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ORIGINAL PAPER

Mathematics Learning Through Online Video-Based Instruction for an Autistic Child

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Abstract
The purpose of this study was to examine the effectiveness of a video modeling (VM) intervention package (including virtual manipulatives and error correction) delivered via synchronous, virtual environment to teach the mathematics skills of addition, number comparison, and subtraction to a five-year old autistic child. Using a multiple probe across skills design of a single-case experimental design, we examined whether a causal relation existed between the intervention and the child's improved accuracy of mathematics problem-solving. Following the intervention, the autistic child showed improved accuracy across all three skills and continued to solve problems with 100% accuracy during the generalization phase, which also served as the immediate maintenance phase.

Keywords Online instruction · Video modeling · Parental support · Autism · Mathematics

Introduction

Providing academic instruction to help autistic students can help fulfill their potential in post-school life, such as independent living and employment (Wong et al., 2021). Teaching fundamental academic concepts and mathematics skills can help virtually every autistic student succeed throughout one's daily life (Stroizer et al., 2015). Regarding mathematics skills specifically, it is important that all students develop both basic and complex computational and conceptual skills (National Council for Teachers of Mathematics (NCTM, 2000). While challenges with academic performance is not a defining characteristic of autistic individuals, many autistic students experience challenges in mathematics learning (Wei et al., 2015). For instance, challenges with executive functioning that may impact organization, problem solving, and self-management skills (Ozonoff & Schetter, 2007), decreased on-task behavior and engagement (National Research Council, 2001), and perceived challenges in processing abstract concepts in mathematics (Rourke & Strang, 1978) may contribute to difficulties in learning mathematics concepts among autistic students. Yet, when students receive explicit instruction with visual and concrete representations to help them comprehend various mathematical concepts, improved skill acquisition has been observed (Bouck et al., 2018; Satsangi et al., 2019; Yakubova et al., 2016).

Video-Based Intervention in Teaching Mathematics

A type of visually supported instruction that uses technology is a video-based intervention (VBI), an evidence-based practice for teaching a wide range of skills to autistic individuals from early childhood to young adulthood (Steinbrenner et al., 2020). VBI can be used to provide systematic instruction with consistent vocabulary and explicit modeling for the individual to watch and imitate the target skills or concepts (Hughes & Yakubova, 2019). VBI has been examined in teaching both functional and grade-level mathematics to autistic students and students with other disabilities (Cox & Jimenez, 2020; Gevarter et al., 2016; Satsangi et al., 2019; Weng & Bouck, 2014; Yakubova et al., 2015). Studies using VBI have targeted a variety of skills ranging from arithmetic and computation to word problem solving. For example, Satsangi et al., 2019 found VBI effective in teaching geometry word problems to students with learning disabilities, while Yakubova et al., 2016 found VBI effective when teaching word problem solving to autistic students.

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Furthermore, systematic reviews have found VBI to be an evidence-based or effective practice for teaching mathematics (Hughes & Yakubova, 2019) and science, technology, engineering, and mathematics (STEM) skills (Wright et al., 2020) to autistic students. While VBI alone can be effective, using VBI in combination with concrete or virtual manipulatives and behavioral strategies such as self-monitoring checklists, reinforcement, and prompting techniques to help students comprehend the abstract nature of mathematics has been most effective in improving student learning (Gevarter et al., 2016; Hughes & Yakubova, 2019). While VBI is effective when used in in-person learning, no research to date has examined the effects of VBI in an online instructional format.

The Use of Manipulatives in Mathematics Instruction

The use of manipulatives, whether concrete or virtual, for teaching mathematics concepts is a common and recommended practice in both general and special education (NCTM, 2000). Manipulatives, such as base ten blocks, fraction tiles, number lines, and unifix cubes, can offer students alternative representations to abstract mathematics concepts and language. This may be particularly helpful for students who have strengths in visual processing or challenges with attention and language processing, which are common traits among autistic students. There is a significant body of literature which supports the use of both virtual (Bouck & Park, 2020; Bouck et al., 2020; Jimenez & Besaw, 2020; Park et al., 2020; Root et al., 2021) and concrete (Yakubova et al., 2016, 2020) manipulatives for teaching mathematics skills to K-12 autistic students. Although both types of manipulatives have been shown to be effective for teaching mathematics skills to autistic students, past studies that have compared the two types of manipulatives have found that typically students both preferred and performed better with virtual manipulatives (Root et al., 2017; Shurr et al., 2021). In addition, students have also been shown to complete more problem-solving steps and reach independence faster with virtual compared to concrete manipulatives (Bassette et al., 2019; Bouck et al., 2014). However, the effects of providing virtual-manipulative-based instruction via online, rather than in-person, instruction has been rarely examined. While not specific to autistic students, a recent study found that students struggling in mathematics improved their skills in finding equivalent fractions after receiving an online explicit instruction with virtual manipulatives (Bouck & Long, 2021). Given the recent increase in online instructional settings, additional research on providing online instruction using best practices is necessary to accommodate the learning of students with diverse needs.

Online Learning for Children Receiving Special Education Services

The U.S. Department of Education, National Center for Statistics (NCES), reported that during the 2019–2020 school year, there were 7.3 million students between the ages of 3–21 that received special education services under the Individuals with Disabilities Act (IDEA). Eleven percent of the 7.3 million students were identified as autistic students (de Brey, 2021). These students were required to receive instruction via an online platform during the COVID-19 pandemic as schools closed across the nation. With the rise of online learning, challenges for student learning and teacher instruction became prominent. When learning in an online environment, the lack of student and parental engagement was a primary concern based on findings from a virtual focus group study with 35 special education teachers and related service providers (Smith, 2020). Another difficulty for special educators to overcome was the capability to provide adequate special education services to students with disabilities, especially those with multiple and significant disabilities (Smith, 2020).

Even before the COVID-19 pandemic, educators reported significant strengths and concerns regarding not only online instruction for students with disabilities. In a survey of 80 asynchronous general and special education teachers about the benefits of online learning for students with disabilities, Marteney & Bernadowski (2016) found that teachers felt online education made it easier for students to achieve academic goals if they had auditory or physical limitations, saw an increase in student motivation, and reported that students received more support and feedback individualized to their needs in the online environment compared to a traditional class setting. Two areas of concern in regard to online learning and teaching included teachers feeling that students did not utilize online resources effectively and teachers finding it difficult to implement student accommodations for those with disabilities (Marteney & Bernadowski, 2016). While the demand to examine effective online instructional practices for autistic students prior to the onset of pandemic may not have been prioritized as high as in-person learning practices, it is now essential to research best practices in online learning to accommodate the learning of autistic students in various formats.

The Purpose of the Study

While VBI is an evidence-based practice for teaching mathematics to autistic children, a wide range of diversity exists in the topics, characteristics of students, and the types of strategies used with VBI, and this makes it challenging to determine what works for whom under what conditions (Hughes

& Yakubova, 2019). In addition, while both concrete and virtual manipulatives have been found to be effective in teaching mathematics to students with a variety of disabilities (Peltier et al., 2020), use of manipulatives in pre-school and intermediate phase have been less common than in other age groups. In addition, examining the effects of VBI with virtual manipulatives in teaching young autistic children is lacking in research, whether in physical classrooms or online settings. Therefore, the purpose of this study was to examine the effectiveness of a video modeling intervention package (including virtual manipulatives and error correction) delivered via synchronous, virtual environment to teach the skills of addition, number comparison, and subtraction to an autistic child. Research questions included: (1) Is there a causal relation between the synchronous, online video modeling instructional package with non-computational parent support and the acquisition of mathematics skills measured by the accuracy of solving addition, number comparison, and subtraction problems for an autistic child? (2) Does the child generalize the skills to daily-use household items immediately upon of the conclusion of the intervention phase? And a secondary question (3) What are the perceptions of the parent and the child towards the synchronous, online video modelling instructional package with the parental support?

Methods

Participant

One child with one parent participated in this study. This child was chosen based on the following criteria: (a) having a diagnosis of autism spectrum disorder (ASD), (b) parent recommendation for additional help with math skills, (c) ability to participate in a virtual intervention, and (d) willingness of the child and parent to participate. *Camille* was a 5-year-old biracial (Caucasian and Asian) female who was diagnosed with ASD at the age of 19 months by a pediatric psychologist. Camille had stronger expressive language than receptive language. When administered the Bayley Scales of Infant and Toddler Development, Camille had a composite score of 105, representing average cognitive functioning, appropriate for her chronological age. Her language composite score was 65, displaying a significant difference between receptive and expressive language. Camille's scaled score of three on the receptive language subscale showed a severe delay, whereas her scaled score on the expressive language was five, representing a mild to moderate delay.

At the time of the study (Fall semester in the Northern Hemisphere), Camille was five years old and scheduled to begin Kindergarten in the subsequent academic year. Camille had previously received services for speech/language, occupational therapy, and applied behavioral analysis (ABA), but services for ABA and occupational therapy had been discontinued due to the pandemic. Speech/language services were being provided virtually. During the parent interview, Camille's mother reported that she could count to 20 or 30, had little to no exposure to addition or subtraction, and displayed some inconsistencies when counting objects. Camille's mother also reported that Camille had no significant interfering behaviors other than difficulty sustaining attention. Camille was eager and excited to participate in each session.

The child lived in a two-parent household and Camille had an elder sister. Camille's parents were in the 40–50 age range, both employed, with the highest level of education being a Ph.D. The household and child spoke the English language as the primary language. The household also involved a set of grandparents. Camille's mother participated in the study sessions to provide support as needed per parent guidelines described in the procedures section.

Setting and Interventionist

All sessions took place virtually during a Zoom meeting with the interventionist, parent–Camille's mother, and child in attendance. Researchers sent the parent a secure individualized Zoom link authorized by the university to join each session of the study. Faculty members and students at the authors' university are given university-authorized Zoom accounts. The university default setting for Zoom included a waiting room for anyone signing in with a non-university email identification. Therefore, when the parent joined the Zoom meeting each time, the parent was automatically placed into the Zoom waiting room by the system. Then, the interventionist accepted the parent from the waiting room to enter the main room. The interventionist used the share screen function to play the video modeling clip at the start of the intervention. The interventionist also shared the Google forms (study probes) through the share screen function on Zoom. She also sent the weblinks for the virtual manipulatives used in the study to the parent during the session via the Zoom chat function. The child used the virtual manipulatives on her computer while displaying her screen for the interventionist to observe via the Zoom share screen function. The parent was present during all sessions. The parent logged into the secure Zoom link and sat with the child for the entirety of each session. The parent prompted the child to stay in the sessions and provided positive reinforcement to maintain child engagement with the task.

The child sat at a table with her mother beside her while interacting with the interventionist. The mother assisted in limiting distractions in the home environment by verbally prompting Camille to watch the video, restating questions for her, and encouraging Camille to remain seated during the intervention, however, at times the child became distracted by internal and external factors, such as drawing or rewriting numbers, her older sister, or engaging in stereotypy behaviors.

The interventionist was a doctoral student in special education, the second author, who was a former special education teacher with dual certifications in special education from birth to 21 years of age and elementary education from grades one to six. She had extensive experience working with children with disabilities in virtual and in-person classrooms while providing both academic and nonacademic supports. She implemented the intervention and collected data during all phases of the study with the training provided by the faculty advisor who specialized in mathematics interventions and single-case research designs. Upon conclusion of each session, the interventionist completed the rubric for the child's responses.

Independent Variable and Materials

The independent variable involved a point of view video modeling clip with virtual mathematic manipulatives (https://www.didax.com/math/virtual-manipulatives.html) and error correction in the form least to most prompting technique. The point-of-view video modeling clips demonstrated solving problems related to foundational skills of mathematics (i.e., addition and subtraction within 10 and comparing three single- or double-digit numbers to determine the smallest) at the virtual level and included an explicit step-by-step audio explanation. One point-of-view video modeling clip per problem type, recorded from a first-person perspective, featured a visual of the virtual mathematic manipulatives site being manipulated by the interventionist. Each video clip featured a sample problem related to one of the three target concepts. The sample problems used in the video clips were not used in any of the data collection phases of the study. The interventionist utilized the tens frames 1–100 to model concepts of addition and subtraction and unifix cubes to model the concept of number comparison in the video modeling clips.

The point-of-view video modeling clip for each of the three target skills differed in content, however, followed the same instructional modeling using the appropriate type of virtual manipulatives. For instance, the point-of-view video modeling clip for the skill of addition began on the ten frames virtual manipulative screen accessed from: https://didax.com/apps/ten-frames/. The screen opened on the tens frame screen with the interventionist stating, "Today, I am going to solve an addition problem. Watch carefully, as it will be your turn next." The interventionist stated the addition problem $6+3=$ while using the pencil function to write the problem on the screen. The interventionist then moved a tens frame onto the work screen. Next, the interventionist referred to the first number in the addition problem. "My first number in the addition problem is six. I am going to use the red chips to count out six." The interventionist then counted each red chip individually as she moved it from the virtual stack into the tens frame. She then referred back to the problem to determine the second addend. "My second number is three. I am going to use three yellow chips." The interventionist then counted each yellow chip individually while moving it from the stack into the tens frame. She stated, "Now, I need to count my total chips to find the answer to $6+3=$." The interventionist moved the mouse cursor over each chip in the tens frame while counting each chip out loud arriving at the answer of nine. She used the virtual pencil function to write the answer of nine after the equal sign on the screen. The interventionist reiterated verbally $6+3=9$ and ended the video recording. This video clip was two minutes and seven seconds in length.

The second video-modeling clip demonstrated how to compare three numbers within 20 to determine the smallest using unifix cubes. The comparison video-modeling clip was three minutes and 24 s long. The third and final video-modeling clip demonstrated subtraction within ten, with the only difference in directions being that the interventionist noted the subtrahend and removed that number of chips from the tens frame. The subtraction video clip was one minute and 31 s long. All three video clips were recorded using Zoom. The video clips were then saved on Box for easy access and use during the intervention.

The virtual manipulatives used from the https://www.didax.com/math/virtual-manipulatives.html website included tens frames used for both addition and subtraction, and unifix cubes used for comparing three numbers within 20 to determine the smallest or least value. The tens frames were accessed through: https://didax.com/apps/ten-frames/. The virtual manipulatives screen a had blank workspace in the center and on the right-hand side there was a box containing the tools that could be dragged and dropped onto the blank workspace. These tools consisted of tens frames in both horizontal and vertical formats, red chips in stacks of ones, fives, or tens, yellow chips in the same denominations, a virtual pencil and eraser to make annotations, and a reset button to clear the entire workspace. Likewise, we accessed the virtual unifix cubes from: https://www.didax.com/apps/unifix/. The virtual unifix manipulatives had a blank workspace and the tools were located on the right-hand side of the screen again. This toolbox consisted of unifix cubes in ten different colors in a staked format (meaning the user could drag one at a time to the workspace and connect them), a virtual pencil and eraser for annotations, and a reset button to clear the entire workspace.

Error correction procedures in the form of least to most prompting involved the following steps. The first step of error correction was to re-watch the video clip while telling the child "That's not quite right, let's watch the video modeling clip again". If the child continued to make an error or failed to initiate the task after 30 s, a verbal prompt for error correction was outlined as the next level of prompting (e.g., drag and drop three red chips into the first row of the ten-frames box). The next level of error correction was a verbal and gestural prompt. This was defined as verbally prompting the child by telling the correct completion of the step (e.g., drag and drop three red chips into the first row of the ten-frames box) while pointing to the red chips and the first row of the ten-frames box. The final level of error correction involved providing a live modeling prompt. If after another 30 s, if the child was still unable to initiate or correctly complete the step, the interventionist would get the child's attention and share the Zoom screen to do live modeling of the step for the child.

The child needed only the first level of error correction, which was watching the video modeling clip again, two to three times throughout the intervention per skill type. She did not need any other levels of error correction for any of the problems during the intervention phase. She was able to correctly and independently solve problems after watching the video modeling clip once or twice.

Dependent Variable and Measurement

The accuracy of completing numeracy problems out of three problems per skill was the primary dependent variable. Three numeracy skills targeted in the study involved (a) addition of two single-digit numbers within the value of 10, e.g., 2 + 7, (b) comparing three numbers in the number range of 1–20 determine the least value, e.g., 2, 8, and 17, and (c) subtraction of two single-digit numbers within the value of 10, e.g., 7—2. These numeracy skills met the components of the Maryland College and Career Ready Standards (MCCRS) for Kindergarten in the areas of Counting and Cardinality and Operations and Algebraic Thinking.

Prior to starting the study sessions, researchers created a list of problems to be used throughout the study and selected three problems per skill type during each session. Different sets of problems were used during each session of baseline, intervention, and generalization. Researchers used event recording to collect data on the percentage accuracy of solving three problems per skill type during each session. Mastery criterion for solving problems was set at 100% independently correct (i.e., no error correction) for two consecutive sessions. Only for the skill of addition we decided to continue the intervention for three more sessions after Camille reached mastery criterion. We made this decision based on ongoing visual analysis of data: Her performance accuracy dropped to 33.33% accuracy during the third intervention session but increased to 100% during the following session. We decided to continue intervention for a few more sessions after she reached the mastery criterion during the fifth session to determine whether her performance would fluctuate or continue to remain at 100% accuracy. This decision was also ethical to ensure the child mastered the skill with repeated practice opportunities.

Experimental Design

We used a multiple probe across three skills design of single-case research design (SCRD) to determine the presence or absence of a causal relation between the online, synchronous video modeling instructional package with parental support and the child's acquisition of three target skills (Gast et al., 2018). We chose this design as it is most appropriate when teaching a trial-based, non-reversible behavior, such as an academic skill. (Gast et al., 2018). Using this design, the replication of intervention effects across three mathematics skills with at least three attempts of effect at three various points in time was observed (Kratochwill et al., 2013). We set the minimum number of three sessions for baseline and five sessions for intervention phases described in the procedures section according to What Works Clearinghouse (WWC) design standards (version 4.1) for SCRD and best practices in SCRD (Ledford & Gast, 2018; Kratochwill et al., 2013).

Procedures

General Procedures

According to the mother's schedule and availability, the study sessions were held one to two times per week. The sessions lasted up to 30 min. During each session of the study, the parent logged into the Zoom link to start the study session for the child. The interventionist started each session by greeting the parent and the child, asking the child how she was doing that day and if she was ready to work on math problems, and then gave the session directions once the child's attention was secured. The parent was present during all sessions of the study and provided positive reinforcement in the form of a verbal praise and assisted the child in maintaining attention and engagement during Zoom sessions. The researchers provided the parent with the parent guidelines (see Table 1) for each phase of the study describing what the parent can do and should refrain from doing to ensure the experimental control. The beginning of the parent protocol explained that the sessions were for a research study, not a class or therapy session. The interventionist explained through the protocol that too much parental assistance could affect the ability of the interventionist to draw conclusions about how well the intervention worked.

Baseline

The baseline phase involved a minimum of three sessions per skill and continued until there was evidence of stable responding. The child worked on a set of three problems per skill per session and did not receive intervention or assistance in completing the problems. The interventionist began each baseline session by stating, “I want you to try to solve some math problems. Do your best, it’s okay if you are not sure.” During baseline, the interventionist displayed a Google form with the identified mathematic skills with three problems per skill during each session. The Google form was linked to the university authorized official Google mail account used for university employees and students. The interventionist read the directions and math problems out loud to the child and recorded the child’s response by clicking on her verbally provided answer in the Google form. As the child responded, the interventionist and parent provided verbal praise in the form of “Thank you for your answer, let’s try the next problem.” The interventionist ended the session by telling Camille she did a good job by working hard on the math problems and confirming the next session scheduled to meet.

Intervention

The intervention phases lasted a minimum of five sessions per skill and until the child reached the mastery criterion by achieving 100% accuracy across two sessions consecutively. This phase consisted of watching a video modeling clip and then the child used virtual mathematic manipulatives to solve the problems. At the beginning of the intervention session, the child and parent were greeted. The interventionist would inquire how the parent and child were doing that particular day. After discussing their day, the interventionist would ask Camille if she was ready to watch the video clip and begin completing some math problems. Once Camille agreed, the interventionist shared the video modeling clip for each skill accordingly via Zoom screen sharing, instructed the child to watch the video modeling clip, and started playing the video modeling clip. Specifically, the interventionist would state, “Let’s watch the video clip. Pay attention because it will be your turn next to complete some math problems.” If the child appeared to not be watching the video or left the area and could no longer see the screen, the interventionist paused the video and prompted the child to return and finish watching. After the child viewed the video modeling clip, the interventionist shared the link to the virtual manipulatives through the chat feature of Zoom. The interventionist also made the parent a co-host, so the parent could share their screen. The parent opened the link to the relevant

Table 1 Parent Protocol

Guideline	Phase
Please do not offer any prompting or assistance related to computation or math problem-solving skills	• All phases
If your child looks to you for help or for confirmation of their problem-solving, you may tell them “Try your best,” “it’s OK if you’re not sure,” “good job working hard, keep going,” etc., but please do not give them any hints or prompts as to how to solve the problem, or confirm or deny that they are solving it correctly	• Baseline • Generalization
You may prompt your child *behaviorally*, such as directing their attention to the problem (e.g., pointing, verbal prompts to look at the question, etc.), asking if they would like pencil/paper, or prompting him/her to keep going or stay on task	• All phases
If your child is not watching the video while it is playing, please prompt him/her to watch it	• Intervention
If your child has trouble moving the virtual manipulatives, you may provide verbal prompts or modeling, but do not prompt or model how to solve the problem (In other words, you can model/prompt how to move the manipulatives, but not in a specific way related to solving them problem)	• Intervention
You may: 1.Tell your child to watch the video again 2.Tell your child to look at the screen or the math problem 3.Tell your child to try their best	• Intervention
Your child is allowed to use paper and pencil if they would like to do so	• Baseline • Generalization
If your child needs help with the technology, you may provide assistance	• All phases
At the end of each session, please provide positive verbal praise to your child for completing the worksheet (e.g., “great job working hard!”). We will also provide similar verbal praise	• All phases
Please do not explicitly practice these math skills outside of the study sessions	• Baseline • Intervention

virtual manipulative screen and shared their Zoom screen. This enabled the interventionist to follow along as the child solved the problems with the manipulatives. During the intervention sessions, the interventionist directed the child to look at the screen and follow along. At the completion of each math problem, the interventionist took a screenshot of the child's virtual work on the virtual manipulative site to score the total problems solved correctly. The child would then reset her virtual manipulative screen to begin the next problem. Both the interventionist and the parent verbally praised the child after each problem for each skill type in the form of "Thank you for working so hard," or "Good job, let's keep going."

Addition within 10

Upon watching the video clip for addition, the interventionist provided the first addition problem orally and either the parent or the child used the pencil function on screen to write the problem. The child or parent also put a tens frame on the screen. The interventionist directed the child to solve the problem by saying, "Your problem is __ + ___ = . Can you find the answer?" If the child did not initiate the task or initiated the task incorrectly, the interventionist used error correction procedures. The child did not require the last three levels of the error correction procedure when solving addition problems during intervention. When the child made an error, the interventionist told her that it was not quite correct and directed her to watch the video modeling clip one more time. This only occurred one to two intervention sessions for addition within 10. Then the child solved the same problem again and got the correct answer. The child used red and yellow circles to represent each addend on the virtual tens frame. The child then counted the total number of circles within the tens frame to provide the sum to the addition problem. The child then wrote this sum using the pencil function on the virtual screen.

Comparing three numbers to determine the smallest

Upon watching the video clip for number comparison, the interventionist provided the first three numbers for comparison verbally. Either the parent or the child used the pencil function on screen to write the three numbers being compared across the bottom of the virtual unifix screen. The interventionist then gave the child directions to begin building each number with the cubes. The interventionist stated, "Now, you have your numbers, let's create the first amount. Which color are you going to use to create the number ___?" The child only required verbal prompting two to three times throughout all intervention sessions to recount cubes as an error correction procedure. The child used varying colors of unifix cubes to represent the numbers provided. Once the child represented each number, the interventionist asked, "Which one is the smallest?" The child responded verbally. After two sessions, the child began to place a checkmark with the online virtual pencil above the smallest number.

Subtraction within 10

Once the child completed watching the video, the interventionist provided each subtraction problem orally and either the parent or the child used the pencil function on screen to write the problem. The child or parent also put a tens frame on the screen. The interventionist then gave directions to solve the problem. The interventionist stated, "Your first problem is ___—___ = . Can you find the answer?" The child used red circles to represent the minuend of the subtraction problem on the virtual tens frame. The child then moved the correct number of circles out of the tens frame to represent the subtrahend. Finally, the child counted the remaining number of red circles within the tens frame to determine the difference. The child then wrote this answer using the pencil function on the virtual screen. The interventionist would take a screenshot of the completed problem. After each problem, the child was prompted to reset the screen and prepare for the next problem.

Generalization

Once the child entered the generalization phase, the parent was contacted to locate multiples of an easy-to-use, everyday item that could be utilized for addition, comparison, and subtraction. The parent chose elbow macaroni for the generalization phases. For the addition task during generalization sessions, the interventionist shared her Zoom screen so the child could view the virtual whiteboard. The interventionist wrote each addition problem on the whiteboard screen one at a time. The interventionist gave the child direction to solve the presented problems using the macaroni available. The child used the macaroni to count out the addends and calculate the sum. After each problem calculated correctly, the interventionist provided verbal praise such as "Correct! You are doing so well!" During the comparison generalization sessions, the interventionist continued to use the whiteboard feature of Zoom to write out the three numbers to be compared. The child then formed three rows of macaroni to determine the smallest amount. The same procedures for the task of addition were used for the task of subtraction.

Social Validity

Following the completion of the generalization sessions, the interventionist provided the parent and child a social validity questionnaire. We used Google Forms to present a social validity questionnaire using a Likert scale with three different options of smiley face icons representing happy, okay/neutral, and sad faces. The interventionist shared the screen with Google Forms and read each question at a time with three response options each represented by smiley face icons: "I like it a lot, it is okay, and I don't like it". The child verbally stated her response to each question. The questions included: (1) Did you like the things you did in the study? (2) Was it easy to learn using the videos and websites? (3) Would you like to watch more videos and use the online tools in the future? The interventionist asked the parent the following four questions and wrote down the parent's oral responses: (1) What did you like about your child's use of video modeling and virtual manipulatives in learning math topics? What did you not like? (2) What do you think were the advantages/disadvantages of the intervention? (3) Would you like to use these strategies to support your child in the future? (4) Is there anything else you would like to tell us about your likes and dislikes of using this approach to support your child's learning?

Interobserver Agreement and Procedural/Treatment Fidelity

A second trained observer simultaneously collected data on Camille's percentage of accuracy in solving addition, number comparison, and subtraction problem for 41.6% of baseline, 42% of intervention, and 66.6% of generalization phases for each target skill. The interobserver agreement (IOA) was calculated using the point-by-point agreement approach. The IOA was calculated by dividing the number of agreements by the number of agreements plus disagreements and then multiplying by 100% (Ledford et al., 2018) and resulted in 100% IOA per skill for each phase.

The same second observer collected data on the procedural fidelity for each phase (baseline, intervention, and generalization) and treatment fidelity for the intervention implementation of the study. These data were collected for 44.4% of baseline, 38.8% of intervention, and 66.6% of generalization phases for each target skill. The fidelity checklist included the following steps: (1) Each session was conducted over Zoom, with the interventionist, child, and parent present; (2) The interventionist presented the child with three problems per skill during each study session (baseline, intervention, and generalization); (3) All materials to complete the task were available for the child at the start of each session during baseline, intervention, and generalization (worksheets, problem sets, virtual manipulatives, video clips, and macaroni pieces); (4) The interventionist provided the direction to solve three problems per skill type during each session of each phase; (5) The interventionist told the child to watch the video clip during the intervention phase and played the video modeling clip via Zoom and paused every time the child got distracted and resumed once the attention was gained; (6) The child watched the video clip in its entirety at least once during every session of the intervention phase; (7) The interventionist provided error correction in the form of least to most prompting during the intervention phase; (8) The parent only provided non-computational assistance, as directed by research team during baseline, intervention, or generalization phases (i.e., only verbal prompts to "try your best" or "watch or rewatch the video clip"); and (9) The interventionist and the parent verbally praised the child after the child attempted to solve or solved each problem during each session of each phase. The fidelity data (both procedural and treatment) were calculated by dividing the number of steps the interventionist completed correctly by the number of total steps and multiplying by 100%. The fidelity data resulted in 100% for baseline per skill, 93% for generalization of addition and number comparison, 100% for generalization for subtraction, and 100% for treatment fidelity during intervention per skill.

Data Analyses

Visual analysis served as the primary method of data analyses as it is the foundational standard in SCRD to determine the presence or absence of a functional relation between the independent and dependent variables (Barton et al., 2018). We used the systematic process of visual analysis as suggested in Barton et al. (2018), which involved analyzing data within and across adjacent phases for consistency, level, trend, stability, overlap of data and immediacy of effects. To analyze the stability of data, we used the 80–25 rule per Barton et al. (2018) that indicated if 80% of the data appeared within 25% of the median in each phase, then the data were stable. To calculate trend, we used the split-middle technique and described the trend as accelerating, decelerating, or zero-celerating. Additionally, we calculated the effect size using the *Tau-U* method, a commonly used effect size in SCRD, (Parker et al., 2011) using an online Tau-*U* effect size calculator (http://www.singlecaseresearch.org/calculators/tau-u; Vannest et al., 2016). We then calculated the overall average Tau-*U*. We interpreted Tau-*U* results within a range score of 0 to 1.0 using Parker and Vannest (2009) guidelines: weak effect (0–0.65), medium to high effect (0.66–0.92) and strong effect (0.93–1.0). When readers interpret Tau-*U* results, one should use caution as Tau-*U* is used as supplementary to the main method of data analysis, i.e., visual analysis, has inherent limitations, and does not capture the immediacy of effect and individual variability within a study phase.

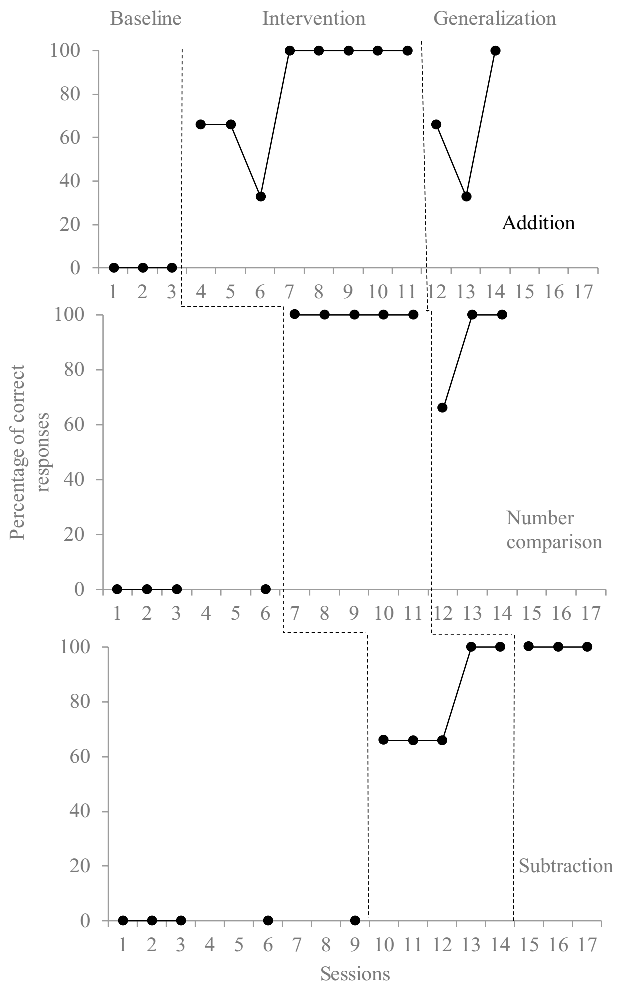

Fig. 1 Camille's correct responses displayed as percentages for across three skills

Results

Figure 1 includes the percent accuracy of Camille solving three types of mathematic problems per phase. According to visual analysis of data, a functional relation exists between the point-of-view video modeling using virtual manipulatives and error correction (i.e., watching the video modeling clip twice during two to three sessions) and the accuracy of solving addition, number comparison, and subtraction problems. Table 2 includes the mean percentage of accuracy of Camille's responses per skill type and phase with the standard deviation and the number of sessions the child needed to reach mastery criterion. Effect size calculation using the *Tau-U* method resulted in a score of 1.0 for each of the three skills between baseline and intervention and baseline and generalization. Table 3 includes Tau-*U* scores for all skills and phases and an omnibus score.

Addition

When presented with the task of adding numbers within 10, Camille had a mean baseline performance of 0% with a stable trend across all three baseline sessions. Upon introduction of the intervention, Camille demonstrated an immediate increase in addition within 10, with a mean intervention performance of 83% and no overlap of data between baseline and intervention. There was an accelerating trend with slight variability, across eight intervention sessions, with 62.5% of the data falling within the stable range. During the three generalization sessions, Camille's mean, independent addition within ten score was 66.3% with accelerating trend, no overlap of data between baseline and generalization, and

Table 2 Mean percentage of accuracy of responses per skill type and phase with the standard deviation and the number of sessions needed to reach mastery criterion

Skill	Baseline (SD)	Intervention (SD)	Generalization (SD)	Number of sessions until mastery
Addition	0% (0)	83% (25.4)	66% (33.5)	5
Number comparison	0% (0)	100% (0)	88% (19.6)	2
Subtraction	0% (0)	79% (18.6)	100% (0)	5

Table 3 Tau-U effect size trend comparisons for each skill, including a weighted average

Skill	Baseline-intervention			Baseline-generalization		
	Tau-U	p-value	90% CI	Tau-U	p-value	90% CI
Addition	1	0.0143	0.328–1	1	0.0495	0.162–1
Number comparison	1	0.0143	0.328–1	1	0.0339	0.225–1
Subtraction	1		0.370–1	1	0.0253	0.264–1
			Tau-U		p-value	90% CI
Weighted average		0.009	1		0	0.6201–1

high variability in the form of 33% of the data falling within the stable range.

Number Comparison

During the second task of comparing three numbers within 20 to determine the smallest value, Camille had a baseline mean performance of 0% with a zero-celerating trend across. Upon introduction of the intervention, Camille displayed an immediate increase in comparing numbers with a mean score of 100%, no overlap of data with baseline data points, and an accelerating and stable trend across all five intervention sessions. However, the generalization phase had slight variability with a mean performance of 88.6% across three sessions and accelerating trend with no overlap of data with baseline data points.

Subtraction

Lastly, Camille had a mean score of 0% with a stable, zero-celerating trend across the five baseline sessions for the task of subtracting within 10. During the intervention phase, Camille showed an immediate improvement in subtracting numbers and had a mean score of 79.6%, demonstrating slight variability with 60% of the data falling within the stable range across the five intervention sessions. The intervention data points showed an accelerating trend with no overlap of data between baseline and intervention data points. Camille's mean independent score during the three generalization sessions was 100% with a stable and zero-celerating trend.

Social Validity

The child's responses to the social validity questions demonstrated that Camille enjoyed the intervention and would like to continue further instruction in the future using video-based instruction through an online platform. Similarly, the parent expressed positive feedback about the intervention during the social validity interview. The parent felt that the virtual intervention was beneficial for Camille's learning and that she would like to use the strategies to continue to support Camille with mathematics. Overall, the feedback from both parent and child was positive.

Discussion

The aim of this study was to examine the effects of an online, synchronous video modeling intervention with virtual manipulatives and error correction with parental support to teach the skills of addition, number comparison, and subtraction to Camille, a five-year old autistic child. We found a functional relation between the intervention and dependent variable and that the intervention was effective in acquisition of all target skills for Camille. These findings complement prior research on video modeling and virtual manipulatives to teach mathematics skills to young autistic children (Hughes & Yakubova, 2019; Peltier et al., 2020) and add novel findings to providing online, synchronous instruction with parental support for young children.

This study is one of the early studies focused on teaching mathematics concepts to a young, pre-kindergarten autistic child in an entirely online environment. It also adds novel findings on the effects of using video modeling and virtual manipulatives with children of this age group. The majority of the research on teaching mathematics skills using video modeling and virtual manipulatives has focused on upper elementary, middle, and high school autistic students (Kellems et al., 2016; Root et al., 2021; Yakubova et al., 2020). It also adds to scarce evidence on effective online instruction provided synchronously to help students continue instruction, particularly, at times when a student cannot attend school in-person due to medical illness, public health crisis, or other situations.

This study also adds to research on using virtual manipulatives as a stand-alone strategy rather than using it in a virtual/concrete-representational-abstract (VRA/CRA) framework in teaching autistic children. Prior research in teaching mathematics skills to autistic children used primarily the full framework in VRA or CRA formats (e.g., Flores et al., 2014; Yakubova et al., 2016). Few studies examined the mathematics manipulatives either in virtual or concrete formats alone (Jimenez & Besaw, 2020; Yakubova et al., 2020). For example, in Yakubova et al. (2020), it was noted that some students self-transitioned to the abstract phase following the instruction with concrete manipulatives. Camille learned how to use the virtual manipulatives through watching the video modeling clips and was eager to interact with the virtual manipulatives to solve the equations. During the beginning of the addition intervention sessions, Camille struggled to utilize both the red and yellow chips when completing the addition problems. Once Camille rewatched the clip, she was able to use the virtual manipulatives as demonstrated. For the number comparison and subtraction intervention sessions, Camille utilized the virtual manipulatives as demonstrated through the video modeling clip. During the generalization phases, Camille transitioned to using elbow macaroni to perform her mathematical problems. She did not exhibit any difficulty transitioning from the virtual manipulatives to the macaroni for generalization. The findings of our study add to limited research on a stand-alone manipulative-based intervention and suggest that it can be effective in helping autistic children acquire mathematics skills.

Limitations and Directions for Future Research

As an early study examining the effects of online, synchronous video modeling intervention with virtual manipulatives, future replications are necessary to enhance the generalizability of findings. While SCRD can include one participant with at least three replications across skills to establish a causal relation, future replication studies need to be conducted with at least three participants to allow for stronger replication. Future studies should also consider examining the effects of instructional on the learning of participants representing different racial/ethnic backgrounds. While the findings of this study suggest the effectiveness of the online video modeling intervention with virtual manipulatives on improving arithmetic skills of one autistic child replicated across three skills, future replication studies are necessary to examine the effects of the intervention with more participants to teach a wide range of basic and advanced mathematics skills. We examined generalization and immediate maintenance of Camille's skills. When examining generalization, we did not include generalization probes in all phases, rather examined generalization only upon the conclusion of the intervention phase. Therefore, generalization findings should be interpreted with caution. Future studies should embed generalization probes throughout study session to establish stronger evidence on the extent to which students display stimulus and response generalization skills. Future studies could examine the long-term maintenance of skills following the online video modeling instruction with virtual manipulatives. Further research might also examine the level of parental involvement and role in providing an online intervention for autistic children. Along with parental involvement, future research could also examine the effects of asynchronous online video modelling to teach autistic children.

Practical Implications

The findings of this research on the effects of using an online video modeling intervention with virtual manipulatives to teach mathematics skills offer implications for educators. The intervention was effective and efficient in helping a five-year old autistic child improve three arithmetic skills within a few sessions of instruction. Given the visual nature of the instruction and the relative simplicity of creating short instructional video clips (e.g., educators do not need professional video cameras and technical expertise to create high quality video modeling instruction), educators can create short, instructional videos using virtual manipulatives to explain and model a new concept through visual, systematic instruction with concise and consistent vocabulary. When creating video modeling clips, teachers can use free virtual manipulatives that allow students to interact using drag and drop functions, write equations on an electronic whiteboard, and edit their answers, as needed. In order to create video clips, free screen recording software can be used (e.g., Zoom), and videos can be saved on an electronic device for future use. The findings of this study also offer implications for parental involvement in teaching. Educators can provide clear expectations and guidelines for parents to help support their child's learning, such as when and how to provide an assistance (e.g., computational versus non-computational, verbal, or gestural prompting versus hand-over-hand prompting).

Author contribution GY designed the study, trained the interventionist, assisted with data collection and data analysis, and wrote the paper. MAD served as the interventionist and assisted with data analysis and writing of the paper. BBC assisted with conducting the intervention and writing of the paper.

Declarations

Conflict of interest On behalf of all authors, the corresponding authors states there is no conflict of interest.

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