

The Effectiveness of Natural Environment Teaching in Improving Early Numeracy Skills in Children with Autism Spectrum Disorder in Inclusive Elementary Schools: A Single Subject Research Study

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ABSTRACT

This study aimed to evaluate the effectiveness of Natural Environment Teaching (NET) in improving early numeracy skills among children with Autism Spectrum Disorder (ASD) in inclusive elementary school settings. Early numeracy is a fundamental academic prerequisite that is often impaired in children with ASD due to core deficits in communication, cognitive flexibility, and generalization. This study employed a quantitative approach using a Single Subject Research (SSR) design with a multiple baseline across participants. Three children with ASD (DSM-5 Level 1–2), aged 6–8 years and enrolled in inclusive elementary schools, participated in the study. The intervention was conducted over 12 sessions (approximately 30–45 minutes each), integrating numeracy learning into natural classroom activities. Data were collected through direct observation and frequency recording and analyzed using visual analysis and the Percentage of Non-Overlapping Data (PND) method. Interobserver agreement (IOA) averaged 92.3%, while implementation fidelity averaged 91.7%. The results revealed consistent improvement across all participants, from baseline phases (mean 21.7%–31.7%) to intervention phases (57.5%–63.8%), with PND scores ranging from 90%–100%, indicating a highly effective intervention. Skill maintenance was observed at 72.5%–82.5%, demonstrating strong learning retention. These findings confirm that NET is an effective and ecologically valid naturalistic instructional approach for improving numeracy skills in children with ASD in inclusive educational settings.

INTRODUCTION

Basic numeracy is a fundamental cognitive competency that serves as a prerequisite for children's academic readiness and daily functioning. In the framework of learning trajectories developed by Clements and Sarama (2020), numeracy development includes mastery of number sense, one-to-one correspondence, understanding of cardinality and ordinality, and quantitative operations using concrete objects. These abilities progressively form the foundation for more complex mathematical understanding in later developmental stages (Clements & Sarama, 2020; Dienes, 2026; Geary et al., 2017; Vijayaprabha et al., 2016).

Globally, the PISA 2022 report (OECD, 2022) indicates that Indonesian students' mathematical performance remains below the global average. This issue becomes more complex within the population of children with Autism Spectrum Disorder (ASD). The Centers

for Disease Control and Prevention (CDC, 2023) reported an ASD prevalence of 1 in 36 children, reflecting a significant increase compared to previous estimates. This trend underscores the need for adaptive, evidence-based, and contextually relevant educational interventions (Ikram et al., 2026; Singh et al., 2025).

Children with ASD exhibit core characteristics including deficits in social communication, limited cognitive flexibility, and repetitive behavioral patterns (American Psychiatric Association, 2013). These characteristics directly affect their ability to process abstract concepts, including numeracy. Knight et al. (2019) identified that the primary barrier to mathematics learning in children with ASD is not solely cognitive, but more specifically related to deficits in generalization—the inability to transfer learned skills across different real-life contexts.

Within Vygotsky's Zone of Proximal Development (ZPD) framework, optimal cognitive development occurs when learning is embedded in meaningful social contexts with appropriate scaffolding (Vygotsky, 1978, as cited in Bodrova & Leong, 2007). For children with ASD, naturalistic contexts provide a cognitive framework that is easier to process because it is connected to familiar routines and objects, thereby reducing the cognitive load associated with abstract stimuli.

Discrete Trial Training (DTT) has traditionally been a primary method in Applied Behavior Analysis (ABA) interventions for children with ASD. Although it has demonstrated effectiveness in teaching basic skills through structured stimulus–response–consequence sequences (Lovaas, 1987), DTT has inherent limitations in promoting skill generalization. Leaf et al. (2020), in their systematic review, emphasized that skills acquired through DTT often do not spontaneously transfer to everyday contexts, limiting their functional relevance.

Natural Environment Teaching (NET) is an ABA-based approach that emphasizes learning within naturalistic contexts by leveraging children's intrinsic motivation and functional interactions (Sundberg & Partington, 1998). In contrast to Incidental Teaching, which is fully child-initiated, or Pivotal Response Training (PRT), which targets pivotal areas such as motivation and responsiveness to social cues, NET allows practitioners greater flexibility to proactively create learning opportunities within natural settings (Schreibman et al., 2015).

Within the broader framework of Naturalistic Developmental Behavioral Interventions (NDBI), NET integrates behavioral principles with developmental learning theories, making it more responsive to the individual characteristics of children with ASD (Schreibman et al., 2015). The core components of NET include the use of natural contexts and functional materials, natural reinforcement directly linked to target responses, stimulus variation to reduce overselectivity, and meaningful consequences for learners.

The literature indicates that NET research has predominantly focused on language and social skill domains (Leaf & McEachin, 2016; Schreibman et al., 2015), while its application in academic domains, particularly numeracy, remains limited. Browder et al. (2020) demonstrated the effectiveness of context-based mathematics instruction for learners with special needs, although not within the NET framework specifically. There is also a scarcity of studies conducted in inclusive school settings rather than clinical environments, as well as limited application of Single Subject Research (SSR) designs for in-depth individual analysis in numeracy instruction.

Based on these gaps, this study aimed to: (a) evaluate the effectiveness of NET in improving basic numeracy skills in children with ASD in inclusive elementary school settings; (b) examine changes in numeracy behavior using a multiple baseline across participants design; and (c) assess skill maintenance and generalization during the follow-up phase.

METHOD

This study used a quantitative approach with a Single Subject Research (SSR) method employing a multiple baseline design across participants (Kazdin, 2011). This design was selected because it is suitable for evaluating intervention effects in individuals with heterogeneous characteristics such as Autism Spectrum Disorder (ASD) and allows for the identification of functional relationships between the intervention (NET) and numeracy outcomes through replication across participants.

The study was conducted in three phases: Baseline (A), involving initial measurement without intervention across 3–5 sessions until data were stable; Intervention (B), involving the implementation of NET across 12 sessions; and Maintenance (A'), involving a follow-up assessment conducted two weeks after the intervention to evaluate skill retention.

Participants were selected using purposive sampling with the following inclusion criteria: (a) a formal ASD diagnosis based on DSM-5 criteria by a certified psychiatrist or clinical psychologist; (b) aged 6–8 years and enrolled in inclusive elementary schools; (c) ability to follow simple two-step verbal instructions; and (d) limited baseline numeracy skills based on initial assessment. Exclusion criteria included severe uncorrected sensory impairments and severe intellectual disability (IQ < 40) that would prevent meaningful participation.

Table 1. Complete Characteristics of Research Participants

Sub-Jek	Age	Classes	Level ASD (DSM-5)	Kognitif Profile	Expressive Language	Parallel Intervention	Comorbidities	Baseline Rata-rata
S1	6 th	1 SD	Level 2	Intellectual Function Limit (FSIQ 72)	Limited functional, ±2 words	Speech therapy 2x/week	None	21,7%
S2	7 th	1 SD	Level 1	Bottom average (FSIQ 84)	Functional, short sentences	None	Mild ADHD	31,7%
S3	8 th	2 SD	Level 2	Bottom average (FSIQ 79)	Limited, echolalic	OT 1x/week	None	25,0%

Catatan: FSIQ = Full Scale Intelligence Quotient; OT = Occupational Therapy.

Research Setting

The research was carried out in two inclusive elementary schools: Yamet School Cendana Lampung and Sekolah Bumi Grande Bandar Lampung. Interventions were carried out in the natural context of daily learning and activities at school, including classroom learning activities, structured play activities, shared meal activities, and social interaction with peers. The selection of this naturalistic setting is based on the main principle of NET which emphasizes the importance of generalization of skills in real-life situations.

Operational Variables and Definitions

The independent variable in this study is the application of Natural Environment Teaching (NET), which is operationally defined as a learning procedure that integrates numeracy targets into natural activities using functional objects, natural reinforcement, and customized prompt hierarchy (full physical prompt → partial physical prompt → gestural prompt → verbal prompt → independent).

Dependent variables are basic numeracy ability, which are measured through the following four indicators:

- a. Number symbol recognition (1–10): the child is able to point or say the number displayed on the number card/marked object without a verbal prompt within 3 seconds.
- b. One-to-one correspondence: the child is able to match the number of concrete objects with the corresponding number symbol independently.
- c. Quantity comprehension: the child is able to choose a group of more/fewer objects when asked, or to fulfill quantity-based requests ("take three pieces").
- d. Counting concrete objects: the child is able to count objects sequentially and declare the total number (principle of cardinality) without prompts.

Research Instruments

1. Basic Numeracy Observation Sheet

This instrument was developed based on the number sense framework of Clements and Sarama (2020) as well as the assessment guide for the development of early numeracy. The assessment uses a dichotomous scale (1 = true independent; 0 = false or requires prompt). The validity of the content was quantified using the Aiken's V coefficient based on the assessment of five experts (child psychologists, certified ABA practitioners, and inclusive education teachers). The obtained Aiken's V coefficient was 0.87 (range 0.80–0.93), exceeding the recommended minimum threshold of 0.80 (Aiken, 1985), so that the instrument was declared to have good content validity.

2. NET Implementation Fidelity Checklist

This checklist contains 12 core components of NET that are evaluated each session, including: use of natural contexts, active involvement of children, use of natural reinforcement, variety of activities, implementation of appropriate prompt hierarchy, error correction procedures, and transfer trials. The fidelity score is calculated as the percentage of the components that are correctly implemented out of the total components evaluated.

3. Interobserver Agreement (IOA)

The reliability of the data was measured using IOA by involving two independent observers who had been trained in a standardized manner. IOA is calculated using the formula: $IOA = (\text{Total Deal} / \text{Total Deal} + \text{Disagreement}) \times 100\%$. IOA measurements were performed at a minimum of 33% sessions per phase for each subject. An IOA value of $\geq 80\%$ is set as an acceptable reliability standard (Cooper et al., 2020).

Table 2. Data Interobserver Agreement (IOA) per Subject per Phase

Subject	Baseline Phase (%)	Intervention Phase (%)	Maintenance Phase (%)	Average (%)
S1	91,7	93,3	90,0	91,7
S2	90,0	93,3	91,7	91,7
S3	91,7	95,0	93,3	93,3
Average	91,1	93,9	91,7	92,3

Table 3. NET Implementation Fidelity Data per Subject

Subject	Initial Session (%)	Final Session (%)	Average (%)
S1	83,3	100,0	91,7
S2	91,7	100,0	95,8
S3	83,3	91,7	87,5
Average	86,1	97,2	91,7

NET Intervention Procedure

Each NET intervention session is implemented through the following stages: (1) Environment Setup: practitioners prepare a naturalistic environment that contains relevant objects as numeracy media; (2) Opportunity Creation: practitioners proactively create learning opportunities when children interact with objects or activities; (3) Prompt & Transfer Trial: the prompt is given according to a predetermined hierarchy, followed by a transfer trial to encourage generalization; (4) Natural Reinforcement: consequences are given directly and are related to the response (for example: the child counts three fruits and then gets the three fruits). Examples of activities: counting objects while playing, matching numbers to real objects, simple buying and selling activities, and counting objects in a class routine.

Data Analysis Techniques

Data were analyzed using SSR visual analysis approach which included: (1) level analysis (average change between phases); (2) trend analysis (the direction of data development using the split-middle method); (3) data stability analysis (variability in phases); (4) immediacy of effect (the speed of change when the phase changes); and (5) Percentage of Non-Overlapping Data (PND) as a measure of quantitative effect. PND effectiveness criteria: $\geq 90\%$ = very effective, 70–89% = effective, 50–69% = less effective, $< 50\%$ = ineffective (Scruggs & Mastropieri, 2001).

RESULT AND DISCUSSION

Overview of Findings

All participants showed consistent and systematic improvement in basic numeracy skills after the implementation of NET. This improvement is seen in all observed indicators and persists in the maintenance phase. The data is presented in the form of a table per phase below.

Baseline Phase Results (A)

In the baseline phase, all subjects showed low numeracy ability and were relatively stable, indicating no significant changes without intervention. This condition meets the baseline stability requirements in the SSR as a prerequisite for the start of the intervention.

Table 4. Percentage of Correct Responses at Baseline Phase (A)

Subject	Volume 1 (%)	Volume 2 (%)	Volume 3 (%)	Volume 4 (%)	Average (%)
S1	20	25	20	—	21,7
S2	30	30	35	30	31,3
S3	25	20	30	25	25,0

Note: S2 and S3 require 4 baseline sessions to achieve stability ($\pm 15\%$). A sign (—) indicates the session is not in progress.

Outcome of the Intervention Phase (B)

After the implementation of NET, all three subjects showed gradual and consistent improvement. Behavioral changes were already seen in the first session of the intervention, indicating a strong immediacy of effect.

Table 5. Percentage of Correct Responses in the Intervention Phase (B)

Subject	S-1 (%)	S-2 (%)	S-3 (%)	S-4 (%)	S-8 (%)	S-10 (%)	S-12 (%)	Average (%)
S1	30	40	45	50	70	75	80	57,5
S2	35	45	55	60	75	80	85	63,8
S3	30	40	45	55	65	70	75	54,3

Maintenance Phase Results (A')

In the maintenance phase (2 weeks post-intervention), the numeracy ability of the three subjects remained stable, indicating significant learning retention even though intensive intervention was no longer given.

Table 6. Correct Response Percentage in Maintenance Phase (A')

Subject	Sound M-1 (%)	Sound M-2 (%)	Average (%)
S1	75	80	77,5
S2	80	85	82,5
S3	70	75	72,5

Visual Analysis and PND

Table 7. Summary of Interphase Visual Analysis (Baseline to Intervention)

Subject	Mean Baseline (%)	Mean Intervention (%)	Level Change	Intervention Trends	PND (%)	Category
S1	21,7	57,5	+35.8 (increased)	Increase consistently	100	Highly Effective
S2	31,3	63,8	+32.5 (increased)	Increase consistently	100	Highly Effective
S3	25,0	54,3	+29.3 (increased)	Gradual increase	90	Highly Effective

Note: PND = Percentage of Non-Overlapping Data; The category criteria refer to Scruggs & Mastropieri (2001).

Changes per Numeracy Indicator

Table 8. Change in Average Score per Numeracy Indicator (Baseline → Intervention → Maintenance)

Indicator	S1-BL (%)	S1-INT (%)	S2-BL (%)	S2-INT (%)	S3-BL (%)	S3-INT (%)	S3-MNT (%)
Introduction of Number Symbols	25	80	35	85	25	75	70
One-to-One Correspondence	20	75	30	80	25	70	65
Understanding Quantity	20	50	35	65	25	55	75

Counting Concrete Objects	20	55	25	65	25	50	80
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Note: BL = Baseline; INT = Intervention (phase average); MNT = Maintenance (average phase).

The Effectiveness of NET in Improving Numeracy

The results of this study consistently show that the application of NET is effective in improving basic numeracy skills in ASD children in an inclusive setting. The PND value of 90%–100% in all three subjects indicated very high effectiveness based on the criteria of Scruggs and Mastropieri (2001). This improvement occurs gradually and consistently, in accordance with the characteristics of ABA-based learning that relies on repetition and reinforcement in varied contexts.

The effectiveness of NET in this study can be explained through three main mechanisms. First, learning in a naturalistic context reduces the burden of cognitive processing in ASD children because the stimuli used are familiar and meaningful in daily life. This is in line with the principle of ecological validity in behavioral interventions (Schreibman et al., 2015), which emphasizes that skills are learned most effectively in the context in which they will be used.

Second, the use of natural reinforcement in NET increases the child's intrinsic motivation, which is a critical component in learning for individuals with ASD (Koegel & Koegel, 2019). Reinforcement that is directly tied to the response — such as receiving a recently counted object — creates contingencies that are easier to understand and more powerful, encouraging repetition of behavior than artificial reinforcement in DTT procedures.

Third, from the perspective of Vygotsky's developmental theory, NET operates effectively within the child's Zone of Proximal Development (ZPD). Practitioners act as scaffolding agents who systematically reduce support (prompt fading) as children's competencies increase, thereby encouraging the progressive internalization of numeracy skills. This process reflects developmental learning mechanisms that are social and contextual, not just the acquisition of conditioned responses.

Generalization and Skill Retention

One of the important findings in this study is the stability of numeracy ability in the maintenance phase (72.5%–82.5%), which indicates significant learning retention. This is an advantage of NET over DTT, where skills learned in structured settings often experience a significant decline after the intervention is stopped (Leaf et al., 2020).

It should be noted that S3 showed a lower average intervention but maintained a good maintenance score. This may be related to the S3 learning profile that requires more repetition in the acquisition phase, but instead shows good memory consolidation after the intervention. These findings emphasize the importance of considering individual characteristics in designing NET-based interventions.

Comparison with Previous Research

These findings are consistent with the research of Schreibman et al. (2015) which showed that NDBI approaches, including NET, consistently produce better generalization of skills than structured approaches. In the context of numeracy, these results expand on the findings of Browder et al. (2020) who showed that context-based learning is effective for mathematics in children with special needs, by adding a more specific NET framework and a more representative inclusive school setting.

The difference in PND scores between subjects (S3 = 90% vs S1-S2 = 100%) may be related to differences in cognitive profile and severity of ASD. S3 with more limited expressive language (echolalic) requires a more intensive adaptation of NET procedures, which implies the need for differentiation in the implementation of NET based on the child's individual profile.

Research Limitations

This research has several limitations that need to be critically acknowledged. First, the limited number of subjects (n=3) is an inherent characteristic of the SSR design that limits the generalizability of the findings to a wider population. Second, the lack of direct comparisons between NET and DTT limits the ability to infer the relative superiority of NET. Third, the short duration of maintenance (2 weeks) could not describe the long-term effects of the intervention. Fourth, confounding variables such as parallel interventions undergoing S1 (speech therapy) and S3 (OT) cannot be fully controlled, although the multiple baseline design provides adequate internal control. Fifth, this study did not measure generalizations to non-school settings (e.g. home), which is the ultimate goal of the NET intervention.

Implications and Recommendations

Theoretically, this study extends the application of NET in the ABA literature to the academic domain, specifically numeracy, which has been dominated by language and social studies. In practical terms, these findings imply that inclusive classroom teachers, special adjunct teachers, and ABA therapists can integrate NET as an effective numeracy learning strategy and do not require a special setting outside the classroom.

Further research is recommended to: (a) use a larger number of subjects with a group experiment design to test generalizability; (b) compare NET with DTT directly; (c) to assess long-term effectiveness with a longer maintenance duration; (d) integrate generalized measurements into home settings; and (e) explore NET adaptations for children with ASD with very limited language profiles.

CONCLUSION

This study showed that the application of Natural Environment Teaching (NET) was effective in improving basic numeracy skills in children with Autism Spectrum Disorder (ASD) in the early grades of inclusive elementary schools. Consistent improvements across numeracy indicators—including number symbol recognition, one-to-one correspondence, quantity understanding, and counting concrete objects—along with PND values of 90%–100% (classified as highly effective) and stable skill retention during the maintenance phase, provided strong empirical evidence of NET as an ecologically valid intervention for numeracy instruction in inclusive educational settings.

The high reliability of the data (average IOA of 92.3%) and strong implementation fidelity (mean of 91.7%) reinforced the internal validity of the study. These findings contribute to the development of evidence-based practice in inclusive education in Indonesia, particularly in numeracy instruction for children with ASD. NET, which has been widely applied in language and social skill domains, was also shown to be effective in the academic domain, opening opportunities for the development of more comprehensive and holistic intervention models.

REFERENCE

- Aiken, L. R. (1985). Three coefficients for analyzing the reliability and validity of ratings. *Educational and Psychological Measurement*, 45(1), 131–142. <https://doi.org/10.1177/0013164485451012>
- American Psychiatric Association. (2013). *Diagnostic and statistical manual of mental disorders* (5th ed.). American Psychiatric Publishing. <https://doi.org/10.1176/appi.books.9780890425596>
- Bodrova, E., & Leong, D. J. (2007). *Tools of the mind: The Vygotskian approach to early childhood education* (2nd ed.). Merrill/Prentice Hall.
- Browder, D. M., Spooner, F., Ahlgrim-Delzell, L., Harris, A., & Wakeman, S. (2020). A meta-analysis on teaching mathematics to students with significant cognitive disabilities. *Exceptional Children*, 87(1), 5–22. <https://doi.org/10.1177/0014402919878469>
- Centers for Disease Control and Prevention. (2023). *Autism spectrum disorder: Data and statistics*. <https://www.cdc.gov/autism/data-research/index.html>
- Clements, D. H., & Sarama, J. (2020). *Learning and teaching early math: The learning trajectories approach* (3rd ed.). Routledge. <https://doi.org/10.4324/9781003083528>
- Cooper, J. O., Heron, T. E., & Heward, W. L. (2020). *Applied behavior analysis* (3rd ed.). Pearson.
- Dienes, Z. P. (2026). *The power of mathematics: A study of the transition from the constructive to the analytical phase of mathematical thinking in children*. Taylor & Francis.
- Geary, D. C., Nicholas, A., Li, Y., & Sun, J. (2017). Developmental change in the influence of domain-general abilities and domain-specific knowledge on mathematics achievement: An eight-year longitudinal study. *Journal of Educational Psychology*, 109(5), 680–695.
- Ikram, M., Hanefar, S. B. M., Saleem, S. M. U., & Zulfiqar, F. (2026). Artificial intelligence in education: A systematic review of personalized learning trends and future directions. *Frontiers in Education*, 11, 1782626.
- Kazdin, A. E. (2011). *Single-case research designs: Methods for clinical and applied settings* (2nd ed.). Oxford University Press.
- Knight, V. F., McKissick, B. R., & Saunders, A. (2019). A review of technology-based interventions to teach academic skills to students with autism spectrum disorder. *Journal of Autism and Developmental Disorders*, 49(1), 1–22. <https://doi.org/10.1007/s10803-018-3706-3>
- Koegel, R. L., & Koegel, L. K. (2019). *Pivotal response treatments for autism: Communication, social, and academic development*. Paul H. Brookes Publishing.
- Leaf, J. B., Leaf, R., McEachin, J., Taubman, M., & Ala'i-Rosales, S. (2020). Comparing discrete trial teaching and natural environment teaching: A systematic review. *Journal of Applied Behavior Analysis*, 53(2), 544–559. <https://doi.org/10.1002/jaba.691>
- Leaf, R., & McEachin, J. (1999). *A work in progress: Behavior management strategies and a curriculum for intensive behavioral treatment of autism*. DRL Books.
- Organisation for Economic Co-operation and Development. (2022). *PISA 2022 results (Volume I): The state of learning and equity in education*. OECD Publishing. <https://doi.org/10.1787/53f23881-en>
- Schreibman, L., Dawson, G., Stahmer, A. C., Landa, R., Rogers, S. J., McGee, G. G., Kasari, C., Ingersoll, B., Kaiser, A. P., Bruinsma, Y., McNerney, E., Wetherby, A., & Halladay, A. (2015). Naturalistic developmental behavioral interventions: Empirically validated treatments for autism spectrum disorder. *Journal of Autism and Developmental Disorders*, 45(8), 2411–2428. <https://doi.org/10.1007/s10803-015-2407-8>
- Scruggs, T. E., & Mastropieri, M. A. (2001). How to summarize single-participant research: Ideas and applications. *Exceptionality*, 9(4), 227–244.

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https://doi.org/10.1207/S15327035EX0904_5

- Singh, N. C., Gilead, T., Chakraborty, A., Van Herwegen, J., van Atteveldt, N., Borst, G., Bugden, S., Jasinska, K., Kay, J., & Pugh, K. (2025). A new education agenda based on the International Science and Evidence Based Education Assessment. *npj Science of Learning*, 10(1), 24.
- Sundberg, M. L., & Partington, J. W. (1998). *Teaching language to children with autism or other developmental disabilities*. Behavior Analysts, Inc.
- Vijayaprabha, G., Vasuki, M., & Kumar, A. D. (2016). Cognitive development and mathematical understanding: A review of current educational theories. *Cognitive Development*, 2(1).