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Building the Early Number Sense of Kindergarteners With Autism: A Replication Study

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Abstract

This study reports findings of a systematic replication and as such sought to evaluate effects of an early numeracy curriculum on early number sense attainment for Kindergarten students with autism. Through daily 15-min story-based math lessons with embedded systematic instruction delivered by their classroom teacher, participants learned to compare sets, identify and work with patterns, and use standard and nonstandard measurement, and calendar skills. Results indicate a functional relation between the intervention and early number sense, and students were able to generalize skills when systematic instruction was faded. Similar results were mirrored by pre–post standardized norm-referenced measures of early mathematics abilities. Implementation of the curriculum had positive results on the teacher's perception of self-efficacy. The study's contribution to research, recommendations for practice, and implications for future research are discussed.

Keywords

autism, mathematics, early numeracy, general curriculum access, early number sense, systematic replication

Early number sense is the broad term used to refer to learned skills that involve explicit number knowledge, such as counting items using number words and comparing numbers (Whitacre, Henning, & Atabas, 2017). These skills include number recognition, counting, number patterns, number comparison, number operations, and estimation (Whitacre et al., 2017). Also called early numeracy, early number sense is fundamental for advanced knowledge in mathematics and has long been associated with student future math performance (Jordan, Kaplan, Ramineni, & Locuniak, 2009; Jordan & Levine, 2009). In fact, mathematical skills at Kindergarten entry may be the strongest predictors of both later reading and mathematics achievement (Duncan et al., 2007). Without a firm foundation of early number sense, learners struggle with both acquiring and generalizing future mathematical learning (Jordan et al., 2009).

Although some children acquire early number sense implicitly in early childhood through conversations and activities (Sarama & Clements, 2009)—for example, learning to subitize while sharing food items in the dramatic play center (i.e., quickly recognize three bananas without counting them individually)—many children require specific instruction to develop these skills (Andrews & Sayers, 2015). Students from lower socioeconomic backgrounds (Jordan & Levine, 2009), with or at risk for a mathematical learning disability (Gersten et al., 2009), and students with disabilities, including students with autism, are more likely to have difficulties developing early number sense (Oswold et al., 2016; Titeca, Roeyers, Josephy, Ceulemans, & Desoete, 2014). Furthermore, recent research has shown children with disabilities enter Kindergarten with less number sense skills than typically developing peers and demonstrate less growth than children without disabilities (Hojnoski, Caskie, & Young, 2018).

Educators and researchers have long valued intensive instruction to build early number sense, especially in elementary school, due to its strong correlation with student math achievement in later years (Duncan et al., 2007). In a recent study by Shanley, Clarke, Doabler, Kurtz-Nelson, and Fien (2017), the relationship between early number sense skill attainment and mathematics achievement across Kindergarten and first grade was investigated for students who were identified as "at-risk" for mathematics difficulties. Students in the experimental group who received explicit

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teaching of number skills demonstrated larger gains in relationship to early number sense. In addition, those students who performed higher in early number sense assessments continued to perform higher the following year on math assessments. These findings suggest that interventions designed to meet the specific instructional needs of students struggling with early number sense have the potential to offset later mathematics difficulties. Titeca et al. (2014) found both counting and subitizing to be strong predictors of first-grade mathematics skills, highlighting the critical need for building up mathematical skills of young children.

The math achievement profile of individuals with autism is highly variable, yet large-scale achievements have found underachievement relative to cognitive ability (Charman et al., 2011). School-age students with autism often struggle with problem solving and are more likely to have skills representative of having a mathematical disability (22%) than mathematical giftedness (4%) (Oswald et al., 2016). Providing young children with autism a strong foundation in early number sense may minimize some difficulties related to mathematics learning.

One intervention that has a growing body of research-based support for increasing early number sense is the *Early Numeracy* curriculum (Jimenez, Browder, & Saunders, 2013). A number of different theories and evidence-based practices were combined to create the *Early Numeracy* curriculum. The skills addressed throughout *Early Numeracy* are based on a conceptual model by Browder et al. (2012) that outlines the use of research-based early numeracy skill trajectory (Sarama & Clements, 2009). This model centers on four components: (a) target early math skills based on research on mathematical learning, (b) use systematic prompting and feedback, (c) provide embedded instruction, and (d) vary small group instruction using a math story. Established evidence-based practices for students with severe disabilities (Browder, Spooner, Ahlgrim-Delzell, Harris, & Wakeman, 2008) were used to develop the strategies used to early numeracy skills. Recent reviews support the embedded instructional strategies of prompting, modeling, positive reinforcement, and manipulatives as effective in teaching mathematics skills to learners with autism (King, Lemons, & Davidson, 2016; Spooner, Root, Saunders, & Browder, 2019).

To date, four single-case design studies have found *Early Numeracy* to be effective in increasing the early number sense of students with autism who have comorbid intellectual disability (Jimenez & Barron, 2018; Jimenez & Besaw, in press; Jimenez & Kemmery, 2013; Jimenez & Staples, 2015). In the foundational single-case research study, Jimenez and Kemmery (2013) investigated the effects of the curriculum on early number sense attainment for five elementary students with moderate intellectual disability, including two with comorbid autism. A single-case multiple probe across classrooms design was employed to evaluate the intervention package. Results found that all students showed a substantial increase in early numeracy skill acquisition after receiving the intervention package. As a spectrum that includes students with a wide range of abilities and a documented uneven cognitive profile (Charman et al., 2011), it is particularly important when interpreting the literature to consider "what works for whom" in analyzing the characteristics of included participants and making inferences of generalization.

A recent special issue of *Remedial and Special Education* highlighted the role of systematic replications to tease out answers to this very question. According to Makel et al. (2016), replication is key in determining the contextual and instructional dimensions to which the effects of an intervention may generalize, including across participants and settings. The accumulation of research resulting from systematic replications, be it comprised of convergent or parallel findings across varying procedures, techniques, measurement systems, and samples, answers the question of generality (Jones, 1978). In the era of evidence-based practice for students with severe disabilities, including autism, it is particularly important to use rigorous experimental designs to tease out the factors that produce or do not produce outcomes at individual levels, furthering our understanding of the variables that may or may not affect the effects of given procedures (Courtade, Test, & Cook, 2014).

Analysis of existing research on the effects of *Early Numeracy* highlights the need for expanded measurement systems and inclusion of additional disability groups. What is not yet known from the existing research on *Early Numeracy* is its efficacy for young students with autism who do not have a comorbid intellectual disability or do not take the alternate assessment aligned with alternate-achievement standards (AA-AAS). In addition, researchers across all five studies relied on a single measure of early number sense (i.e., the *Early Numeracy Assessment* [EN-A]). As a result, the effects of the curriculum on daily performance during instruction, impact of learning on standardized measures of number sense, and generalization are largely unknown.

The purpose of this study was to conduct a systematic replication of Jimenez and Kemmery (2013) to expand the research base related to early number sense interventions for students with autism who do not have a comorbid intellectual disability. A secondary purpose was to determine whether students with autism were able to generalize early number sense skills when the systematic prompting was faded during teacher-delivered lessons.

Method

Student Participants

Students had to meet the following criteria for inclusion in the study: (a) medical diagnosis of autism, (b) enrolled in

Kindergarten, and (c) limited early numeracy skills as measured by a score below the 25th percentile on the *Test of Early Mathematics Ability–3rd Edition* (TEMA-3; Ginsburg & Baroody, 2003). After consent was obtained, the TEMA-3 and EN-A were administered by a researcher (second author) who had experience administering standardized tests to young children with autism. Three students who met inclusion criteria were selected to participate.

Ted was a 6-year-old White male with a diagnosis of autism from a physician. Ted was very social with peers and adults within the classroom. According to the TEMA-3, Ted had an overall math ability score of 79 (within the 8th percentile of same-aged peers) pre-intervention with strengths in counting numbers, identifying numbers, and writing numbers. Weaknesses prior to intervention were in the areas of adding small quantities, cardinality, and whole to part relationships. Nick was a 6-year-old Black male with a diagnosis of autism from a physician. According to the TEMA-3, Nick had an overall math ability score of 76 (within the 5th percentile of same-aged peers) pre-intervention with strengths in the areas of counting and identifying numbers and weaknesses in the areas of adding small quantities and whole-to-part relationships. Josh was a 6-year-old White male with a diagnosis of autism from a physician. According to the TEMA-3, Josh had an overall math ability score of 60 (<1st percentile of same-aged peers) pre-intervention with strengths in the areas of identifying numbers, identifying magnitudes, and counting quantities to five and weaknesses counting quantities up to 10 and cardinality.

Setting

This study took place in a Kindergarten classroom at a small private school for students with autism. Majority of instruction in the classroom was based upon one-on-one programming created specifically for each student by a Board Certified Behavior Analyst (BCBA). Whole group instruction did occur during circle time where math-related content typically included counting how many days were in the month, and singing and dancing to math-related songs. Math centers occurred daily, in which students rotated between one-to-one instruction with the teacher or assistant on individual math goals using discrete trial training, independent worksheets, or computer games. Students remained in each math center for approximately 10 min before rotating to the next. The teacher implemented the early numeracy intervention individually with participants when they rotated to her math center.

Interventionist and Assessors

All intervention sessions were implemented by the participants' classroom teacher during math center time. Ms. Baker was a Black female with 12 years of experience working with children with disabilities in a variety of capacities. She had bachelor's and master's degrees in social work, and a master's degree in applied behavior analysis. Ms. Baker collected all intervention (EN-I) data.

Assessment data were collected by three different individuals (hereafter referred to as research staff) who had been trained in use of the assessment. The second author, a White female doctoral candidate who was also a former special education teacher, supervised both the implementation of the intervention and other research staff in administering and coding the assessment. Other research staff included a Hispanic female graduate student who was enrolled in a master's degree program in special education and a White female undergraduate student who was a child development major and part of an undergraduate research program.

Independent Variable

The independent variable was the *Early Numeracy* curriculum (Jimenez et al., 2013). There are four units of instruction in the curriculum, each of which addresses seven early numeracy domains: (a) counting, (b) sets, (c) symbol use, (d) patterns, (e) measurement, (f) calendar, and (g) numeral identification (see Table 1). The four units are thematic (i.e., math is everywhere, math at celebrations, math in nature, math + me = fun), and the five lessons within each theme use math stories and manipulatives related to the theme to address skills within each of the seven early numeracy domains. For example, in Unit 3 (math in nature), when the story was about math in the garden, students were provided with small plastic worms as manipulatives. Some student and teacher materials for the curriculum remained consistent across lessons and themes, such as set makers, line counters, and a pattern maker. For additional information on materials included in the curriculum, see Jimenez and Kemmery (2013).

The five lessons within each unit are of equal difficulty, but the order of presentation of the targeted early numeracy skills (as shown in Table 1) are randomized, meaning the order in which they were presented within each lesson varied. Skills progress in difficulty across units (see Table 1). For this study, the fifth lesson in each unit was modified by redacting all explicit and systematic instruction by marking it out with a black marker—otherwise, it followed the same format as Lessons 1 to 4. These redacted lessons (hereafter referred to as generalization lessons) were then used to measure stimulus generalization (see "Procedures" section for more information).

Ms. Baker was trained in the use of the *Early Numeracy* curriculum on an evening after school by the first author. The training lasted approximately 1.5 hr and included modeling and role-playing, with multiple opportunities to practice each instructional strategy. After the training, the

Table 1. Skills of *Early Numeracy* Grouped by Domain and Unit.

Domain	Unit 1	Unit 2	Unit 3	Unit 4
Counting	1. *Count 1 to 5 movable objects in a line.* 2. *Count 1 to 5 nonmovable objects in a line.* 3. *Rote count from 1 to 5.*	1. *Count out 1 to 5 movable objects from a group.* 2. *Count 1 to 5 scattered, nonmovable objects.* 3. *Rote count from 1 to 10.*	1. *Count 1 to 10 movable objects in a line.* 2. *Count 1 to 10 nonmovable objects in a line.* 3. *Rote count from 1 to 15.*	1. *Count out 1 to 10 movable objects from a group.* 2. *Count 1 to 10 scattered, nonmovable objects.* 3. *Rote count from 1 to 20.*
Set	4. *Make sets of 1 to 3.* 5. Add premade sets with sums to 5.	4. *Make sets of 1 to 4.* 5. Add sets with sums to 5.	4. *Make sets of 1 to 9.* 5. Add sets with sums to 10.	4. *In context, make sets of 1 to 9.* 5. In context, add sets with sums to 10.
Symbol Use	6. Compare sets for same/equal. 7. Identify the symbol for equals (=).	6. Compare sets for greater than. 7. Identify the symbol for greater than (>).	6. Compare set for less than. 7. Identify the symbol for less than (<).	6. Compare sets and numbers for equal, greater than, and less than. 7. Use symbols for equal, greater than, and less than.
Patterns	8. Identify an ABAB pattern.	8. Extend an ABAB pattern.	8. Create an ABAB pattern.	8. Complete an ABAB pattern with missing components.
Measurement	9. Use a nonstandard unit of measurement to measure 1 to 5.	9. Use a standard unit of measurement to measure 1 to 5 inches.	9. Use a standard unit of measurement to measure 1 to 10 inches.	9. Convert inches to feet.
Calendar	10. Identify dates from 1st to 5th on a calendar. 11. Identify 1 to 5 days later in a week using a calendar.	10. Identify dates from 1st to 5th on a calendar. 11. Identify 1 to 10 days later across 2 weeks using a calendar.	10. Name dates from 1st to 5th on a calendar. 11. Identify 1 to 10 days later across 2 weeks using a calendar.	10. Name dates from 1st to 10th on a calendar. 11. Identify 1 to 10 days later across 3 weeks using a calendar.
Number Identification	12. *Identify numerals 1 to 5.*	12. *Name numerals 1 to 10.*	12. *Name numerals 1 to 5.*	12. *Name numerals 1 to 10.*

Source. Adapted from *Early Numeracy Curriculum* (Jimenez, Browder, & Saunders, 2013) scope and sequence.
Note. Italicized items were not included in the assessment for this study.

second author supported her during the first day of teaching and biweekly throughout the study to address fidelity of implementation.

Dependent Variables and Measurement

Three dependent variables were measured throughout the study. The primary dependent variable was percent of early number sense skills mastered during the EN-A from the *Early Numeracy* curriculum. This assessment is intended to be used as curriculum-based measure (CBM), though technical adequacy has not been formally established. Adaptations to the assessment included removal of all skills students had demonstrated mastery of during the pre-screening (i.e., rote counting, making sets, one-to-one correspondence, and number identification). Assessors from the research team administered the assessment during math centers 2 to 3 days per week. Four versions of the assessment were created to control for threats to internal validity (i.e., testing effects). Each assessment contained a total of 32 items across seven domains: (a) adding sets, (b) comparing sets, (c) identifying symbols, (d) patterns, (e) measurement, (f) identifying and naming dates on a calendar, and (g) identifying later dates on a calendar. The assessment contained multiple items for each domain, which aligned with each unit of instruction (see Table 1) to measure both receptive and expressive demonstration of the concept. For example, when asked about dates on a calendar, students were asked to point to a date named by the assessor (i.e., point to the five, find the fifth) and also to name a date pointed to by the assessor (i.e., assessor points to the fifth and participant says five).

Basal and ceiling rules were put in place to increase efficiency of the assessment and decrease testing fatigue (Jimenez & Kemmery, 2013). If a participant had correctly answered a question for two consecutive sessions, it was skipped in future sessions as it was assumed to be mastered (and therefore counted as correct). If a student answered two questions incorrectly in a domain within a session, the

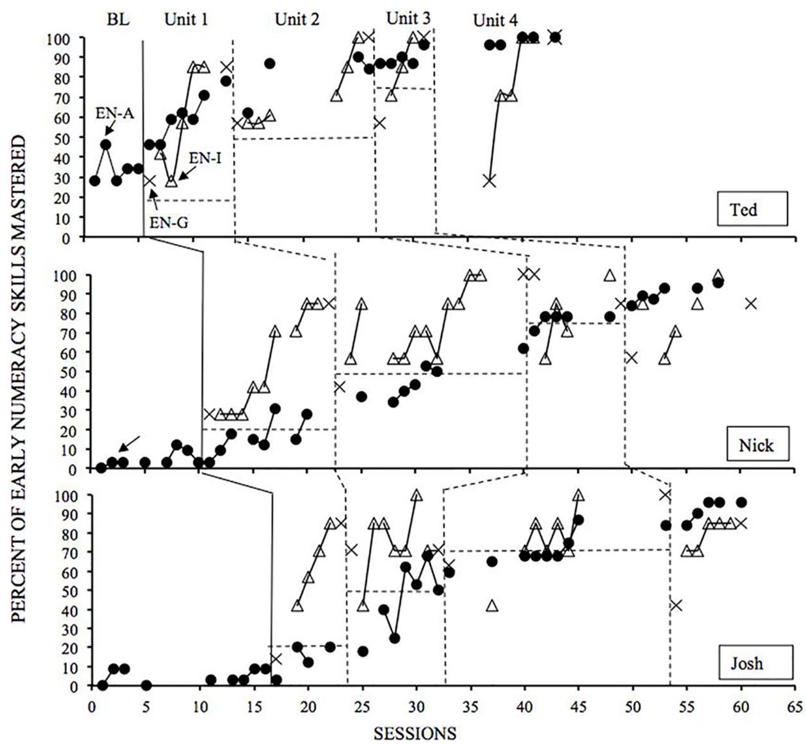

Figure 1. Percent of early number sense skills mastered across units across participants.
Note. Closed circles represent assessment data (EN-A; primary dependent variable), open triangles represent instructional data (EN-I), and hash marks represent generalization data (EN-G). Horizontal lines represent mastery criteria for the unit based on the percent of skills taught during that unit.

research staff moved to the next domain, as it was assumed they had reached a ceiling and would be unable to answer subsequent more difficult questions within that domain. Mastery criteria were set for each unit and had to be achieved for 2 days before progressing to the next unit or concluding the intervention. A total of 32 points were available on the EN-A in each session, and participants were expected to earn seven out of 32 possible points to master Unit 1 (20%), 16 out of 32 possible points to master Unit 2 (50%), 23 out of 32 possible points to master Unit 3 (75%), and 30 out of 32 possible points to master Unit 4 (93%). The mastery criterion for each unit is indicated by horizontal dashed lines in Figure 1.

The secondary dependent variable was percent of early number sense skills mastered during instruction (EN-I) with the *Early Numeracy* curriculum. See Table 1 for the skills assessed across each domain and unit. Students had one opportunity to demonstrate each skill in each lesson, though the order of presentation differed across lessons (e.g., Unit 1 Lesson 1 started with Skill 6 and Unit 1 Lesson 2 started with Skill 7). The teacher took data during instruction each day on whether the student performed each of the seven targeted skills independently correct the first time the skill was presented during the lesson. The number of skills performed independently correct was divided by the number of targeted skills (7) and multiplied by 100 to calculate the percent of early numeracy skills mastered during instruction. Participants had to earn a minimum of 6 points (85%) for 2 days during instruction to move to the next unit. The third dependent variable was generalization of early number sense skills (EN-G). This was measured using the same procedures as EN-I. No criteria for mastery were set, as one generalization lesson was conducted at the beginning and end of each unit.

Experimental Design

This study used a single-case multiple probe across participants design (Ledford & Gast, 2018). The implementation of the design adhered to the criteria established by the What Works Clearinghouse (WWC; 2017). The primary dependent variable was performance on the EN-A, as it was not possible to obtain baseline intervention (EN-I) data. There were two experimental conditions of baseline and intervention. Intervention spanned across four units of the *Early Numeracy* curriculum, as indicated in Figure 1 by vertical dashed lines. Authors chose to make response guided decisions (as opposed to using randomization) for phase changes (Ledford & Gast, 2018). The first participant entered intervention when he had a minimum of five stable baseline data points. The second participant entered intervention when there was evidence of a positive effect of the intervention on both EN-A and EN-I in the first unit for the first participant. This systematic introduction to intervention continued for the third participant. Participants progressed through units of intervention at their own pace depending on meeting mastery criteria on both EN-A and EN-I (as described above). Generalization was measured at the beginning and end of each unit to allow for correlational conclusions regarding changes in behavior (Ledford & Gast, 2018).

Procedures

Baseline. No formal curriculum was in place prior to beginning the study. During baseline, the students received their typical instruction as previously described. The assessment probes were administered during the math center time following the procedures outlined above.

Intervention. The intervention consisted of all four units of the *Early Numeracy* curriculum. The specific early numeracy objectives for each unit are listed in Table 1. The targeted skills within each unit remained the same across lessons, but the order was randomized. The teacher began each lesson by reading the thematic story. The teacher then re-read the story and followed the scripted lesson to use explicit instruction to first model targeted skills and then ask the students to perform the skill on their own. For example, when working on counting with one to one correspondence within a pirate themed lesson in Unit 1, the teacher is instructed to say,

> I can't remember how many coins the pirates found on their treasure hunt. Let's check by counting them on my line counter. Count with me: 1, 2, 3, 4, 5. Your turn. You count the coins on your line counter.

A system of least prompts was used to assist students when they were unable to make an independent response within 5 s by first providing a model, such as "Count like this: 1, 2, 3, 4, 5 (modeling moving coins across line). Your turn, you count." The second level of prompting in the hierarchy was physical, such as "Let me help you count (physically help student move coins on line counter) 1, 2, 3, 4, 5." A model prompt was used as an error correction. Behavior-specific praise was used throughout the lessons to reinforce correct responding and model academic language, such as "awesome counting."

The assessment probes were administered approximately 2 to 3 days per week in a subsequent math center by a member of the research team. Participants remained in a unit, repeating lessons if necessary, until they met mastery criteria for both EN-A (i.e., independent correct responding to items aligning with current and prior units, represented by horizontal dashed lines in Figure 1) and EN-I (i.e., answering 6/7 or 85% of the questions during instruction independently correct for two sessions).

Generalization. Lesson 5 from each unit of the *Early Numeracy* curriculum was used to measure stimulus generalization at the beginning and end of each unit. The teacher followed the redacted Lesson 5 script, reading the entire thematic story once, and then re-reading the story and asking students questions without providing models or prompts.

Post-testing. The TEMA-3 was individually administered to each participant at the conclusion of the study as a post-test of early number sense.

Reliability

To maintain reliability, interobserver agreement (IOA) was taken on assessment (EN-A), instructional (EN-I), and generalization (EN-G) sessions across phases for all participants. To meet WWC standards, IOA was collected for a minimum of 30% of sessions for each dependent variable and each participant. IOA was taken both in vivo and through video observation by members of the research team who were trained in assessment procedures.

Mean baseline IOA for EN-A was 100% for Ted (2/5 sessions), 100% for Nick (3/8 sessions), and 100% for Josh (3/9 sessions). Mean intervention IOA for EN-A was 100% for Ted (5/14 sessions), 97.23% for Nick (7/23 sessions), and 100% for Josh (5/20 sessions). Mean IOA for EN-I was 98.74% for 100% for Ted (3/18 sessions), 100% for Nick (10/32 sessions), and 95.86% for Josh (7/24 sessions). Mean IOA for EN-G was 99.65% for Ted (2/6 sessions), 98.05% for Nick (2/6 sessions), and 100% for Josh (2/6 sessions).

Procedural Fidelity

Research staff used a checklist to measure the degree to which the intervention was implemented as intended. The intervention checklist contained a total of 95 items including for each objective the need to use the correct materials, read the script, model, gain attention, provide cues, wait for student to respond, and prompt/praise. The generalization checklist was similar to the intervention checklist minus the items of providing cues, modeling, and prompting for each objective for a total of 43 items. Fidelity data were taken for 30% of both intervention and generalization sessions via live and video observations by the second author. The mean procedural fidelity in intervention was 98.8% for Ted (range of 97.70%–100%), 98.93% for Nick (range of 95%–100%), and 100% for Josh. The mean procedural fidelity for generalization was 97.5% for Ted (range of 95%–100%), 100% for Nick, and 97.6% for Josh (both fidelity scores were 97.6%).

Social Validity

Ms. Baker completed a social validity survey pre- and post-intervention to indicate her confidence and self-efficacy in developing the early number sense of her students. The social validity survey was modeled after the *Self-Efficacy for Teaching Mathematics Instrument* (SETMI; McGee & Wang, 2014) and contained 19 questions using a Likert-type scale (i.e., 1 = *not at all or not confident* and 5 = *a great deal or very confident*). A copy of the instrument is available from the first author upon request. She also participated in an interview with the first author with open-ended questions.

Results

Figure 1 shows the percent of early number sense skills mastered across units across participants as measured during assessment (EN-A), instruction (EN-I), and generalization (EN-G) sessions. All participants demonstrated a stable baseline. Upon beginning intervention in Unit 1, all participants increased both EN-A and EN-I. Generalization data held a consistent pattern across units and participants (shown by hash marks in Figure 1), as they each had initial EN-G scores in each unit at or below the first EN-I data point and final EN-G scores in each unit at or above mastery levels at the end of the unit. Visual analysis was completed by analyzing changes in level and/or trend and immediacy of effect between conditions for each participant as well as consistency of effect across participants. Visual analysis of the data in Figure 1 shows a functional relation between math instruction using the *Early Numeracy* curriculum and percent of early number sense skills mastered, as there are three demonstrations of effect at three different points in time. Each participant also showed improvement on the TEMA-3, as described for each participant below.

Ted demonstrated the strongest early number sense skills in baseline of the three participants, scoring an average of 34% across five baseline sessions for EN-A (range of 28%–46%), which was above the mastery criteria for Unit 1 (20%). Authors determined it was still necessary to begin intervention in Unit 1 to ensure Ted received instruction on critical foundation skills, as they sequentially build across domains through the four units. After receiving Unit 2 instruction, he demonstrated an immediate increase in level with an ascending trend on EN-A and reached mastery criteria after five sessions. Ted continued to make progress through the remaining three units of the curriculum, as demonstrated by an ascending trend in EN-A data in Figure 1. His EN-G data (hash marks in Figure 1) demonstrate a consistent pattern across all units of being below the first EN-I data point and at or above mastery criteria at the end of the unit. Ted's pre-intervention TEMA-3 score indicated he was in the 8th percentile for his age, and after 18 total intervention sessions, his post-intervention TEMA-3 score indicated growth to the 30th percentile.

Nick was the second participant to enter intervention after demonstrating a low and stable pattern of responding in baseline, scoring an average of 4.5% across eight sessions for EN-A (range of 0%–12%). Nick did not demonstrate an immediate change in level of EN-A on the first day in intervention when instructed with the generalization lesson, which did not contain any modeling or systematic instruction of skills. Nick did demonstrate a change in level and trend following instruction with the intervention lessons and met mastery criteria of Unit 1 after eight sessions. Analysis of Nick's progress in Figure 1 demonstrates a stable ascending trend in EN-A through the four units and he met overall mastery criteria after 27 total intervention sessions. His EN-G data replicate Ted's pattern of being at or below the first EN-I data point and at or above mastery criteria at the end of each unit. Nick's pre-intervention TEMA-3 score indicated he was in the 5th percentile for his age and after 32 intervention sessions rose to within the average range at the 47th percentile at the post-intervention TEMA-3 assessment.

Josh was the third and final participant to enter intervention after demonstrating a low and stable pattern of baseline responding, scoring an average of 5% (range of 0%–9%) across nine sessions for EN-A. Similar to Nick, Josh did not demonstrate an immediate change in EN-A following instruction with the generalization lesson in Unit 1. However, following instruction with the intervention lessons, he met mastery criteria of Unit 1 in four sessions. His progress on EN-A demonstrated a change in level and trend and he met mastery of the entire curriculum following 24 total intervention sessions across the four units. Josh's EN-G data followed the same pattern as Ted and Nick for all units with the exception of Unit 2, when he scored the same on both the first and last sessions (70%). Ted's score on the TEMA-3 prior to intervention indicated he was below the 1st percentile compared with other children his age, but following 24 intervention sessions, he grew to the third percentile.

Social Validity

Prior to intervention, Ms. Baker's responses to the social validity survey indicated she believed she could teach mathematics to her students, early number sense was important, and early number sense would affect her students both socially and educationally. These beliefs did not change post-intervention. In the post-test survey, Ms. Baker showed overall improvements in confidence in her ability to teach students early numeracy skills (3 pre to 4 post), develop math lessons that relate to students (3 pre to 4 post), and motivate her students (4 pre to 5 post). Her confidence in task analytic instruction improved (4 pre to 5 post).

Table 2. Study Dimensions That Were Held Constant and Intentionally Varied Between Systematic Replication and Initial Study.

Dimension	Jimenez and Kemmery (2013)	Current study (systematic replication)
Participants	N (Autism, Moderate ID) = 2 N (Moderate ID) = 3 Grades = 2nd–4th	*N (Autism) = 3* *Grades = Kindergarten*
Interventionist	Certified Special Education teachers • Received training prior to implementation • Fidelity of implementation taken during study by research staff	*Non-certified Kindergarten teacher* • Received training prior to implementation • Fidelity of implementation taken during study by research staff
Setting	Public elementary schools in southeastern United States	*Private school for students with autism in southeastern United States*
Instructional format	Dyads	*1:1*
Intervention	Early numeracy • Units 1–2 • Lessons repeated for 3 days	Early numeracy • *Units 1–4* • *Lessons changed daily*
Outcome measures	Early Numeracy assessment • Biweekly by research staff • Two versions • Basal and ceiling rules	1. Early Number Sense using Early Numeracy assessment • *2–4 times per week by research staff* • *Four versions* • *Basal and ceiling rules* *2. Early Number Sense during intervention* *3. Early Number Sense Generalization* *4. Distal Measure of Early Mathematics Ability (TEMA-3)*
Research design	Multiple probe across participants design • Meets What Works Clearinghouse Standards With Reservations	Multiple probe across participants design • *Meets What Works Clearinghouse Standards Without Reservations*

Note. Italics indicate items that were intentionally varied. ID = intellectual disability; TEMA-3 = *Test of Early Mathematics Ability–3rd Edition*.

However, her confidence in least intrusive prompting and early number sense skill progression decreased (4 pre to 3 post).

During the post-intervention interview, Ms. Baker reflected on the overall impact *Early Numeracy* had on both her instruction and student learning. She felt the curriculum streamlined mathematics instruction and improved her systematic instruction and attention to individual student instructional needs. She observed students gain confidence and decrease dependency on prompts. Relatedly, she observed students spontaneously generalize skills in natural settings. For example, she shared that Ted commented on seeing an ABAB pattern on a bulletin board in the hallway and his mother reported a new interest in measuring things at home.

Discussion

The purpose of this study was to conduct a systematic replication of Jimenez and Kemmery (2013) by altering the targeted population and refining measurement systems. Through daily implementation of the *Early Numeracy* curriculum by their classroom teacher over the course of 4 months, Kindergarten students with autism gained early number sense skills. Visual analysis of the graphed data indicates a functional relation between *Early Numeracy* and the percentage of early numeracy skills mastered. All three participants demonstrated growth during both measures (assessments and instruction) and were able to generalize skills when systematic prompting was faded. Completion of the *Early Numeracy* curriculum resulted in an increase in standardized early mathematics scores as measured by the TEMA-3.

Replication studies increase scientific credibility of findings, as they examine the validity of prior research through subsequent similar investigations (Coyne, Cook, & Therrien, 2016). Replication in single-case research provides the field with knowledge on how an intervention works for individuals under specific varied conditions (Travers, Cook, Therrien, & Coyne, 2016). We will discuss our findings in terms of the dimensions that were held constant and those intentionally varied between Jimenez and Kemmery (2013) and the current study as recommended by Coyne et al. (2016), as shown in Table 2.

The primary purpose of this systematic replication was to provide evidence of external validity of the intervention for students with autism. Autism is a heterogeneous condition with great variability within complexity of needs and developmental trajectories, including comorbidity (e.g., intellectual disability). Therefore, we intentionally varied participant characteristics, including age (i.e., younger students) and diagnosis (i.e., autism without intellectual disability). This allowed us to investigate the effect of the intervention under specific varied conditions, as suggested by Travers et al. (2016). Although prior research has found *Early Numeracy* to be effective for teaching early number sense to students with autism who have a comorbid intellectual disability (e.g., Jimenez & Barron, 2018; Jimenez & Besaw, in press; Jimenez & Kemmery, 2013), by varying the participant characteristics this study supports its efficacy for students with autism without comorbid intellectual disability. Relatedly, this study evaluated all four units of the curriculum, whereas no prior study has completed more than two units due to time restrictions (i.e., end of school year) and the amount of intervention (i.e., rate of progress within learning progression) needed to meet established mastery criteria. Differential effects may be due to participant variables that influence dosage and expected outcomes.

Although the primary outcome measure among the research supporting *Early Numeracy* has remained student performance on the EN-A, the design of the current study varies from Jimenez and Kemmery (2013) in the following ways: (a) assessment of early number sense skills during instruction, (b) measurement of generalization, and (c) distal measure of mathematics ability. This variation in measurement is of theoretical importance and answers questions of generalization of skills. The EN-A is in itself a measure of generalization, as it measures demonstration of skills in an environment which differs from the one in which instruction took place (Stokes & Baer, 1977). Prior studies have not simultaneously utilized a distal and proximal measure of early number sense skill acquisition (i.e., instructional data). The current study measured and used both to determine mastery within each unit. Similarly, authors sought to determine whether instructional supports (e.g., prompting, modeling) could be faded once mastery criterion had been met. This novel question of generality had not been addressed by prior studies and was of value to the participants in this study, as their teacher was focused on providing them with the skills necessary to be successful in less restrictive (i.e., general education) settings in the coming school year. A consistent pattern of generalization across units was seen for each participant, facilitating a unique contribution to the literature in terms of fading systematic instruction.

As previously noted, the findings of Shanley et al. (2017) demonstrate the relationship between early number sense skill attainment and mathematics achievement for students who were identified as "at-risk" for mathematics difficulties. These findings suggest that interventions designed to meet the specific instructional needs of students struggling with early number sense have the potential to offset later mathematics difficulties. Intensive interventions such as *Early Numeracy* may be useful to support young students with autism who are at risk for mathematical difficulties. The pattern of responding to the generalization lessons (hash marks in Figure 1) shows that participants consistently had increased levels of responding when taught using systematic prompting and that after mastering targeted skills systematic prompting could be faded.

Modern quality indicators for single-case design studies reflect the emphasis on improving socially meaningful behavior through analysis of social validity (Horner et al., 2005). Ms. Baker's responses on both the pre- and post-social validity survey indicate her agreement that early number sense skills are of social significance for her students. Although the changes in early number sense for the participants, measured both by the assessment and TEMA-3 as a result of just 4 months of intervention, indicate a scientifically meaningful magnitude of change, a socially meaningful magnitude of change is made evident by both Ms. Baker's observations of the students outside of the instructional setting and their maintenance of early numeracy skills when systematic instruction was removed. Given that Ms. Baker is not a certified teacher, these findings may support use of the curriculum by other intervention agents (e.g., paraeducators).

Limitations and Future Research

This study has several limitations that suggest the need for future research, including instructional format and scope of targeted skills. The setting of the current study logistically required a one-on-one instructional format. Future research should focus on the feasibility of using this curriculum additional instructional formats (e.g., small groups) and settings (e.g., Kindergarten classroom in public school). Given its efficacy for students with autism who did not have an intellectual disability, a logical next step would be an investigation into the efficacy of *Early Numeracy* with other populations who are at risk for mathematical difficulties as a preventive or Tier 2 intervention. Similarly, lack of a maintenance measure is a limitation as the retention of the effects is unknown. This study did not include generalization to different materials, settings, or instructors. Future research should consider a more broad measure of generaliation, such as to small group settings or inclusive classrooms, is warranted in future research.

The limited scope of mathematics skills targeted for intervention during this study leads to an additional limitation. Additional early number sense skills such as working with quantities to 100, writing numbers to 20, and decomposition of numbers are expected of Kindergarten students and also foundational to success in future mathematics but were not addressed by the *Early Numeracy* curriculum. It is unknown whether the type of systematic instruction used in this curriculum will also be effective to teach these additional skills.

Implications for Practice

Important implications can be drawn from these results for both teachers of students with autism and professionals involved in the preparation and professional development of teachers. Early number sense is crucial to future mathematical learning and therefore should be an instructional priority for all students. Through building a strong base of early number sense for young learners with autism, teachers can ensure they have prerequisite math skills to make progress in the general curriculum. Teachers should use evidence-based practices for teaching mathematics skills such as those included in the *Early Numeracy* curriculum, including story-based thematic lessons, graphic organizers, manipulatives, and systematic instruction (Spooner et al., 2019). Teachers should use data to inform their decisions on what early number sense skills to target, and follow a research-based learning progression for teaching identified skills. For example, the *Early Numeracy* curriculum breaks down skills into small "chunks," with each unit expanding students' repertoires (i.e., rote counting 1–5 before rote counting 1–10, etc.). Table 1 provides this learning progression which teachers can then use to both assess and teach skills.

Prior to beginning the study, Ms. Baker valued development of early number sense but was unsure about how to teach it to her students. After receiving support in the form of a research-based curriculum, she grew confident in her own abilities and implemented instruction with a high degree of fidelity. Teacher preparation programs and school leaders should be in tune with the needs of their teachers to support teacher development, especially aligned to those skill sets the teachers themselves value.

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