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Increasing the Number Sense Understanding of Preschool Students With ASD

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Abstract

Teaching children with autism spectrum disorder (ASD) academic skills supports their future opportunities. For example, early number sense skills are predictive of future mathematical success for all children including children with ASD. Yet, research on foundational early childhood mathematics skills of children with ASD is limited. This study used an adapted version of Number Talks to increase the number sense skills of preschool children with ASD. Number Talks is a constructivist approach that was combined with systematic instruction (i.e., system of least prompts and modeling) in this study. A multiple probe across participants design established a functional relation between using an adapted version of Number Talks and the early number sense skills of preschool children with ASD. Findings suggest using an adapted version of Number Talks can increase the early number sense skills of preschool children with ASD. Implications for practice and future research are discussed.

Keywords

autism spectrum disorder, early childhood, mathematics, number sense, Number Talks, small group instruction

Defining Early Number Sense (ENS)

Early number sense understanding is predictive of future mathematics performance as children with limited number sense skills in kindergarten are more likely to struggle with mathematics instruction including calculations and problem-solving (Carlson et al., 2011; Sarama & Clements, 2009; Witzel et al., 2013). These influential ENS skills emerge during the first 2 years of life and continue to develop during the preschool years (Sarama & Clements, 2009). Because a strong number sense understanding is associated with more advanced mathematics learning, early attention to these skills is essential (Witzel et al., 2013).

Early number sense refers to the ability to subitize, discriminate between quantities, compare magnitudes, count objects, and perform simple addition/subtraction (Jordan & Levine, 2009). For definitions of these terms, see Table 1. Some debate about the developmental order of these skills exists. Some researchers believe that subitizing is a skill learned before one-to-one correspondence counting, whereas some believe one-to-one correspondence counting occurs first, and others believe children learn these skills in tandem (Sarama & Clements, 2009). These skills are predictive of future mathematical abilities and vary based on individual ability and experience (Jordan & Levine, 2009). Often ENS skills are learned implicitly in early childhood through conversations and activities (Sarama & Clements, 2009). An example of this implicit learning is children learning to subitize while sharing food items in the dramatic play center. However, many children require specific instruction to develop these skills (Andrews & Sayers, 2015).

Instructional Practices for Early Childhood Mathematics

The National Association for the Education of Young Children (NAEYC) and the National Council of Teachers of Mathematics (NCTM) (2010) promoted the importance of teaching early numeracy skills including ENS; the NCTM addresses these skills in the number and operation standards. Both organizations emphasize that early mathematics instruction should be socially constructed and include asking questions, providing extension activities

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Table 1. Terms and Definitions of Early Number Sense Skills.

Term	Definition
Number sense	In early childhood education, number sense involves a specific set of skills including subitizing, magnitude comparison, one-to-one correspondence, and number conservation (Jordan & Levine, 2009).
Perceptually subitize	The ability to rapidly or immediately comprehend the magnitude of small numbers (i.e., knowing there are three dots without having to count the dots; Clements, 1999).
Conceptually subitize	Immediately knowing how many dots are present because the pattern is one that is known to you such as on dice or dominoes (Clements, 1999).
Magnitude comparison	The ability to compare two different amounts of dots without counting the dots. Magnitude comparison follows Weber's law (Halberda & Feigenson, 2008).
One-to-one correspondence	The ability to count objects by assigning a specific number to each object. No items are counted more than once or skipped.
Number conservation	The ability to recognize that a group of items have the same amount, regardless of how the items are organized (i.e., spread apart or moved in a different direction).
Weber's law	This law indicates that the closer the ratio is between an amount, the more difficult it is to judge magnitude differences. Typically developing 3-year-old preschool students can judge magnitudes at a 3:4 ratio and 4-year-old students at a 4:5 ratio.
Number Talks	A 15-min lesson in which students discuss different strategies used to solve a given mathematical problem (Parrish, 2014).

(i.e., instruction and materials that build on concepts that children already know), and developing new understandings of mathematical content. Typically, adults facilitate a discussion with children and their peers using manipulatives as learners notice, describe, compare/contrast, predict, explain, manipulate objects/events, and draw conclusions (Cameron, 2012). In quality early discussions about mathematics, the adult scaffolds communication through modeling and provides specific feedback to support socially constructed learning.

Similarly, the Council for Exceptional Children Division for Early Childhood's (DEC, 2014) recommended practices in instruction address many practices teachers should use to enhance the learning of their children. Recommended practice INS6 indicates the importance of using systematic instructional strategies to prompt both learning and engagement (DEC, 2014). Another recommended practice INS8 indicates the importance of peer-mediated interventions to support the learning and engagement of all children (DEC, 2014). The recommended practices related to interaction are also important during instruction involving interaction with peers and adults. DEC (2014) recommended practices INT2 and INT3 point to the importance of supporting communication development and sustained interactions with the use of language expansion, modeling, feedback, and guided support. Therefore, quality mathematics instruction in the early childhood years pairs socially constructed learning with systematic instruction to enhance the engagement, communication, and understanding of children. This combination of instruction provides a unique opportunity for children to have the supports of systematic instruction while participating in the developmentally appropriate practice of socially constructed learning. This type of instruction further provides an opportunity for children to learn in an inclusive environment in the same manner as their peers, but with the simultaneous inclusion of needed supports.

Social Communication Needs of Children With Autism Spectrum Disorder (ASD)

Participating in conversations about mathematics that involve explanations and conclusions presents challenges for some learners with disabilities. This may be especially true for children with ASD as difficulty with social communication is foundational *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.; *DSM-5*; American Psychiatric Association, 2013). That is, learners with ASD have difficulty engaging in reciprocal interactions and conversational discourse. Moreover, they are likely to struggle with the communication skills required to explain their thinking (Volkmar et al., 2014). Children with ASD are also less likely to use language to share or request information (Kim et al., 2014).

Mathematics and ASD

Although participating in this type of instruction may be challenging, developing these early conceptual skills is important as many children with ASD achieve below expected levels in mathematics (Whitby & Mancil, 2009). ENS skills are predictive of future mathematics learning

(Jordan et al., 2006), and emerging research suggests that the subitizing and one-to-one correspondence counting skills of preschool children with ASD are predictive of their first-grade mathematics ability (Titeca et al., 2014). One-to-one correspondence counting and subitizing are specific skills addressed within ENS (Jordan & Levine, 2009). Moreover, although few studies have investigated the mathematical skills of individuals with ASD (Titeca et al., 2014), research suggests variability in mathematical understanding among learners with ASD with some children scoring above and some below expectations based on IQ score (e.g., Mayes & Calhoun, 2006; Oswald et al., 2016; Titeca et al., 2015; Wei et al., 2014). Researchers have found that about 22% of children with ASD who have average IQ scores qualify for a mathematical disability (Mayes & Calhoun, 2006; Oswald et al., 2016). It is possible that this difference in mathematical ability and IQ could be related to limited number sense understanding (Gersten & Chard, 1999). Providing children with ASD a strong foundation in ENS prior to entering school could potentially minimize some difficulties related to mathematics learning.

Teaching ENS Skills to Young Children With ASD

There are a growing number of studies addressing teaching mathematics to children with ASD, but a limited number focus on ENS skills and fewer still for preschool children. Three reviews (Barnett & Cleary, 2015; Gevarter et al., 2016; King et al., 2016) investigating the current research on teaching mathematics to children with ASD found two studies addressing early numeracy skills, but none including preschool children. These studies addressed kindergarten-age children who were learning various ENS skills including, number identification, rote counting, one-to-one correspondence counting, patterning, and equal (Jimenez et al., 2013; Jowett et al., 2012). Each of these studies demonstrated an increase in one-to-one correspondence counting and number recognition and suggests that direct, systematic instruction including modeling, visuals, and prompting is beneficial to learners with ASD. Root and colleagues (2019) further reinforced the importance of systematic instruction in a replication study utilizing the Early Numeracy Curriculum (same curriculum as used by Jimenez & Kemmery, 2013) with kindergarten children with ASD.

Another literature review completed by Knight et al. (2013) addressed teaching academic skills to children with ASD. Findings indicate three studies addressed ENS for children ages 3 to 5 years (Chen & Bernard-Opitz, 1993; Kelly et al., 1998; Whalen et al., 2010). These studies used a combination of prompting strategies, modeling, visual supports, time delay, and computer systems to teach children with ASD.

Although there are limited studies which specifically teach ENS to children with ASD, there is a growing body of research about teaching mathematics to children with ASD. A common thread seen in this research is using systematic instruction including a system of least prompts (SLP; also called least to most prompting), visual supports, and modeling (e.g., Cox & Root, 2020; Root et al., 2018; Yakubova et al., 2020). Missing from the literature are studies that support children with ASD to engage in mathematical discussions about number sense as recommended by the NAEYC and NCTM (2010) and studies that include an emphasis on a broader range of ENS skills (e.g., magnitude discrimination, subitizing).

Number Talks

Number Talks is one instructional activity consistent with NCTM standards related to mathematical discourse as well as understanding numbers and operations. Number Talks are 15-min mini-lessons designed for children of all ages that provide a deep understanding of foundational mathematic concepts (Humphreys & Parker, 2015) including ". . . composition and decomposition of numbers, our system of tens, and the application of properties" (Parrish, 2014, p. 5). In Number Talks, consistent with other social constructivist approaches, peers hold mathematical conversations facilitated and scaffolded by an adult (Humphreys & Parker, 2015; Parrish, 2011, 2014). These conversations support the learner's understanding of core mathematical concepts and the language used in mathematics instruction (Boonen et al., 2011).

Because all young children have difficulty participating in higher order discussions, Number Talks embeds teacher scaffolding, including teacher-supported discussion and leading questions (Parrish, 2014). Although these scaffolds will support learners, to fully engage in and benefit from mathematical conversations, children with ASD will likely require additional supports. For example, the evidence-based practice of using visual supports provides a way for children with ASD to participate in mathematical discussions even if they do not yet have the language skills to be independent (Wong et al., 2015). In addition, DEC recommends bridging the practices associated with learning intuitively (e.g., through play) and explicit instruction (DEC, 2014). King et al. (2016) found that 68% of mathematical intervention studies for children with ASD used prompting. In addition, the studies endorsed modeling the language to support understanding (Wong et al., 2015) and development of language (Paul & Norbury, 2012). These findings support the need for use of both explicit instruction and socially constructed learning opportunities.

Therefore, this study evaluated the effectiveness of an adapted version of Number Talks that incorporates evidence-based practices for children with ASD (i.e., visual supports, SLP, and modeling) to increase the ENS skills of preschool children with ASD. Specifically, our study addresses the following question: Is there a functional relation between adapted Number Talks and the ENS skills of young children with ASD?

Method

Participants and Setting

We conducted our study in two different inclusive preschool classrooms that consisted of children with and without disabilities. These classrooms were located in different public voluntary prekindergarten programs in the Southeastern United States. During interviews, teachers reported that mathematics instruction consisted mostly of calendar activities (e.g., counting days in a month, jumping 10 times while counting). One program also included small group mathematics activities a few times a month, which involved tracing numbers and coloring a specific number of items (e.g., trace the number three and color three apples).

Following human subjects approval, the first author contacted each preschool to identify young children with ASD struggling with mathematics. The preschool directors suggested potential children and the school sent letters to parents/guardians explaining the study and asking for consent for their child to participate. To be eligible, children had to (a) have a diagnosis of ASD from a pediatrician or psychologist, (b) answer questions using two to three words as indicated by the teacher and observed during testing, and (c) score below average (mean of 100 with a standard deviation of 15) on the Test of Early Childhood Mathematical Ability 3rd Edition (TEMA-3; Ginsburg & Baroody, 2003). The TEMA-3 specifically addresses the ENS skills (i.e., subitizing, one-to-one correspondence counting, magnitude discrimination, and number conservation) of young children (ages 3–8 years) and meets standards for validity and reliability (Spies & Plake, 2005). After obtaining consent, the first author, who had prior experience administering standardized assessments to children with ASD and previously worked as an early childhood special education teacher in an ASD classroom, administered the TEMA-3. Four children were tested and met inclusion criteria; however, we excluded one student who scored in the above-average range on the assessment.

Chris was a 4-year 11-month-old White male with ASD. Chris received special education and speech and language services. His teacher reported that he requested items in three- to four-word utterances. During calendar activity, Chris answered questions by repeating what his peers or teacher said. Chris scored in the 6th percentile on the TEMA 3. During TEMA-3 testing, Chris counted items to five but inconsistently counted larger quantities. The first author observed that Chris occasionally refused to join circle time and engaged in behaviors such as crying and being physical with the teacher (e.g., pushing).

Laura was a 4-year 4-month-old White female with ASD. In addition to special education services, Laura received speech/language therapy. Laura's teacher reported that she answered questions in short two- to three-word utterances and requested needed items. The researcher observed that Laura occasionally wandered away during circle time but willingly came back when asked by her teachers. Laura scored in the 37th percentile on the TEMA-3. When assessed, she struggled to count items to five, rote count to 10, and perceive numbers quickly (i.e., subitizing).

Jessica was a 4-year 5-month-old White female with ASD. Jessica received special education services and speech/language services. Her teacher also noted that Jessica used few words but answered questions in two- to three-word utterances. Jessica's teacher reported that Jessica refused to complete work that was new or undesired (i.e., said, "no" and cried), but she will complete tasks when reinforced with stickers, songs, or free-play opportunities. Jessica scored in the 3rd percentile on the TEMA-3. When taking the TEMA-3, she counted a small group of items up to three but struggled to respond to questions involving higher quantities or activities requiring subitizing.

In one preschool (Chris and Laura), intervention sessions and number sense probes took place in a room used for therapy (e.g., speech, occupational therapy, etc.), and in the second preschool (Jessica), sessions occurred in a hallway outside of the classroom. Both were quiet locations. Small groups consisted of two to three typically developing peers and one student with ASD.

With the support of the classroom teachers, the first author identified peer groups to use for this study. The classroom teacher assisted with recruitment of peers by identifying children who (a) included children with ASD in play and routines throughout the day and (b) had average to above-average mathematical ability. Parental consent was obtained for eight typically developing peers (ages 4–5 years). Peers included three females and five males ages 4 to 5 years and represented a diverse group (i.e., three White, two Hispanic, two African American, and one Asian).

Experimental Design

We used a multiple probe across participant design to measure the impact of the intervention on participants' ENS skills; we included baseline, intervention, and maintenance conditions. The first participant began intervention after he achieved five stable baseline data points. The other participants remained in baseline until the previous participant had 3 days of correct responding above baseline levels. Intervention continued until the participant correctly answered at least seven of the eight questions on the probe for three consecutive sessions.

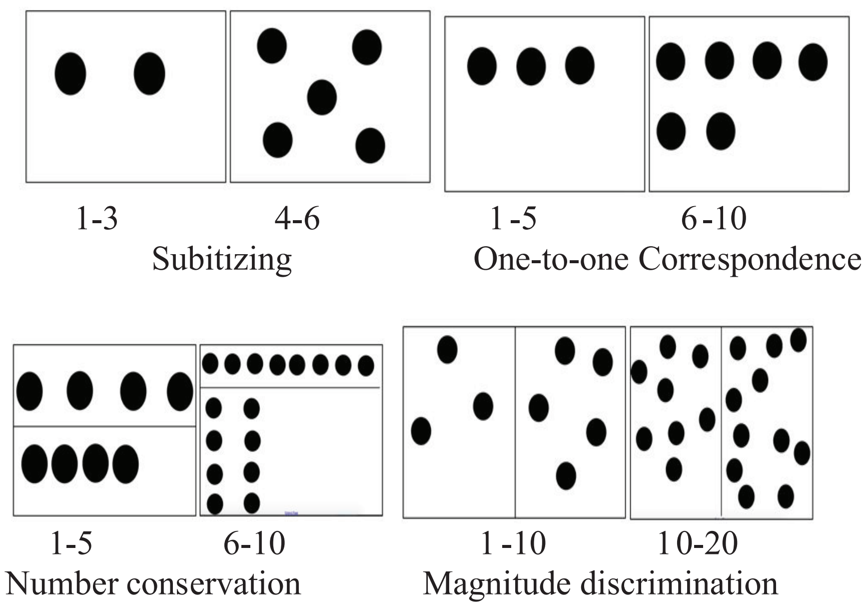


Figure 1. Example of eight question probes.

Dependent Variable

Data collection occurred 3 days a week immediately after math instruction during baseline (i.e., calendar math during circle time) and after instruction during intervention. All sessions were video recorded for coding purposes. The dependent variable was the percentage of correct answers on a number sense probe. Children had to provide a correct response within 5 s for the response to be considered correct. Correct responses were either identification of the correct number of dots shown (subitizing and one-to-one correspondence counting), yes or no response (number conservation), or pointing to the correct image (magnitude discrimination). For one-to-one correspondence counting, children had to touch and count each dot in the correct order to receive credit for this response. This probe included two items addressing each of the targeted number sense skills (i.e., subitizing, one-to-one correspondence counting, number conservation, and magnitude discrimination) with eight total items (see Figure 1 for an example of the probe and Table 1 for definitions of the targeted skills).

To measure subitizing, one question assessed perceptual subitizing of Numbers 1 to 3, and one measured conceptual subitizing with the dots organized as on a die for Numbers 4 to 6. Children were shown the dot image for 2 s and then asked to say how many dots were present. To assess one-to-one correspondence counting, children counted numbers ranging from 1 to 5 (one item) and 6 to 10 (one item). The first author asked the children to touch and count the dots. Number conservation items consisted of two sets of dots each containing the same number of dots but in a different order. Children were asked, "If I have (number of dots) and move them to look like this is it still (number of dots)?" Magnitude discrimination items required children to indicate which of the two groups of dots had more (one item amounts 1–10, and one item amounts 11–20). Magnitude discrimination problems all followed the typical norms for Weber's law (see Table 1) with a ratio of no more than 4:5 for 4-year-olds (Humphreys & Parker, 2015). The first author asked the children to point to the group of dots that had more. Children were provided no clarification, prompting, or feedback for any items. Fifteen probes were created and randomly selected for both baseline and intervention sessions. The first author repeated some items on the probes (e.g., subitizing Numbers 1–3) but in different orders on each probe.

Interobserver Agreement (IOA)

Sessions were video recorded for coding purpose. The first author trained two coders with prior experience working with children with disabilities (e.g., a doctoral candidate and an undergraduate). Training consisted of watching videos of probe sessions that differed from the videos used for IOA. Training continued until coders reached 80% agreement on two consecutive videos which we reached after watching four videos. Then, we randomly selected 50% of the sessions from each condition for each participant. The coders were not naïve to the study's purpose but were blind to the condition. IOA was calculated point by point by dividing the number of agreements by the number of total items and multiplying by 100 (Gast & Ledford, 2014). IOA was 100%, 95.8% (range: 87.5%–100%), and 100% in baseline for

Chris, Laura, and Jessica, respectively. For intervention, IOA was 100% for Chris, Laura, and Jessica.

Procedures

The first author served as the intervention agent and administered the probes.

Baseline. In baseline, the first author administered probes immediately after typical classroom mathematics instruction that consisted of calendar activities involving whole group counting, patterning, and number recognition. There was no small group instruction during baseline, but classroom teachers included all participants in calendar activities. During the transition after calendar time, participants were brought to the table and asked, "Is it okay for me to ask you some math questions today?"

Intervention. Intervention occurred 3 days a week for 15 to 20 min. Small groups consisted of two to three typical peers and one child with ASD. We based these sessions on the dot images provided in Number Talks by Parrish (2014). Each session consisted of three dot images designed to help children recognize numbers, the parts of numbers, and subitize (Parrish, 2014). The researcher provided these images on a SMART Notebook app (SMART Technologies, 2017). After intervention, the peers returned to the classroom, and the children with ASD completed the probe.

During Number Talks, the researcher followed eight steps similar to those in Humphreys and Parker's (2015) book *Making Number Talks Matter*: (a) children sat at a small table clear of all items; (b) the researcher showed a dot image on the iPad; (c) children determined the number of dots and indicated they were ready to share the number by placing their thumb up; (d) children shared how many dots were present by verbally naming a number or pointing to a picture (with the researcher using SLP as needed to help the child answer), and the researcher wrote down each answer and gave no indication of correctness; (e) children shared how they counted the dots by verbally explaining or drawing on the iPad; (f) the researcher helped all children compare their answers to obtain consensus, if children failed to reach consensus, and the group counted the dots together out loud; (g) the researcher helped the children compare answers; and (h) children repeated Steps 2 through 7 for each of the three dot patterns. Refer to Table 2 for examples corresponding to each step.

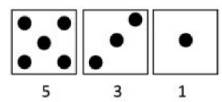
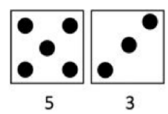
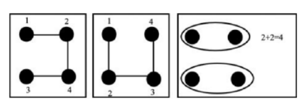
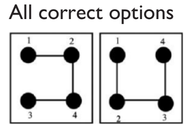
To ensure that there were no biases associated with who answered questions first during intervention, the researcher asked a different person to share their answers first for each dot image. The groups had four children, so this left one child who did not go first for each intervention session. The researcher made sure that this child had an opportunity to answer first in the next intervention session.

We adapted Number Talks in three specific ways: (a) adding an SLP, (b) ensuring each child shared answers, and (c) having the researcher specifically model each of the strategies. Humphreys and Parker (2015) stated that a teacher asks for an answer until children provide no more responses, both when providing an answer to the number of dots and when explaining the strategy used. We adapted this process to ensure that children with ASD were active participants during this learning opportunity. We included the SLP to help support the children with ASD in their ability to respond to questions. We also added the modeling of the strategies to better support comprehension for children with ASD.

Specifically, the researcher used SLP to support children with ASD when they had difficulty responding to questions about the number of dots shown (i.e., Step 4) and explaining how they came to their answers (i.e., Step 5). The researcher initiated the hierarchy only if a child failed to respond to the original question. First, the researcher restated the question (Level 1). If the child did not respond, the researcher provided the child with three visual answer choices (Level 2). If the child still did not respond, the choice field was limited to two options (Level 3). If the child did not respond to the binary choice, the researcher guided the child's hand to choose the correct answer and asked them to repeat the answer (Level 4). Consistent with Number Talks, the researcher did not correct errors but considered these learning opportunities; therefore, they introduced the SLP only when the child failed to respond (Humphreys & Parker, 2015). For example, if the researcher asked 2 times, "How many dots are present?" and the child did not answer, they utilized the visuals. If the child then chose a visual, the researcher verbally modeled the choice, regardless of whether the response was correct, saying "Oh, you chose (number chosen). Say (number chosen)."

The learning opportunity occurred as the group discussed the answers, came to an agreement, and the adult modeled the effective strategies. That is, peers commented on each other's counting or subitizing strategies and indicated whether those strategies were successful or reasonable. The researcher helped to support the conversations by questioning and leading the children to discover the correct answers together. For example, if a child showed a counting strategy of touching the dots and counting but did not correctly touch all the dots, the researcher would ask questions like "What do you think about how (child name) counted?" If the child offered no response to this question, the researcher would ask more questions such as "Do you think (child name) counted all the dots?" or "What about this dot (pointing to missed dot). Did (child name) count this dot?" When a child proved a correct strategy, the researcher also asked questions to build the child's understanding such as "Hmm, I see (child name) started counting starting from the bottom and (another child name) started counting from the top. Does it change our answer depending on where we start counting?" We derived these questions from examples found in the book

Table 2. Number Talk Steps.

Step number	Step explanation		Step example	Connections to NCTM, DEC, and/or EBP for ASD
Step 1	Went to small table with only the iPad on the table		Made sure there were no papers, counters, or other items on the table	DEC: Students are working in small groups; engaging in materials
Step 2	Showed one of the three dot images on the iPad		 Parrish (2014)	NCTM standards: to compose and decompose numbers
Step 3	Students determined the number of dots and put a thumb up when done		The students are reminded to remain quiet and not shout their answers, but wait until everyone is ready	NCTM standards: to use mental mathematics to solve problems
Step 4	Students share how many dots they counted	Used the system of least prompts if needed for Steps 4 and 5	Use when students are unable to verbally answer, but not used if the answer is wrong	EBP for ASD: system of least prompts EBP for ASD: visual supports DEC: receiving the level of support needed and using systematic instruction
		1. Repeated question	How many dots are there?	
		2. Provided visual options	 One correct answer	
		3. Limit field to two choices	 One correct answer	
		4. Hand over hand support	Took the student's hand to support the student in choosing an answer	
Step 5	Students shared their strategies by verbally explaining or drawing on the iPad	Used the system of least prompts if needed for Steps 4 and 5	Use when students are unable to verbally answer, but not used if the answer is wrong	NCTM standards: proofs and reasoning DEC: receiving the level of support needed and using systematic instruction
		1. Repeated question	Can you show how you knew there were (the number stated by the child) dots?	
		2. Provided visual options	 All correct options	
		3. Limit field to two choices	 All correct options	
		4. Hand over hand support	Took the student's hand to support the student in choosing an answer	
Step 6	Teacher models effective strategies		The student says, "I counted like this" and points from left to right. The teacher says, "Oh you counted like this one, two, three, four" and points to each dot from left to right while counting. Then the students practice the strategy	EBP for ASD: explict modeling DEC: modeling and feedback
Step 7	Teacher helped the students compare answers		"Do you agree with how Chris counted the dots?" "Did everyone think there was the same number of dots?"	DEC: peer modeling and feedback
Step 8	Repeat Steps 2 through 6			NCTM standards: realted to ENS

Note. NCTM = National Council of Teachers of Mathematics; DEC = Division for Early Childhood's; ASD = autism spectrum disorder; ENS = early number sense; EBP = evidence-based practice.

Making Number Talks Matter by Humphreys and Parker (2015). The first author also used additional questions based on professional judgment.

Once the children attained consensus, the researcher modeled the correct answer by repeating strategies the children applied. For example, if there were four dots, the researcher said, "(Child name) counted the dots from left to right like this," and showed how they counted the dots. Then, the children practiced counting the dots using the same method. This occurred for each successful strategy discussed. In this way, children had the opportunity to attempt each successful strategy instead of only verbally hearing the strategy.

Maintenance. After meeting the mastery criteria of seven of eight correct on the probe for three consecutive sessions, the researcher removed the intervention and collected maintenance data once a week. The maintenance conditions mirrored the baseline conditions. We collected maintenance on two of the three children because the school year ended (3 weeks for Chris, 2 weeks for Laura).

Fidelity

The same two researchers who conducted IOA measured procedural fidelity across all conditions. Fifty percent of intervention sessions were randomly selected and coded for procedural fidelity using a checklist of intervention steps (i.e., the steps of Number Talks) and the correct use of the SLP. The first author trained the researchers using video recordings of Number Talk sessions. We coded video recordings until 100% reliability occurred. Procedural fidelity was 100% for Chris, 95% (range = 90%-100%) for Laura, and 94.7% (range = 90%-100%) for Jessica. We took fidelity on 30% of the probes in both baseline and intervention conditions. These probes were randomly selected and coded for fidelity based on a checklist. Fidelity was 96% in baseline (100% for Chris, 95% for Laura, and 93% for Jessica) and in intervention 96% (100% for Chris, 93% for Laura, and 94% for Jessica).

Data Analysis

We analyzed the data for formative visual analysis both within conditions and adjacent conditions (Barton et al., 2018). Features included for within conditions are changes in level, changes in trend, and variability. For adjacent conditions, features include changes in data patterns, immediacy of change, and overlap (Barton et al., 2018).

Results

Figure 2 illustrates the number of correct items on the probe in baseline and intervention sessions for each participant. This section provides the results by participant that indicate an immediate positive change. The data are consistent across all three participants. That is, the data show a consistent change in level immediately after introducing Number Talks. An increasing trend followed this immediate level change, and there was no overlap between baseline and intervention data points.

Chris

During baseline, Chris ranged from one to three correct responses indicating some variability. The graph indicates an immediacy of effect with a change in level as Chris correctly responded to five items on the probe after the intervention. Chris' correct responses trended upward until he correctly responded to all questions in Session 5. No overlapping data points occurred between baseline and intervention. Although Chris met mastery criteria after his sixth intervention session, he did have one extra day of intervention before entering the maintenance condition. After withdrawing intervention, Chris maintained mastery-level performance for three maintenance sessions.

During baseline, Chris's correct responses varied, but were most frequently subitizing Numbers 1 to 3 and occasionally an item addressing number conservation or magnitude discrimination. During intervention, the task that Chris continued to miss on the probe was subitizing Numbers 4 to 6. On these items, Chris demonstrated perceptual subitizing (i.e., seeing six dots and responding three and three dots), but he did not conceptually subitize (i.e., combining the three and three dots to say there are six dots).

Throughout the intervention, Chris required minimal levels of prompting (i.e., only Levels 1 and 2 of the SLP). Initially (first three sessions), the first level of the SLP (i.e., repeating the question) was required for Chris to respond to questions, and the researchers applied the second level only once in the first session. By the fourth session, Chris independently answered questions consistently without any prompting.

Laura

Laura demonstrated some variability in responding during the baseline condition with correct responses ranging from two to four. After the introduction of the intervention, the data showed an immediate effect and a change in level as Laura correctly responded to six items on the probe including all items except those requiring subitizing. Laura continued to trend upward until she met mastery criteria after four sessions, and she maintained this level of mastery after removing the intervention. However, with only two data points in maintenance, it was not clear about whether this trend would have continued.

Laura correctly answered one-to-one correspondence counting questions during baseline and occasionally magnitude discrimination items. There were no overlapping data points between baseline and intervention.

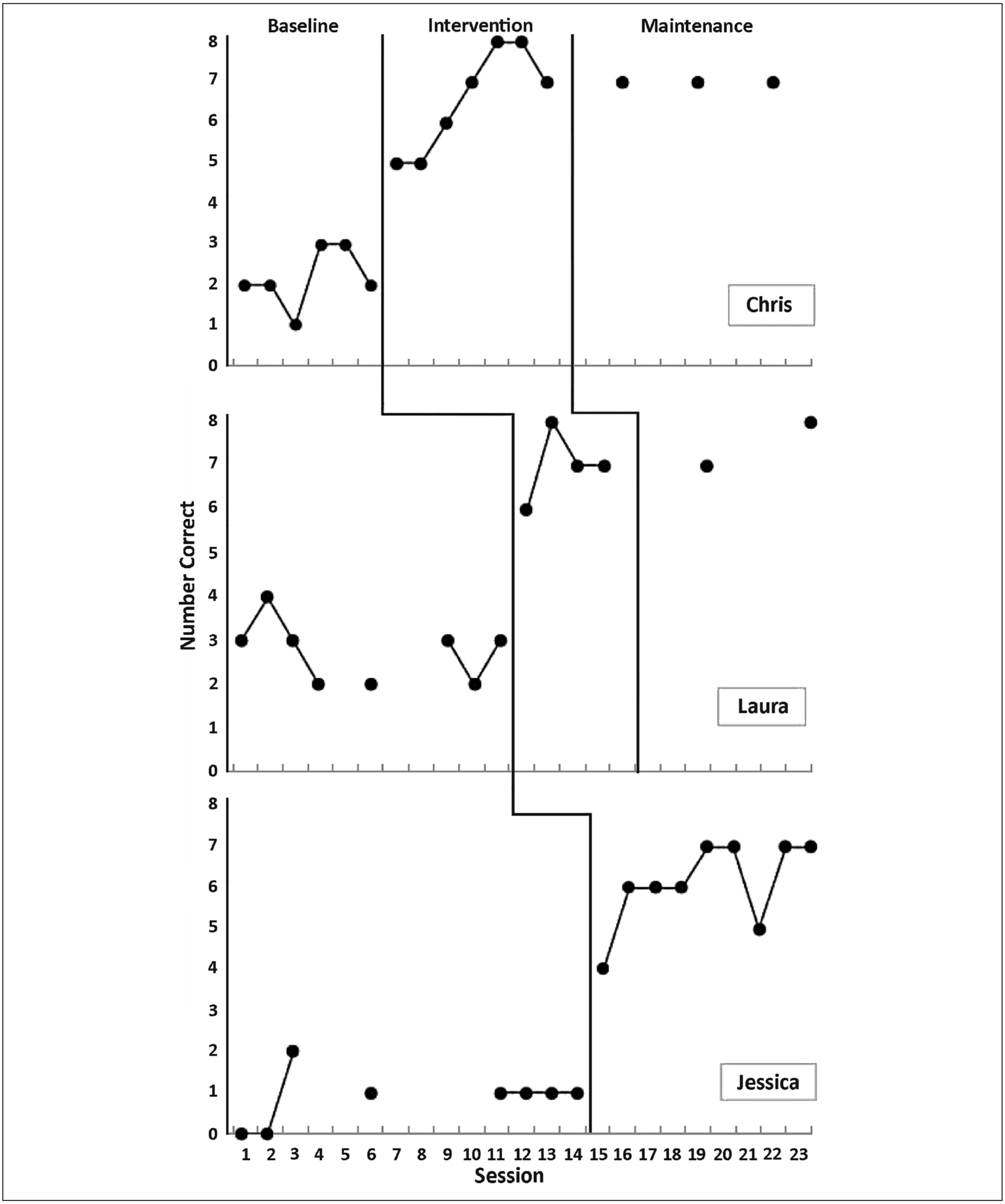


Figure 2. Number of correct responses on probe.

Laura required little prompting throughout the intervention. The SLP Levels 1 and 2 were initiated only in the first three sessions. Laura consistently responded to questions without any prompting after the third session.

Jessica

Jessica's correct responses in baseline ranged from zero to two, suggesting some variability, which stabilized after three sessions. Researchers did not continue the probe sessions after this initial upward trend because Jessica was absent from school. Jessica's correct responding immediately increased to four items after the intervention, and data trended upward to seven correct responses after five sessions indicating a change in level and trend. There were no overlapping data points between baseline and intervention. Jessica reached mastery criteria for four sessions but not for three consecutive sessions. It was not possible to continue collecting data as the school year ended.

In baseline, Jessica often correctly answered one-to-one correspondence counting (Numbers 1–5) items correctly, and she answered a magnitude discrimination item correctly once. During intervention, Jessica continued to respond to subitizing four to six items incorrectly.

For the first three sessions, Jessica needed the SLP (Levels 2 and 3) to respond to questions. Over time, prompting faded. Jessica needed SLP Level 2 occasionally over the next four sessions, and in the final two sessions, Jessica responded to all questions spontaneously without any prompting.

Discussion

We investigated the impact of adapted Number Talks on the number sense skills of preschoolers with ASD. The results indicate that adapted Number Talks successfully increased the ENS skills of three preschool children with ASD. This clinically significant change, observed in all three participants, was shown to be a direct result of the conversations involved in Number Talks with the added adaptions of ensuring all children answer, providing the SLP, utilizing visuals, and modeling of the mathematical language. The use of SLP, visuals, and modeling to support the ENS learning of children with ASD is consistent with previous research (Jimenez & Kemmery, 2013; Root et al., 2019) and shows the effectiveness of these strategies paired with a socially constructed learning opportunity with preschool children. This study is an example of how materials created for the general population can be implemented with adaptations to successfully affect the learning outcomes of children with disabilities.

One of the participants, Chris, struggled at first with the process of Number Talks. At the beginning of intervention, Chris became upset if the number of dots counted was not four (i.e., yell and insist the number of dots was four even after having counted with the group a different number of dots). Later he started to say, "It is not four." By the end of intervention, Chris counted independently and corrected his own and his peers' errors. For example, he said, "That's not right; you missed one."

Two children continued to demonstrate ENS skills after intervention was removed for two to three sessions (with one reaching maintenance criteria), whereas the third child was not observed without intervention (i.e., maintenance) due to the school year ending. Moreover, the findings suggest that children with ASD required varying levels of support, and their need for support faded quickly (e.g., a decrease in the use of the SLP by Sessions 3–7). The goal of SLP is to allow the child to be as independent as possible with the eventual goal that prompting is no longer needed (Walte et al., 2017). In this case, when the researcher provided the children with opportunities to practice and model the language necessary to engage in mathematical discourse, they quickly began to utilize these skills in future sessions, and therefore, the SLP was no longer needed.

In this study, perceptual subitizing was evaluated rather than conceptual subitizing due to the age of the children. In perceptually subitizing, a child immediately knows the number of dots (i.e., there are two dots or for numbers above three decomposing the number such as for four, there are two and two dots). When a child uses conceptual subitizing, they can internally compose the parts of a number (i.e., realizing that two and two dots make four; Clements, 1999). None of the children conceptually subitized Items 4 to 6 consistently, although they demonstrated some growth. The process of composing parts of numbers may require more time and practice to acquire and children do not typically master this until kindergarten or first grade (Clements, 1999). Therefore, the children received full points for answering subitizing Questions 4 to 6 with perceptual subitizing (i.e., if four dots are shown, the child could answer two and two dots, or if six dots are shown, a child could answer three and three dots) instead of requiring them to provide a conceptually subitized response/number. Even with this acceptance of perceptual subitizing, it was still a struggle for Laura and she only correctly answered once.

This study bridges two often seemingly incompatible instructional practices. In this study, we adapted Number Talks strategies and combined it with systematic instruction. This allowed a combination of children constructing knowledge together with the support of explicit modeling to enhance understanding and participation of children with ASD. This intervention research started with NCTM (2000) standards and then embedded evidence-based practices known to support the learning of children with ASD (i.e., prompting hierarchies/SLP, and explicit modeling; Wong et al., 2015). NCTM standards (2000) for preschool children addressed by Number Talks are the number and operation standards as well as the reasoning and proof standards

(Parrish, 2011). Number Talks address the standards for reasoning and proof through mathematical conversations that occur as children share and discuss their strategies with peers. In Number Talks, researchers treated wrong answers as learning opportunities to better understand child thinking, so children increase their ability to learn (Parrish, 2014).

This concept of learning implicitly through peers can be viewed as contrasting with explicit instruction. Although children with ASD learned ENS skills with occasional support of the SLP, they did not consistently need this support. The SLP was faded completely for all three participants by their final two intervention sessions. In other words, the children learned these skills implicitly through peer discussion and modeling with the support of the researcher, who modeled the effective strategies generated by the children with ASD and their peers. Thereby, the process used in this study alleviated the need for an SLP. Consequently, this aligned with previous research as King and colleagues (2016) found that the majority of the studies effectively used SLP to teach mathematics to children with ASD.

Moreover, even though the intervention approach was systematic, flexibility was modeled by demonstrating different problem-solving processes used by children with ASD and their peers. Through the discussion of the various strategies within the Number Talks sessions, children observed that the problems had multiple correct answers. The small group learning with peers supports the joint statement by NAEYC and NCTM (2010) and DEC recommended practices in instruction and interaction (DEC, 2014). We found our approach was feasible and effective, as participants with ASD increased their ENS understanding.

Implications for Future Practice

Mathematics in the classroom is changing from being taught in a rote procedural way to expecting children to have a deep conceptual understanding of numbers, including number sense, to meet NCTM standards (2000). The ENS skills that children learn in preschool are predictive of their mathematical abilities later in life (Carlson et al., 2011). For children with ASD who are struggling to learn number sense skills, this adapted version of Number Talks can potentially support them to gain a deeper conceptual understanding of essential ENS skills. This study also provided support for ENS learning with peers. Practitioners can support the ENS learning of children with ASD during activities involving conversations with peers. For example, if children can explain their thinking by saying, "I just counted them all in a row," the practitioner can model for the children specifically how to count in this manner so all understand the concept. The teacher can model by touching and counting the dots in a row, then talking about how the child counted starting on the left and moving to the right while pointing to the dots. Such mathematical discourse involves the social communication skills children with ASD often have trouble developing and could potentially create an opportunity to improve not only their mathematical ability but also their social communication skills.

Limitations and Future Research

One limitation in this research is that, although the children all improved their ENS skills, they did not consistently answer questions using conceptual subitizing. Instead, these children used perceptual subitizing. Future research should address whether more explicit instruction, time, or maturity is needed to effectively learn the skill of conceptual subitizing.

This study specifically addressed children with limited support needs in the area of communication. Future research should include children with more limited communication skills to assess what kinds of supports would be appropriate for these children to effectively learn through adapted Number Talks.

Because the school year ended, the teachers were unavailable for interviews about the impact of the intervention, and we collected maintenance short term for only two participants. Additional social validity data are important to assess the value and usefulness of the practices with practitioners. The conclusion of the school year also limited the amount of maintenance data we were able to collect. We collected three data points for Chris, two for Laura, and did not collect maintenance data for Jessica. Follow-up data are needed to determine whether children maintain their gains in the long term.

In this study, the first author led the adapted Number Talks sessions and collected probe data. Future research should investigate the feasibility of classroom teachers or paraprofessionals implementing Number Talks in similar small group contexts. IOA was collected on 50% of probe sessions and demonstrated high rates of reliability indicating little bias (IOA range: 87.5%–100%). However, because the interventionist collected the data, ideally, IOA should have been collected for 100% of the sessions. Finally, researchers should adapt the measures to include more response options as some of the variability in the data may reflect children randomly choosing the correct answer from a binary choice (e.g., magnitude discrimination questions).

Conclusion

NCTM (2000) indicated the need for children to construct their knowledge to gain a deeper understanding that leads to better generalization. This is echoed by what is considered appropriate practice in early childhood education (NAEYC, 2009). Yet, research shows that children with disabilities often need the support of explicit instruction (Doabler & Fien, 2013). This study demonstrated how teachers can align these approaches by having children with ASD participate in small group adapted Number Talks and providing the children with the needed supports to increase their understanding. The researcher used adapted Number Talks to include the explicit instruction techniques of modeling, an SLP, and visual supports. The children had the opportunity to learn implicitly by constructing their knowledge during adapted Number Talks with embedded evidence-based practices to support their participation and learning. This combination of implicit and explicit teaching was successful in teaching ENS skills to all three participants with ASD.

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