teachers to simultaneously support multiple students with different mathematics competency needs.

Conclusion

The field of special education must have socially valid and effective mathematics interventions for students who require particularly intensive mathematics instruction that are sustainable in classroom settings. Findings from this research support using POV-VM, EI, and AR to teach mathematics to students with MD. Being challenged to improve mathematics competency and achievement of students with and without disabilities, educators must implement such research-based methodologies that have the potential to bridge the research to practice gap.

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ORCID iDs

Jared R. Morris https://orcid.org/0000-0003-3321-047X

James D. Stocker https://orcid.org/0000-0002-4330-2354

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