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Early arithmetic boost for low-performing pre-school class students

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Abstract: Early arithmetic skills form a critical foundation for the development of students' reasoning and problem-solving abilities in mathematics, making early support essential. This study investigated the impact of a targeted intervention designed to strengthen early arithmetic skills among Swedish preschool-class pupils (ages 6–7) identified as having weak arithmetic proficiency. The intervention emphasized key components of early numeracy, including counting, number recognition, understanding number relations, nonverbal counting, story-based problem solving, and number operations. Results indicated that pupils in the intervention group achieved significantly greater gains in basic arithmetic performance, particularly in number relations, story problems, and number operations, compared to the control group. No significant differences were observed between groups in rote counting ability.

Keywords: Arithmetic abilities; Low-performing students; Pre-school class; Direct instruction.
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Introduction

Early arithmetic skills constitute a fundamental basis for the development of students' mathematics proficiency (Devlin, Moeller, Reynvoet, & Sella, 2022; Siegler & Braithwaite, 2017). A substantial body of research has shown that student's early arithmetic performance, observable as early as ages three to five, is a strong predictor of later academic achievement, occupational status, and income, even after accounting for background variables (Duncan et al., 2007; Chetty et al., 2010). Longitudinal studies further highlight the enduring impact of early arithmetic: preschoolers' number sense at age five has been robustly linked to mathematics achievement by the end of third grade (Jordan et al., 2008). Watts et al., (2014) extend this evidence, demonstrating that number perception skills developed between ages 4.5 and 7 are strongly associated with mathematics performance at age 15. Key competencies, such as numerical comparison, basic addition and subtraction, and problem-solving across varied contexts, emerge as reliable predictors of future mathematical proficiency. Taken together, these findings underscore the critical importance of early interventions aimed at supporting students' mathematical development from a young age.

The present study aimed to implement and evaluate an arithmetic intervention using a direct instruction model in a preschool class (student aged six to seven), with a particular focus on enhancing arithmetic abilities among students identified as low performing in mathematics.

Low performing students in mathematics

In educational research, students who struggle with mathematics are frequently identified as having special educational needs in this domain. These learners often exhibit pronounced deficits in core arithmetic skills, including number sense, counting, and basic calculation abilities (Aunio, 2019; Geary, 2011; Nelson & Powell, 2018). Their challenges are further reflected in the use of developmentally immature strategies, persistent difficulties in mastering mathematical facts, and inefficiencies in retrieving those facts from memory (Andersson, 2010; Dowker, 2005; Fuchs et al., 2008; Geary, 2011; Mazzocco et al., 2008). Struggles with single-digit addition and subtraction are particularly common (Baroody, 2016; Cowan et al., 2011; Fuchs et al., 2008; Xu & LeFevre, 2021), and these students often face difficulties in transferring mathematical thinking to real-world problem-solving situations (Lein et al., 2020). Such challenges tend to be persistent, with performance levels frequently remaining at or below the 25th percentile over time (Bryant et al., 2008; Mononen et al., 2014; Swanson & Beebe-Frankenberger, 2004; Nelson & Powell, 2018).

Intervention and low performing students

Numerous studies have identified arithmetic as a key focus in early interventions targeting students with mathematical difficulties (MD) from kindergarten through first grade (Dennis et al., 2016; Mononen et al., 2014; Nelson & McMaster, 2019). Interventions grounded in growth mindset principles have demonstrated particular effectiveness for lower-achieving students, who appear to derive greater benefit from enhanced motivational and psychological support (Paunesku et al., 2015; Yeager et al., 2019).These interventions typically address multiple domains of early mathematics, including counting skills, number relationships, strategies for addition and subtraction, quantity discrimination, numerical magnitude, and number identification. Their main objective is to enhance both conceptual understanding and procedural fluency among students with mathematics difficulties (Clarke et al., 2016; Nelson et al., 2025).

Effective interventions often integrate several core components: explicit instruction, extensive practice (Engvall et al., 2020; Fuchs et al., 2008), teacher modeling (Codding et al., 2011), and ongoing progress monitoring (Fuchs et al., 2012). Among these, intervention intensity and the use of explicit instruction are consistently highlighted as critical to success (Dennis et al., 2016; Gersten, Beckmann et al., 2009; Gersten, Chard et al., 2009; Powell & Fuchs, 2015). Explicit instruction is characterized by clear demonstrations, systematic sequencing of subskills, frequent opportunities for guided and independent practice, regular review of previously taught content, and timely, targeted feedback from teachers (Clarke et al., 2015; Doabler & Fien, 2013; Stockard et al., 2018).

Additionally, the use of manipulatives, visual aids, and other forms of number representation has been shown to support meaningful connections between mathematical concepts and relationships, particularly for students with MD (Carbonneau et al., 2013; Doabler & Fien, 2013; Xin & Jitendra, 1999).

Meta-analyses have reported moderate effect sizes for interventions targeting early arithmetic. Dennis et al. (2016) found an average effect size of Cohen's $d = 0.47$ for interventions focused on basic math facts and $d = 0.36$ for early arithmetic among elementary students. A more recent meta-analysis by Dietrichson et al. (2021) reported an effect size of Hedge's $g = 0.51$ for early arithmetic interventions targeting struggling elementary school students.

More specifically, studies focusing on preschool-aged student (ages 6–7) reveal variation in intervention design, including group size, duration, and instructional delivery. For example, Bryant et al. (2011) implemented a small-group intervention led by researchers over 1,900 minutes, resulting in an effect size of Hedge's $g = 0.33$. Fuchs et al. (2006) reported an individual, computer-assisted intervention lasting 500 minutes, with an effect size of $g = 0.19$. In another study, Fuchs et al. (2013) provided one-to-one instruction over 1,440 minutes, yielding an effect size of g = 0.41.

Rationale of the study

We evaluated the impact of a supplemental intervention program explicitly designed to target early arithmetic skills among Swedish preschool class students (ages 6–7) identified as having weak arithmetic abilities, skills that are considered indicative of risk in foundational mathematics learning. The intervention aimed to improve key areas of early numeracy, including counting ability, number recognition, number relations, nonverbal counting, story problem solving, and number operations. We hypothesized that students in the intervention group would demonstrate significantly greater gains in these domains compared to their peers in a control group.

To strengthen the ecological validity of the study relative to previous preschool intervention research, the program was delivered by the students' regular classroom teacher during standard instructional time. This approach ensured that the intervention was embedded within the existing educational context, thereby enhancing its feasibility and potential for broader implementation.

Methods

Research design

To evaluate the program, we employed a quasi-experimental design (cf. Shadish et al., 2002). The intervention spanned twelve weeks, from January to March, and comprised 24 lessons of 30 minutes each. Two to three lessons were delivered weekly to small groups of 3–5 pupils by preschool teachers trained to implement the intervention. Pupils in the control group (groups of approximate 15 pupils) continued with their regular mathematics lessons with the same content three times per week. Written consent was obtained from all parents for pupil participation and for the use of pre- and post-test data in the research. The average teaching experience was 15.25 years in the control group and 11.36 years in the intervention group. All teachers had comparable qualifications, having completed training to teach primary school pupils.

This study involved 793 pupils in Sweden from 19 schools and 39 preschool classes (six years old). The pupils allocated to the intervention condition attended schools in which the teachers had expressed an interest in participating in the study. In total, 414 pupils completed the pretest in the intervention schools, compared with 379 pupils in the control schools.We used the 25th percentile as a benchmark on pre-test to indicate low performance (cf. Bryant et al., 2008; Mononen et al., 2014; Swanson & Beebe-Frankenberger, 2004), resulting in the identification of 103 pupils attending the intervention and 96 pupils in the control group.

Test and test procedure

The pre- and post-intervention assessment consisted of 32 items designed to measure basic arithmetic skills (Cronbach α=.885) aligned with the intervention content (Jordan et al., 2012). Pupils were tested immediately before the intervention and again upon its completion. Each correct answer was scored by one point. The tasks included the following types:

- Counting Ability: Pointing to and counting objects (3 points) + rote counting (up to 100).
- Number Recognition: Identifying numbers such as 2, 4, 9, 13, 37, 82, and 124 (7 points).
- Number Relations: Determining which number is largest/smallest, which comes after 7, and which is closest to 5 in the number row (7 points).
- Nonverbal Counting: The test leader shows a few dots, then hides them under a hand. The leader then adds one or more dots under the hand. The pupil should point to the correct number of dots on a piece of paper with four alternatives presented (4 points).
- Story Problems: Calculations in a narrative context, such as "Albin has 4 crayons and gets 3 more" (5 points).
- Number Operations: Solving basic arithmetic problems like 2+1, 3+4, 7-1, and 6-2 (6 points).

All assessments were administered individually by two researchers affiliated with the project and four teachers involved in the project.

Intervention procedure

The intervention program was grounded in the Direct Instruction model (Stein et al., 2006), with all lessons fully scripted. Previous research by Jordan et al. (2012) has shown that this approach positively influences preschool children's development of number sense. The program incorporated several key principles: new skills were introduced alongside reinforcement of previously mastered skills; more challenging tasks were alternated with easier ones; pupils were encouraged to monitor their own progress to enhance motivation; and each lesson consistently included a mix of skills, instructional methods, and levels of difficulty (Stein et al., 2006).

To ensure adherence to these principles, each lesson was thoroughly scripted, detailing both the mathematical content and the execution of exercises. Teachers were instructed to follow the script closely, which specified gestures and key points to emphasize, as well as strategies for addressing incorrect responses. The script directed teachers to respond to errors by saying, 'That was a good attempt, but the correct answer is…,' followed by providing the pupil with another opportunity to answer correctly. During meetings held throughout and after the intervention, teachers confirmed that they had followed the prescribed script.

The mathematical content followed a hierarchical progression, beginning with the number range 0–2 and expanding incrementally by one number per lesson. In the final three sessions, pupils practiced generalizing to larger ranges. This incremental approach ensured that each lesson served both as a review of the previous range and an introduction to the next.

Whole Number Knowledge

Number-based exercises were designed to develop pupils' ability to manipulate and represent numbers in multiple formats, including numerical symbols, sets of objects, and positions on a number line. Cardinality, the understanding that the final number in a count represents the total quantity, was practiced repeatedly, alongside subitization, the rapid recognition of small quantities. Each lesson began with calculation practice, starting within the 0–10 range and gradually extending to 0–100. Pupils practiced counting from 1 and from various starting points within this range. Cardinality was reinforced through activities such as representing numbers with fingers or markers in a 10-frame (a two-row frame with five squares per row). Subitization was trained using cards displaying up to five circles, requiring pupils to quickly identify quantities. For numbers above five, pupils used fingers (a full hand plus additional fingers) or a 10-frame to support estimation skills.

Relationships between numbers

Exercises targeting number relationships included activities where pupils identified the largest and smallest numbers and practiced ordinality—the understanding of numerical order on a number line. Pupils learned how numbers and symbols change by one with each step along the line and applied concepts such as greater than and less than by comparing sets of circles on subitization cards or number cards. Additional activities involved decomposing two-digit numbers using single units and ten-blocks, identifying numbers immediately preceding and following a given number, and making ten jumps from a midpoint on the number line. Relationships between numbers were further strengthened through addition and subtraction exercises embedded in narrative contexts, as well as fluency-building activities within the 0–5 range.

Operations with numbers

The third component of the program addressed operations with numbers. Activities focused on performing calculations, working with symbolic number operations, and solving problems embedded in narrative contexts. Instruction began in the first lesson with the number 2, where pupils practiced identifying number pairs (e.g., 1 + 1, 0 + 2, 2 + 0), solving contextual problems involving the number 2, and repeating related operations. This structured approach was applied consistently across lessons, with adaptations for newly introduced numbers as the program progressed.

Fidelity

Teachers in the intervention groups documented their adherence to the lesson scripts and, following the intervention, completed a brief questionnaire regarding the program's content and procedures. Overall, the scripts were followed with approximately 90% fidelity. Only two minor deviations occurred. In one instance, during a group counting exercise, when a pupil was unsure of the next number, the teacher provided the missing number and repeated the sequence rather than prompting the pupil to do so, thereby offering additional support. For example, if the missing number was 5, the teacher said '3, 4' before giving the pupil another opportunity to respond. In another case, teachers reported difficulty implementing exercises requiring pupils to draw; to address this, they modeled the drawing process and verbalized their reasoning. Attendance in the intervention groups was exceptionally high, with nearly all pupils participating in every session. This was facilitated by a guiding principle that any student who was absent would be given an opportunity to complete the missed session.

Analysis

To investigate to what extent the intervention group and control group developed and compared their development the study employed a split-plot factorial design, with group as the between-subjects factor and time (pre- and post-intervention, following 24 lessons over eight weeks) as the within-subjects factor (cf. Field, 2018; Björkhammer et al., 2025). Developmental differences between groups were analyzed using ANOVA, and expected improvements for both control and intervention groups are reported as Cohen's *d* effect sizes (Field, 2018).

Results

The first section presents descriptive statistics for both groups' performance on rote counting and the basic arithmetic test at pre- and post-test, along with intervention effects. The second section reports descriptive statistics for subdomains of basic arithmetic skills, number recognition, number relations, story problems, and number operations, together with intervention effects.

Rote counting and basic arithmetic skills

Table 1 provides means and standard deviation on pre- and post-test with respect to rote counting performance and basic arithmetic performance.

Table 1

Means (M), Standard deviation (SD) for rote counting, basic arithmetic for each group and timepoint. In addition, the improvement is also presented.

		Pre-test			Post-test			Improvement	
Test	Group	*n*	*M*	*SD*	*n*	*M*	*SD*	*M*	Cohens *d*
Rote counting	Control	96	24.38	18.54	96	42.91	29.77	18.35	0.77
Rote counting	Intervention	103	27.13	22.52	103	54.30	32.98	27.17	0.80
Basic arithmetic	Control	96	15.41	2.77	96	20.53	4.99	5.12	1.13
Basic arithmetic	Intervention	103	14.99	3.42	103	24.86	4.74	9.87	2.52

To investigate whether there were any differences in the development of rote counting skills between the groups, we conducted an ANOVA with rote counting skills as the dependent measure. This analysis revealed no significant interaction effect between group and time, $F(1, 197) = 3.26$, $p= .072$, $\eta^2=.02$. There was a main effect of time, $F(1, 197) = 91.46$, $p< .001$, $\eta^2=.32$, and a main effect of group, $F(1, 197) = 5.85$, $p= .017$, $\eta^2=.03$.

To determine if there were any differences in the development of basic arithmetic skills among our groups, we performed another ANOVA, using basic arithmetic skills as the dependent variable. This analysis revealed a significant interaction effect between group and time, $F(1, 197) = 62.78$, $p< .001$, $\eta^2=.24$. There was also a main effect of time $F(1, 197) =626.33$ $p< .001$, $\eta^2=.76$ and a main effect of group $F(1, 197) = 15.56$, $p<.001$, $\eta^2=.07$.

In summary, the results indicate that the intervention group showed significantly greater improvement than the control group in basic arithmetic performance. However, no significant differences in development were observed between the groups in rote counting ability.

Sub areas of basic arithmetic skills

While this study encompassed various sub-areas of basic arithmetic skills, we specifically examined differences in the development of number recognition, number relation knowledge, story problem-solving abilities, and number operations. We did not include results from tasks involving pointing at and counting objects or nonverbal counting, as nearly all pupils performed these tasks adequately during the pre-test.

Table 2

Number of participants (N), Mean (M), and SD for subtest (number recognition, number relation knowledge, ability to solve story problem and perform number operations) for each group and timepoint. In addition, the improvement is also presented as mean differences.

			Pre-test			Post-test		Improvement	
Subtest	**Group**	***n***	***M***	***SD***	***n***	***M***	***SD***	***M***	**Cohens *d***
Number recognition	Control	96	3.19	.89	96	4.47	1.55	1.28	1.01
Number recognition	Intervention	103	2.96	1.87	103	4.59	1.52	1.63	.96
Number relations	Control	96	4.00	1.78	96	4.72	1.76	0.72	.40
Number relations	Intervention	103	3.45	1.74	103	5.95	1.28	2.50	1.64
Story problem	Control	96	1.88	1.35	96	2.94	1.25	1.06	.81
Story problem	Intervention	103	1.44	1.11	103	3.85	1.42	2.41	1.89
Number operations	Control	96	1.06	1.18	96	2.41	1.74	1.35	.91
Number operations	Intervention	103	1.45	1.61	103	3.76	1.62	2.31	1.43

An ANOVA with total scores for number recognition as the dependent measure revealed no significant interaction effect between group and time, $F(1, 197) =3.39$, $p= .067$, $\eta^2=.017$. There was a main effect of time $F(1, 197)=234.93$, $p< .001$, $\eta^2=.544$ but no main effect of group $F(1. 197) = .10$, $p=.750$, $\eta^2=.001$

A second ANOVA with total scores for number relation skills as the dependent measure revealed a significant interaction effect between group and time, $F(1, 197) =46.53$, $p< .001$, $\eta^2=.19$. There was also a main effect of time $F(1, 197)= 151.56$, $p< .001$, $\eta^2=.435$ but no main effect of group $F(1, 197) = 3.07$, $p=.081$, $\eta^2=.015$.

A third ANOVA with total scores for story problem skills as the dependent measure. This revealed a significant interaction effect between group and time, $F(1, 197) = 37.70$, $p < .001$, $\eta^2=.16$. There was also a main effect of time $F(1, 197)=248.67$, $p < .001$, $\eta^2=.58$ but no main effect of group $F(1, 197) = 2.70$, $p=.10$, $\eta^2=.014$.

A fourth ANOVA with total scores for number operation skills as the dependent measure revealed a significant interaction effect between group and time, $F(1, 197) = 16.00$, $p < .001$ $\eta^2=.075$. There was also a main effect of time $F(1, 197)=228.66$, $p < .001$, $\eta^2=.54$ and a main effect of group $F(2, 217) = 22.14$, $p<.001$, $\eta^2=.10$.
In summary, the results show that the intervention group demonstrated significantly greater improvement than the control group in tasks assessing number relation skills, story problem-solving abilities, and number operation skills.

Discussions

This study investigated the effects of a targeted arithmetic intervention for preschool class students (ages 6–7) identified as being at risk for early mathematical difficulties (MD). Both the intervention group (Cohen's $d = 2.52$) and the control group (Cohen's $d = 1.13$) showed substantial gains on a basic arithmetic assessment, with effect sizes well above the threshold for a large effect ($d > 0.8$). These improvements are notable when compared to the average annual gain ($d = 1.14$) typically observed in U.S. students transitioning from kindergarten to first grade (Bloom et al., 2008).

Several factors may explain the exceptionally high effect size observed in the intervention group. First, the assessment was closely aligned with the content of the intervention, and it is well-established that treatment effects tend to be significantly larger, often two to four times, when measured using proximal assessments rather than broad, standardized tests (Cheung & Slavin, 2016; Hill et al., 2008; Lipsey et al., 2012; Lynch et al., 2019). Second, interventions that incorporate growth mindset principles have shown effectiveness among lower-achieving students, who may benefit more from motivational and psychological supports (Paunesku et al., 2015; Yeager et al., 2019).

The intervention program integrated several evidence-based components known to enhance student learning. These included high instructional intensity (Dennis et al., 2016; Gersten et al., 2009; Powell & Fuchs, 2015), the use of concrete materials to support conceptual understanding (Carbonneau et al., 2013; Doabler & Fien, 2013; Xin & Jitendra, 1999), and a structured instructional design featuring sequenced subskills, frequent practice opportunities, systematic review, and immediate feedback (Clarke et al., 2015; Doabler & Fien, 2013; Fuchs et al., 2012; Stockard et al., 2018). A key instructional strategy was Direct Instruction (Stein et al., 2006), with fully scripted lessons guiding teachers on verbal cues, gestures, emphasis points, and corrective feedback procedures to ensure consistency and clarity.

Importantly, the intervention group demonstrated significantly greater improvement than the control group on tasks involving number operations and story problem solving. This is particularly relevant given that low-performing students often struggle with basic single-digit addition and subtraction (Baroody, 2016; Cowan et al., 2011; Fuchs et al., 2008; Xu & LeFevre, 2021), and frequently face challenges in applying mathematical reasoning to real-world contexts (Lein et al., 2020). These difficulties tend to persist over time, with affected students consistently performing at or below the 25th percentile (Bryant et al., 2008; Mononen et al., 2014; Swanson & Beebe-Frankenberger, 2004; Nelson & Powell, 2018).

Overall, the findings confirm that the early arithmetic intervention is effective for implementation in preschool classrooms serving low-achieving students. The results are consistent with prior research conducted in a new national context with similar educational settings (Bryant et al., 2011; Fuchs et al., 2006; Fuchs et al., 2013), contributing to the replication of evidence-based practices in early mathematics instruction. Notably, this study reinforces the value of Direct Instruction approaches in supporting students with MD (Root et al., 2020).

Finally, the findings have important implications for long-term mathematics learning. Previous research has demonstrated a strong and consistent link between early number sense, particularly at age five, and mathematics achievement by the end of third grade (Jordan, Kaplan, Ramineni, & Locuniak, 2008). Moreover, foundational arithmetic skills developed between ages 4.5 and 7 are closely associated with mathematics performance at age 15 (Watts et al., 2014), underscoring the enduring impact of early mathematical competencies.

Conclusion and Limitations

Our findings align with and reinforce existing research on mathematics interventions, particularly emphasizing the effectiveness of explicit instructional approaches in building and restoring foundational skills. Specifically, we show that direct teaching of basic arithmetic yields positive outcomes within a preschool classroom setting. Crucially, the findings suggest that a targeted and supplementary focus on core curricular content during the preschool year can substantially enhance arithmetic competencies among students who initially perform at lower levels in arithmetic.
Several limitations should be considered when interpreting the findings of this study. First, the quasi-experimental design was implemented with a relatively small sample of students, which limits the generalizability of the results to the broader population. To draw more robust and representative conclusions, future research should involve larger-scale studies across diverse educational settings.

Second, implementation fidelity is a critical factor in intervention research. Although teachers in this study followed a scripted instructional protocol, minor deviations were observed, particularly during activities involving number lines and drawing exercises. While these deviations were not extensive, they may have introduced slight variations in instructional delivery. However, we do not believe these deviations compromised the overall quality of instruction. In fact, allowing some students to engage in self-directed drawing may have supported their conceptual understanding. The observed improvements in calculation tasks and number operations suggest that the instruction, as delivered, remained effective.

Third, the potential influence of the Hawthorne effect must be acknowledged. Students were aware that they were participating in a research study, which may have positively influenced their engagement and motivation. While this effect is difficult to quantify, it is plausible that increased attention and novelty contributed to the observed gains, particularly among students who typically struggle with mathematics.

Fourth, the unequal group sizes between the intervention groups and the control group may have influenced the results to some extent. Nevertheless, the findings consistently indicate that the small-group early arithmetic intervention provides greater benefits for low-achieving students than the regular classroom instruction they would otherwise receive.

Finally, while the current study focuses on short-term outcomes, future research should examine the long-term impact of the intervention. Specifically, it would be valuable to assess whether early gains in arithmetic skills translate into sustained improvements in mathematics performance throughout primary education and beyond.

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