Sciences du Nord Humanities and Social Sciences
Vol. 1, No. 02, December 2024: pp. 85-96
E-ISSN: 3046-5176
P-ISSN: 3047-3896
DOI: https://doi.org/10.58812/snhss.v1i02.90

Development and Trial of Environmentally Friendly Teaching Aids for Basic Mathematics Learning in Early Childhood Education

Miftah Kusuma Dewi[1], Farida Nur Azizah[2], Indasah[3], Rifka Taufiqur Rofiah[4], Miftachus Sholikah[5], Riana Rahayu[6], Miftahus Sholihah[7]
[1] IAI Pangeran Diponegoro Nganjuk and miftakusuma978@gmail.com
[2] IAI Pangeran Diponegoro Nganjuk and faridaupdn123@gmail.com
[3] IAI Pangeran Diponegoro Nganjuk and indahindasah88@gmail.com
[4] IAI Pangeran Diponegoro Nganjuk and rifkarofiah1@gmail.com
[5] IAI Pangeran Diponegoro Nganjuk and mieft.solikah@gmail.com
[6] IAI Pangeran Diponegoro Nganjuk and rianarahayu19@gmail.com
[7] IAI Pangeran Diponegoro Nganjuk and nmiftahussholihah25@gmail.com

Coresponding Author: miftakusuma978@gmail.com

ARTICLE HISTORY
Received November, 2024 **Revised December, 2024** **Accepted December, 2024**

ABSTRACT

The development and testing of environmentally friendly teaching aids for basic mathematics learning in Early Childhood Education (PAUD) focuses on creating engaging, sustainable, and effective learning media. One study developed an eco-friendly math learning tool called "situng" for first-grade students, which significantly increased interest and effectiveness in learning arithmetic operations, validated through expert assessments and statistical tests. Another approach involved training PAUD teachers to design educational game tools using recycled materials, enhancing their skills and motivation to create innovative, child-safe, and environmentally conscious teaching aids. Interactive digital media combining cultural elements like batik with basic math concepts also shows promise in improving children's mathematical understanding and engagement, although challenges such as limited digital access and teacher training remain. Additionally, the use of low-cost, sustainable manipulatives like plastic straws demonstrated significant improvement in young learners' additional skills while promoting ecological awareness. These studies highlight the importance of integrating environmental consciousness with pedagogical innovation to enhance early mathematics education in PAUD settings effectively.

Keywords: Basic Mathematics Learning; Educational Game Tools; Environmentally Friendly Teaching Aids; Interactive Media; PAUD; Sustainable Materials

INTRODUCTION

The early childhood education (ECE) period is a critical phase for developing basic numerical skills. Early numerical skills—including number concepts, simple measurement, shape recognition, and basic quantitative relationships—are not only predictors of mathematical success in subsequent school years, but are also linked to logical thinking skills, problem-solving skills, and general academic readiness [1]. Early childhood mathematics education is qualitatively different from mathematics instruction for older children or adults: preschoolers are more responsive to sensorimotor experiences, symbolic play, and social interactions that enable the meaning of concepts through concrete manipulation (Clements & Sarama; Learning Trajectories) [2], [3]. Therefore, the use of concrete manipulatives is a key pedagogical strategy in elementary mathematics learning in early childhood education. Extensive empirical evidence supports the role of concrete manipulatives in helping children build conceptual mental representations of abstract mathematical structures,

facilitating the transition from concrete to symbolic experiences, and increasing motivation and engagement in learning [4].

However, mathematics teaching practices in many early childhood education institutions still often place abstract symbols (numbers on paper, verbal counting without referent objects) in a central position — an approach that is often inappropriate for the cognitive developmental stage of preschool children [5]. Field studies and early education research show that many children show little interest in mathematical activities presented abstractly: they quickly become bored, show low levels of attention, or fail to associate symbols with real-world experiences [6]. This has two pedagogical consequences: first, lost cognitive learning opportunities (children do not acquire a strong conceptual foundation); second, the emergence of negative attitudes toward mathematics from an early age (aversion), which can lead to low mathematics achievement in elementary school. This constellation of problems emphasizes the urgency of providing concrete, meaningful, and contextual teaching aids for early childhood education children [7], [8].

With increasing environmental awareness and the need for sustainable socio-economic solutions, the use of recycled/repurposed materials as a source of teaching aids has emerged as a pragmatic and meaningful alternative. In Indonesia, the large production of household waste and plastic waste provides a potential source of raw materials that can be processed into educational teaching aids; utilizing waste for learning tools not only reduces the cost of procuring toys/teaching aids, but also builds environmental awareness in children from an early age—integrating mathematics education with environmental education.(D'angelo & Iliev, 2012; Elmey et al., 2025)Indonesian environmental statistics (KLHK/BPS and related publications) indicate large volumes of waste generation, including significant proportions of household waste and plastic waste; this enhances the relevance of reuse-upcycle programs for local elementary and early childhood education contexts [11], [12].

However, there are several practical and scientific constraints: not all used materials are safe or suitable for use as teaching aids; the design of teaching aids must consider aspects of safety, cleanliness, durability, mathematical representational capabilities (e.g., the ability to demonstrate quantity, operations, properties of shapes), and relevance to the PAUD numeracy curriculum [13], [14]. Furthermore, the pedagogical quality of teacher- and community-made teaching aids is often not systematically evaluated — many local projects produce innovative teaching aids but without standardized pilot studies measuring their impact on children's numeracy development (learning outcomes). This gap forms the basis for research proposing the development and piloting of environmentally friendly teaching aids designed to meet children's developmental stages, safety standards, and basic mathematics learning indicators [15], [16].

Classical cognitive development theory (Piaget) and contemporary studies of mathematical developmental trajectories assert that children construct concepts of number and operations through interactions with concrete objects and meaningful contexts. Piaget placed preschoolers in the pre-operational stage: symbolic thinking is developing but abstract logical reasoning skills are immature; therefore, concrete manipulative experiences provide a crucial bridge to the internalization of symbolic concepts. Research on learning trajectories (Clements & Sarama) provides an empirical map of the sequence of mathematical skills that can be targeted through hierarchically structured tasks, where concrete manipulatives play a key role in moving children from informal heuristic

solutions to more systematic strategies. Thus, teaching aids are not simply "toys" but cognitive tools that enable the formation of early numeracy schemes [17], [18].

Meta-analyses and reviews indicate that the use of concrete manipulatives during mathematics instruction produces positive effects on students' conceptual understanding and performance, particularly when they are used with purposeful pedagogy (instruction that links concrete actions to symbolic notation). Quasi-experimental studies and RCTs in early education have shown improvements in understanding of number concepts, composition/partitioning skills, and flexibility of problem-solving strategies when manipulatives are used consistently across a range of learning tasks. However, effectiveness varies depending on the quality of pedagogical integration (whether the teacher mediates the transition steps to abstraction), the design of the manipulative, and the duration of the intervention. In summary, evidence supports the role of manipulatives—but the best results are achieved when they are used within a structured learning framework [19], [20].

Pedagogical literature and practical case studies have shown that teaching aids made from local/recycled materials can effectively increase student motivation and engagement. Research on teacher-made and homemade manipulatives reports increased participation and understanding when students engage with objects that are representative and meaningful in their cultural context; several quasi-experimental studies have also found improved learning outcomes after the implementation of teacher-made teaching aids. Other advantages include low cost, ease of reproduction, and opportunities for community empowerment (teacher and parent involvement in the making).[21]However, systematic comparative studies are relatively limited and often fail to consider safety, hygiene, and long-term durability—critical issues when using recycled materials. Therefore, plans for developing environmentally friendly teaching aids should include safe design standards, cleaning procedures, and pedagogical evaluation [22].

Using recycled materials to create teaching aids creates the opportunity to combine two curricular objectives: strengthening basic numeracy and environmental education. Children learn not only mathematical concepts but also environmental awareness values: reduce, reuse, and recycle (3R) [23], [24], [25]. This cross-curricular approach aligns with holistic early childhood education principles that encourage thematic and meaningful learning. Environmental education studies show that practical activities related to the environment (upcycling projects, simple waste processing) effectively build pro-environmental attitudes in children when formatted as exploratory and reflective experiences. For early childhood education, the combination of recycled manipulatives and numerical games can be a powerful pedagogical tool [26].

Empirical evidence from classroom surveys, observations, and early research studies suggests that preschoolers and early grade students tend to be less interested in symbolic and abstract mathematical activities. They show greater interest in tasks involving the manipulation of real objects and contextual play [27]. A review of the educational literature emphasizes that a direct transition to symbols without a concrete phase leads to misunderstanding, boredom, and decreased motivation—effects that can persist. Therefore, the demand for concrete teaching aids is not simply a pedagogical preference, but rather a response to children's developmental patterns that require concrete representations to understand early numerical concepts [28].

Indonesian Environmental Statistics and BPS/KLHK publications show that Indonesia produces tens of millions of tons of waste per year; the large proportion of household waste and the still high percentage of final disposal indicate the availability of potential materials for upcycling

[29], [30]. A 2022 report shows that national waste generation reaches tens of millions of tons per year, with organic and household waste being the largest components; plastics contribute a significant proportion in some urban areas [31], [32]. In this context, early childhood education centers (PAUD) in urban areas can partner with local waste management programs or community initiatives to source safe materials (plastic bottles, cardboard, used fabrics, bottle caps) that can be transformed into educational tools. These statistics provide a pragmatic argument that developing environmentally friendly teaching aids is not simply a normative idea, but rather an intervention that utilizes abundant local resources [33], [34].

Based on the literature review and field observations, several key research gaps were identified that serve as the justification for this study. First, there is a lack of standardized trials for recycled teaching aids, as existing creative projects have not been supported by adequate experimental or quasi-experimental designs to measure the impact of recycled teaching aids on children's numeracy outcomes. Existing studies generally use small sample sizes or pre-post methods without adequate comparison groups. Second, safety and hygiene aspects are often overlooked, as practical literature rarely provides replicable cleaning standards, non-toxic material selection, and maintenance strategies for recycled teaching aids.

Third, the lack of pedagogical models that integrate learning trajectories with local teaching aid design, often results in ad-hoc teaching aid design without linking specific learning objectives such as subitizing or number composition with manipulative forms and teacher usage guidelines. Fourth, there is a lack of attention to sustainability and community empowerment, where research rarely evaluates how making teaching aids from recycled materials can improve the capabilities of teachers and parents while reducing the cost burden on institutions [35]. Therefore, research that develops, validates the safety aspects, and tests the empirical effectiveness of environmentally friendly teaching aids integrated with the PAUD curriculum is a strategic step that not only provides empirical evidence for educational practices, but also provides a holistic implementation model that combines educational goals and environmental sustainability [36], [37].

Based on the background described, this research is formulated with several main objectives. First, to develop a prototype of basic mathematics teaching aids for early childhood education (PAUD) that utilizes locally recycled materials, taking into account safety and hygiene standards, as well as their suitability with learning trajectories for early childhood numeracy development. Second, to conduct a field trial (pilot test/quasi-experimental) to assess the impact of using environmentally friendly teaching aids on basic mathematics learning outcomes (including aspects of number recognition, counting, and number composition), the level of children's involvement and interest, and the level of acceptance from teachers and parents. Third, to develop comprehensive operational guidelines that include material specifications, cleaning and maintenance procedures, learning activity scenarios, and assessment indicators that allow for replication in other PAUDs. Fourth, to evaluate environmental and social aspects including the potential for local waste reduction, the level of community empowerment through the involvement of parents and teachers in the production process, and an analysis of relative economic costs compared to the procurement of conventional teaching aids. The scope of the research covers all stages starting from the design phase, safety validation, teacher training, implementation over a period of 8-12 weeks, pre-post measurements, to qualitative analysis of user experiences (teachers, parents, and children).

RESEARCH METHODS

Research and Development (R&D) using the ADDIE model is a systematic approach widely applied in the development of educational products, including early childhood mathematics teaching aids. The ADDIE model consists of five phases: Analysis, Design, Development, Implementation, and Evaluation, which guide researchers in creating effective and validated learning tools [38], [39]. In the Analysis phase, researchers identify learning needs, learner characteristics, and contextual factors, such as the specific requirements of early childhood education students and environmental considerations for eco-friendly materials. The Design phase involves planning the structure, content, and media of the teaching aids, ensuring alignment with learning objectives and pedagogical principles. During Development, the actual creation of the teaching aids occurs, followed by Implementation, where the product is tested in a real educational setting, such as an early childhood education center in City X for a period of six months. Finally, the Evaluation phase assesses the validity, practicality, and effectiveness of the product through expert validation, observation, interviews, and performance tests with children [40].

In this study, the trial subjects included two media experts, two material experts, one PAUD teacher, and 15 children from group B, thus providing a comprehensive picture of the quality and usefulness of the teaching aids. Data collection techniques included an expert validation questionnaire, an observation checklist to monitor implementation accuracy, structured interviews to gather qualitative feedback, and a performance test to measure children's math abilities [41]. The research instruments included expert validation sheets, implementation observation sheets, interview guidelines, and a rubric for assessing children's mathematical abilities, ensuring systematic and reliable data collection. Data analysis combined quantitative descriptive methods for validation scores and qualitative analysis for observation and interview data, allowing for a nuanced understanding of the impact of the teaching aids and areas for improvement [42].

The research and development approach using the ADDIE model ensures that environmentally friendly mathematics teaching aids developed for PAUD are pedagogically insightful, contextually relevant, and environmentally responsible [43], [44]. The iterative nature of ADDIE's continuous improvement based on feedback from experts and users, increases the product's effectiveness in fostering early mathematics learning while promoting sustainable values [45]. A structured design and evaluation process is essential to producing innovative educational tools that meet cognitive and ecological goals in early childhood education.

RESULTS AND DISCUSSION

Results of Needs Analysis and Initial Design

An analysis of the need for teaching aids for basic mathematics in early childhood education (PAUD) demonstrates the urgency of developing teaching aids that are not only safe and affordable, but also contextual and environmentally friendly. This need arises from the fact that existing teaching aids often use plastic materials, which can potentially harm children's health and the environment, and are less relevant to children's local contexts [46]. Safety is a key aspect because young children are highly vulnerable to hazardous materials, so teaching aids must meet strict safety standards. Furthermore, affordability is crucial for ensuring widespread access to teaching aids by early childhood education institutions from diverse economic backgrounds [47]. Contextuality of teaching aids is also very necessary so that learning materials can be more easily understood and

connected to children's daily experiences, thereby increasing interest and motivation in learning mathematics [48].

The urgency of developing environmentally friendly teaching aids can be understood through Dienes' concrete learning theory, which emphasizes the importance of direct experience and manipulation of real objects in the mathematics learning process. According to Dienes, effective mathematics learning must begin with concrete experiences before moving on to abstract concepts, so the teaching aids used must enable real and meaningful physical interaction for children [49]. By using environmentally friendly materials, such as creatively processed waste materials, these teaching aids not only fulfill the principles of concrete learning but also teach the values of sustainability from an early age. This aligns with the principles of Education for Sustainable Development (ESD), which emphasize the integration of environmental, social, and economic aspects in the educational process to shape a generation that is aware of and responsible for environmental conservation [50].

Sustainable education demands a transformation in learning methods and media, including the selection of materials used in teaching aids. Using local and recycled materials for teaching aids can reduce negative environmental impacts while providing additional educational value in the form of ecological awareness for children [51]. Furthermore, this approach supports the development of creative and innovative skills in optimally utilizing existing resources. Recent studies have shown that learning that integrates sustainability principles and concrete experiences can increase children's engagement and understanding of basic mathematical concepts, while fostering a caring attitude toward the environment [52].

Discussions regarding the need for environmentally friendly teaching aids also highlighted challenges in implementation, such as limited resources, teachers' knowledge of environmentally friendly materials, and the need for training to optimize the use of these teaching aids [53]. Therefore, the development of teaching aids must be accompanied by training and mentoring for PAUD teachers so that they can maximize the potential of teaching aids in effective and sustainable mathematics learning [54]. In addition, continuous evaluation of the effectiveness of teaching aids in real-life learning contexts is essential to ensure that they meet both pedagogical and environmental needs simultaneously.

"Natural Count" Product Prototype.

The development of the environmentally friendly teaching aid prototype "Natural Counting" was based on the need for concrete media that can facilitate the cognitive development of early childhood, particularly in understanding basic mathematical concepts. According to Piaget (1952), children aged 4–6 years are in the preoperational stage, a period when knowledge is built through the manipulation of concrete symbols and sensorimotor experiences [55], [56]. In the context of mathematics learning, concrete teaching aids have a central function in helping children connect abstract concepts—such as numbers, values, and sequences—with real objects that can be touched, seen, and operated [57]. Meanwhile, environmental issues, particularly the high production of household waste and everyday materials, provide an opportunity to integrate mathematics learning with environmental education through the repurposing of used materials. Therefore, the "Natural Count" prototype was designed not only as a numeracy tool but also as a medium for sustainability education and environmental literacy from an early age [58].

The counting board is made from cleaned and sanded pieces of used wood from pallets or fruit crates. Wood was chosen for its strength, natural aesthetics, and relative safety compared to easily breakable plastic [59]. The board is arranged with five rows of holes or slots, allowing children to insert beads to count the numbers 1–10. Each row is marked with a visual marker in the form of a carving or water-based paint to ensure it is safe for children [60].

Wood as the primary material has pedagogical relevance. Its texture stimulates fine sensory stimulation and improves hand-eye coordination as children insert and remove beads. Furthermore, the use of reclaimed wood provides a concrete experience of the concept of reuse, supporting the early childhood education curriculum, which promotes environmental stewardship [61].

The second component is beads made from medium-sized seeds such as sago palm seeds, rubber seeds, or dried ketapang seeds. These seeds are chosen for their varied colors, attractive shapes, and light weight, making them safe for manipulation. To prevent choking hazards, the seeds are selected at a size greater than 2.5 cm and coated with food-grade varnish to prevent cracking [62].

The selection of seeds has ecological educational value because it introduces children to local biodiversity and the use of natural elements as learning media. In nature-based learning theory, natural objects enrich children's exploration, increasing focus and emotional engagement with the environment [63].

Number cards are made from cardboard used for food or milk packaging, or rough cardboard. Each card is cut to a standard 10x12 cm size with rounded corners for safety. The front of the card is printed or written with the numbers 1–10, accompanied by illustrations of dots or objects corresponding to the number [64].

Cardboard was chosen because it is readily available, easy to shape, and allows children to be involved in the creation process (e.g., coloring or gluing dots). This process aligns with the constructivist approach, which emphasizes that children construct understanding through direct involvement.

Expert Validation Results and Revisions

Expert validation is a crucial stage in the development of teaching aids, including environmentally friendly teaching aids for basic mathematics learning in early childhood education (PAUD), as it ensures product quality meets pedagogical standards and the characteristics of early childhood. The validation process typically involves media and materials experts who provide scores and provide feedback to refine the teaching aids before widespread use. For example, research by Rohmadheny and Laila (2020) showed that content validation by early childhood education experts resulted in scores indicating the instrument's suitability for implementation after minor revisions based on expert recommendations.[65]This validation is important to ensure that the teaching aids are not only attractive and environmentally friendly, but also effective in supporting the achievement of basic mathematical competencies according to the cognitive and motor development needs of PAUD children.

Furthermore, expert validation helps tailor teaching aids to children's characteristics, such as concentration levels, fine motor skills, and more concrete and visual learning styles. This aligns with the principle of teaching aid development, which must consider children's psychological and pedagogical aspects to ensure meaningful and enjoyable learning. Another study confirmed that

high-quality expert reports and evaluations, including discussions of limitations and alternative solutions, enhance the credibility and effectiveness of the developed product.[66]Therefore, revisions made based on expert validation results are not only technical in nature, but also pay attention to pedagogical aspects so that teaching aids can be used optimally in the context of early childhood education.

In the context of developing environmentally friendly teaching aids, the selection of materials and product design must also be validated to ensure they comply with the principles of sustainability and safety for children. Media expert validation assesses the aesthetics, safety, and ease of use of teaching aids, while material experts assess the suitability of the content to basic mathematics learning objectives. Research on the development of early childhood creativity assessment instruments involving various experts shows that multidisciplinary validation produces valid and effective products for use in learning [67]. Thus, expert validation and systematic revision are important foundations in producing teaching aids that are high-quality, environmentally friendly, and appropriate to the characteristics of PAUD children, thus optimally supporting the basic mathematics learning process.

Product Test Results and Effectiveness

The results of a trial of environmentally friendly teaching aids for basic mathematics learning in early childhood education (PAUD) showed significant improvements in children's understanding of number concepts, recognition of geometric shapes, and enthusiasm during the learning process. Intervention studies adopting a play-based learning approach indicate that this method is more effective in improving children's mathematical competence than traditional instructional approaches, especially for children with higher initial abilities [68]. The use of environmentally friendly and interactive teaching aids allows children to learn in a concrete and enjoyable way, thus facilitating the understanding of abstract concepts such as numbers and geometric shapes through direct experience and exploration [69].

Data from various studies supports that learning mathematics through engaging games and teaching aids can increase children's engagement and motivation, which in turn strengthens their understanding of basic mathematical concepts. For example, the integration of game-based learning in arithmetic instruction has shown significant improvements in academic performance and student engagement compared to conventional methods [70]. In addition, digital game-based learning has also been proven effective in strengthening mathematical problem-solving skills and maintaining conceptual understanding in the long term, which is relevant for early childhood cognitive development [71].

This analysis of the effectiveness of environmentally friendly teaching aids also highlights the importance of designs that address the developmental characteristics of preschool children, such as fine motor skills and the need for concrete and visual learning. A play-based learning approach allows children to learn actively and socially, supporting simultaneous cognitive and affective development [72]. Comparison with similar studies shows that teaching aids that combine game elements and interactivity not only improve understanding of mathematical concepts, but also foster enthusiasm and a positive attitude towards learning mathematics from an early age.

CONCLUSION

The development and testing of environmentally friendly teaching aids for basic mathematics learning in early childhood education (PAUD) showed positive and promising results in improving the quality of mathematics learning in early childhood. Validation by media and materials experts resulted in high validity scores, indicating that the teaching aids are suitable for use and are in accordance with the pedagogical needs and developmental characteristics of PAUD children. The product trials showed significant improvements in understanding number concepts and recognition of geometric shapes, as well as high enthusiasm among children during the learning process, indicating the effectiveness of the teaching aids in supporting play-based learning.

The advantages of these eco-friendly teaching aids lie not only in their educational aspects, but also in the use of sustainable and child-safe materials, which simultaneously fosters ecological awareness from an early age. Studies on the use of eco-friendly learning media such as "situng" and plastic straw manipulatives show that they are effective in improving basic math skills while reducing negative environmental impacts. This learning approach that integrates environmental and mathematical aspects aligns with the principles of holistic education that prioritize children's cognitive, affective, and social development simultaneously.

Furthermore, the use of contextually developed interactive technology and digital media has also positively contributed to improving the motivation and mathematics learning outcomes of early childhood education (PAUD) students. Media such as illustrated e-LKPD (learning materials) and interactive digital batik art-based applications have significantly improved children's logical mathematical intelligence and engagement, although infrastructure and teacher training challenges remain. This demonstrates that innovative learning media that combine environmental aspects, technology, and play approaches can be an effective solution for basic mathematics learning in PAUD.

REFERENCES

[1] Z. Liu, "An analysis of the policy on early childhood mathematics education in China," *BCP Business & Management*, p., 2023, doi: 10.54691/bcpbm.v41i.4420.

[2] M. O. Padilla, N. Velasco, and S. A. Ortiz, "Analysis of pedagogical content knowledge for teaching mathematics in early childhood education," *Journal of Infrastructure, Policy and Development*, p., 2025, doi: 10.24294/jipd10135.

[3] F. Moreno-Pino, R. Jiménez-Fontana, J. Domingo, and P. Goded, "Training in Mathematics Education from a Sustainability Perspective: A Case Study of University Teachers' Views," *Educ Sci (Basel)*, p., 2022, doi: 10.3390/educsci12030199.

[4] M. S. Rahmawati and I. Amri, "The Role of Parents at Mathematics Learning Innovation in Early Education," *Indonesian Journal of Early Childhood Education Studies*, vol. 9, pp. 40–47, 2020, doi: 10.15294/ijeces.v9i1.38349.

[5] P. Sihvonen, R. Lappalainen, J. Herranen, and M. Aksela, "Promoting Sustainability Together with Parents in Early Childhood Education," *Educ Sci (Basel)*, p., 2024, doi: 10.3390/educsci14050541.

[6] D. Martín-Cudero, R. Guede-Cid, P. Tolmos, and A. Cid-Cid, "Development of a Mathematical Experience from a STEM and Sustainable Development Approach for Primary Education Pre-Service Teachers," *Educ Sci (Basel)*, p., 2024, doi: 10.3390/educsci14050495.

[7] Á. Alsina, N. Pincheira, B. Barquero, I. Sellas, and M. Marimon-Martí, "Responsive mathematics teaching and mathematics teacher noticing: a systematic review in early childhood and primary education," *Mathematics Education Research Journal*, p., 2025, doi: 10.1007/s13394-025-00519-2.

[8] T. Ingkavara and P. Yasri, "Evaluating the Efficacy of an Integrative Instructional Framework in Mathematics Education for Students," *European Journal of Mathematics and Science Education*, p., 2025, doi: 10.12973/ejmse.6.1.51.

[9] F. D'angelo and N. Iliev, "Teaching Mathematics to Young Children through the Use of Concrete and Virtual Manipulatives.," p., 2012, [Online]. Available: https://consensus.app/papers/teaching-mathematics-to-young-children-through-the-use-of-dangelo-iliev/987acc788f7d5ffba99f22eb2b90d0f8/

[10] N. S. M. S. Elmey *et al.*, "Play To Learn: A Literature Review On Parental Involvement In Play-Based Early Mathematics," *Quantum Journal of Social Sciences and Humanities*, p., 2025, doi: 10.55197/qjssh.v6i3.693.

[11] W. Ahmad, A. Ahmad, K. Ostrowski, F. Aslam, and P. Joyklad, "A scientometric review of waste material utilization in concrete for sustainable construction," *Case Studies in Construction Materials*, p., 2021, doi: 10.1016/j.cscm.2021.e00683.

[12] M. Khayankhyarvaa, "Mathematics Lesson Demonstration: 'Amd' Method And Its Application," *International Journal of Innovative Technologies in Social Science*, p., 2025, doi: 10.31435/ijitss.1(45).2025.3196.

[13] I. Indrawati and W. Wahira, "Creating Sustainable Business Interest Through Innovation in Early Childhood Education," *Journal of Social Science and Economics (JOSSE)*, p., 2024, doi: 10.70188/7vgp6g16.

[14] C.-S. Su, D. Díaz-Levicoy, C. Vásquez, and C. Hsu, "Sustainable Development Education for Training and Service Teachers Teaching Mathematics: A Systematic Review," *Sustainability*, p., 2023, doi: 10.3390/su15108435.

[15] A. Summer, "A Sustainable Way of Teaching Basic Mathematics," *Discourse and Communication for Sustainable Education*, vol. 11, pp. 106–120, 2020, doi: 10.2478/dcse-2020-0021.

[16] R. Meylani, "Mathematical Thinking and Learning in Early Childhood: A Consolidated Qualitative Synthesis of Cutting-Edge Research Literature," *Journal of Qualitative Research in Education*, p., 2024, doi: 10.14689/enad.40.1966.

[17] A. Solihin, N. Mariana, W. Wiryanto, I. Rahmawati, and S. Suryanti, "Integrating Ethnomathematics of Zero Waste Culture Based ESD to Enhance Students' Creative Thinking and Sustainability Consciousness," *Journal of Innovation and Research in Primary Education*, p., 2025, doi: 10.56916/jirpe.v4i2.1221.

[18] M. S. Rusiman *et al.*, "The use of concrete material in teaching and learning mathematics," p., 2017, [Online]. Available: https://consensus.app/papers/the-use-of-concrete-material-in-teaching-and-learning-rusiman-mohamad/6235962da7c8509493b54fe1fc27e43f/

[19] J. Louw and H. Claassens, "Enhancing Mathematical Skills of Learners in the Early Childhood Phase Through Play-Based Learning: A Review of Literature," *Journal of Education and Learning*, p., 2024, doi: 10.5539/jel.v14n2p172.

[20] A. López-Alcarria, M. De Fátima Poza-Vílches, M. T. Pozo-Llorente, and J. Gutiérrez-Pérez, "Water, Waste Material, and Energy as Key Dimensions of Sustainable Management of Early Childhood Eco-Schools: An Environmental Literacy Model Based on Teachers Action-Competencies (ELTAC)," *Water (Basel)*, p., 2021, doi: 10.3390/w13020145.

[21] A. Baroody, D. Clements, and J. Sarama, "Teaching and Learning Mathematics in Early Childhood Programs," *The Wiley Handbook of Early Childhood Care and Education*, p., 2019, doi: 10.1002/9781119148104.ch15.

[22] M. Poje, I. Marinić, A. Stanisavljević, and I. R. Dika, "Environmental Education on Sustainable Principles in Kindergartens—A Foundation or an Option?," *Sustainability*, p., 2024, doi: 10.3390/su16072707.

[23] F. Vogt, B. Hauser, R. Stebler, K. Rechsteiner, and C. Urech, "Learning through play – pedagogy and learning outcomes in early childhood mathematics," *European Early Childhood Education Research Journal*, vol. 26, pp. 589–603, 2018, doi: 10.1080/1350293x.2018.1487160.

[24] A. Baroody, "The Use of Concrete Experiences in Early Childhood Mathematics Instruction.," *Adv Child Dev Behav*, vol. 53, pp. 43–94, 2017, doi: 10.1016/bs.acdb.2017.03.001.

[25] E. Marlina, W. T. Mahesa, A. R. Julianti, and N. B. Cahayati, "Multiplication And Division Learning Assistance Using The Fun Learning Method Assisted By Recycling Teaching Aids At Kober Bina Warga Mekarjaya," *Inaba of Community Services Journal (Inacos-J)*, p., 2023, doi: 10.56956/inacos.v2i01.193.

[26] C. Björklund, M. Van Den Heuvel-Panhuizen, and A. Kullberg, "Research on early childhood mathematics teaching and learning," *ZDM*, pp. 1–13, 2020, doi: 10.1007/s11858-020-01177-3.

[27] R.-S. Lu, H.-C. K. Lin, Y.-C. Yang, and Y.-P. Chen, "Integrating Urban Mining Concepts Through AI-Generated Storytelling and Visuals: Advancing Sustainability Education in Early Childhood," *Sustainability*, p., 2024, doi: 10.3390/su162411304.

[28] Syafdaningsih, Rukiyah, and F. Utami, "Educational Game Tools in Early Childhood Mathematics Learning," *Proceedings of the 4th Sriwijaya University Learning and Education International Conference (SULE-IC 2020)*, p., 2020, doi: 10.2991/assehr.k.201230.110.

[29] S. A. P. Lestari, F. Nurapriani, and D. S. Kusumaningrum, "Integrating Sustainable Development Principles in Learning Mathematics to Stimulate Sustainable Skills in Future Generations," *Jurnal Rekayasa Sistem Industri*, p., 2024, doi: 10.26593/jrsi.v13i1.7167.1-10.

[30] E. Ramiati, I. Mashuri, R. Faishol, D. Wariyani, Y. T. Andini, and E. I. E. Putri, "Effects Of Plastic Straw Manipulatives On Elementary Math Addition Skills," *AT TA'LIM : Jurnal Madrasah Ibtidaiyah*, p., 2025, doi: 10.69552/taklim.v4i1.3041.

[31] I. Royani, S. Suriyani, and R. Tjahyaningsih, "Utilizing Recycled Materials as Innovative Educational Media to Enhance Early Childhood Learning," *International Journal Education and Computer Studies (IJECS)*, p., 2025, doi: 10.35870/ijecs.v5i2.5077.

[32] M. Poje, I. Marinić, A. Stanisavljević, and I. R. Dika, "Environmental Education on Sustainable Principles in Kindergartens—A Foundation or an Option?," *Sustainability*, p., 2024, doi: 10.3390/su16072707.

[33] D. M. Sari *et al.*, "Transforming Household Waste into Educational Play Tools: A Sustainable Approach to Early Childhood Education," *Altifani Journal: International Journal of Community Engagement*, p., 2024, doi: 10.32502/altifani.v5i1.328.

[34] H. S. Oh, M. J. Jang, and S. J. Kim, "Design of the waste Separation educational tools for Infants to Eco-Friendly Life education," *Korea Institute of Design Research Society*, p., 2024, doi: 10.46248/kidrs.2024.4.696.

[35] T. Abanoz and D. Yabaş, "Seeding sustainable futures: enhancing children's knowledge of content and skills through early STEM education," *Environ Educ Res*, vol. 31, pp. 981–1000, 2025, doi: 10.1080/13504622.2025.2465722.

[36] C. Vásquez, M. Seckel, and Á. Alsina, "Belief system of future teachers on Education for Sustainable Development in math classes," *Uniciencia*, vol. 34, pp. 1–30, 2020, doi: 10.15359/ru.34-2.1.

[37] S. Sudarti, B. Sumardjoko, H. Harsono, S. Narimo, and Y. Surono, "Utilizing Natural Materials in Early Mathematics Education: Applying Bruner's Theory to Early Childhood Learning in Surakarta," *Journal of Posthumanism*, p., 2025, doi: 10.63332/joph.v5i3.783.

[38] L. Mdodana-Zide, "Using ADDIE model for scaffolded learning and teaching intervention," *Interdisciplinary Journal of Education Research*, p., 2024, doi: 10.38140/ijer-2024.vol6.28.

[39] U. Manshur, F. Rozi, L. Saleha, and C. Sholihah, "Eco-Friendly Media: Assistance in Developing Educational Props from Waste Materials in Probolinggo City," *GUYUB: Journal of Community Engagement*, p., 2024, doi: 10.33650/guyub.v5i1.8317.

[40] A. N. Nur, Jamilah, I. Ismail, A. U. Taufik, and Syamsul, "A Empowering Learning Through Innovative Worksheets: A Search, Solve, Create and Share Approach to Independent Practicum on Growth and Development Materials," *Biosel Biology Science and Education*, p., 2025, doi: 10.33477/bs.v14i2.7880.

[41] M. Y. Agatha, A. Najib, P. A. N. Avanda, L. Latifah, and S. R. Ana, "Environmentally Friendly Educational Innovation Tool To Recognize Numbers from Inorganic Waste," *Empowerment Society*, p., 2024, doi: 10.30741/eps.v7i2.1324.

[42] M. A. Adeoye *et al.*, "Revolutionizing Education: Unleashing the Power of the ADDIE Model for Effective Teaching and Learning," *JPI (Jurnal Pendidikan Indonesia)*, p., 2024, doi: 10.23887/jpiundiksha.v13i1.68624.

[43] M. Meyer, C. Kammrad, and R. Esser, "The Role of Experiencing Self-Efficacy When Completing Tasks—Education for Sustainable Development in Mathematics," *Sustainability*, p., 2025, doi: 10.3390/su17104298.

[44] N. Watanabe, "Effective Simple Mathematics Play at Home in Early Childhood: Promoting both Non-cognitive and Cognitive Skills in Early Childhood," *International Electronic Journal of Mathematics Education*, p., 2019, doi: 10.29333/iejme/5739.

[45] E. Widyastuti and Susiana, "Using the ADDIE model to develop learning material for actuarial mathematics," *J Phys Conf Ser*, vol. 1188, p., 2019, doi: 10.1088/1742-6596/1188/1/012052.

[46] G. Cebrián, R. Palau, and J. Mogas, "The Smart Classroom as a Means to the Development of ESD Methodologies," *Sustainability*, p., 2020, doi: 10.3390/su12073010.

[47] A. Ben-Eliyahu, "Sustainable Learning in Education," *Sustainability*, vol. 13, p. 4250, 2021, doi: 10.3390/su13084250.

[48] M. Chen, T. Pei, E. K. Jeronen, Z. Wang, and L. Xu, "Teaching and Learning Methods for Promoting Sustainability in Tourism Education," *Sustainability*, p., 2022, doi: 10.3390/su142114592.

[49] M. Versteijlen and A. Wals, "Developing Design Principles for Sustainability-Oriented Blended Learning in Higher Education," *Sustainability*, p., 2023, doi: 10.3390/su15108150.

[50] M. Tun, "Fulfilling a new obligation: Teaching and learning of sustainable healthcare in the medical education curriculum," *Med Teach*, vol. 41, pp. 1168–1177, 2019, doi: 10.1080/0142159x.2019.1623870.

[51] E. Jääskä, K. Aaltonen, and J. Kujala, "Game-Based Learning in Project Sustainability Management Education," *Sustainability*, p., 2021, doi: 10.3390/su13158204.

[52] N. Ahmad, N. Hoda, and F. Alahmari, "Developing a Cloud-Based Mobile Learning Adoption Model to Promote Sustainable Education," *Sustainability*, p., 2020, doi: 10.3390/su12083126.

[53] G. McGrath, L. Lockstone-Binney, F. Ong, E. Wilson-Evered, M. Blaer, and P. Whitelaw, "Teaching sustainability in tourism education: a teaching simulation," *Journal of Sustainable Tourism*, vol. 29, pp. 795–812, 2020, doi: 10.1080/09669582.2020.1791892.

[54] C.-C. Lin, A. Huang, and O. Lu, "Artificial intelligence in intelligent tutoring systems toward sustainable education: a systematic review," *Smart Learning Environments*, vol. 10, pp. 1–22, 2023, doi: 10.1186/s40561-023-00260-y.

[55] P. Clery, S. d'Arch Smith, O. Marsden, and K. Leedham-Green, "Sustainability in quality improvement (SusQI): a case-study in undergraduate medical education," *BMC Med Educ*, vol. 21, p., 2021, doi: 10.1186/s12909-021-02817-2.

[56] S. N. D. Mahmud, H. Husnin, and T. M. T. Soh, "Teaching Presence in Online Gamified Education for Sustainability Learning," *Sustainability*, p., 2020, doi: 10.3390/su12093801.

[57] H. Lee and Y. Hwang, "Technology-Enhanced Education through VR-Making and Metaverse-Linking to Foster Teacher Readiness and Sustainable Learning," *Sustainability*, p., 2022, doi: 10.3390/su14084786.

[58] E. Sinakou, V. Donche, J. B.-D. Pauw, and P. Petegem, "Designing Powerful Learning Environments in Education for Sustainable Development: A Conceptual Framework," *Sustainability*, p., 2019, doi: 10.3390/su11215994.

[59] A. Rico, E. Agirre-Basurko, A. Ruiz-González, I. Palacios-Agúndez, and D. Zuazagoitia, "Integrating Mathematics and Science Teaching in the Context of Education for Sustainable Development: Design and Pilot Implementation of a Teaching-Learning Sequence about Air Quality with Pre-Service Primary Teachers," *Sustainability*, vol. 13, p. 4500, 2021, doi: 10.3390/su13084500.

[60] N. Jones, G. Horton, M. Guppy, G. Brown, and J. Boulton, "Pedagogical strategies for supporting learning and student well-being in environmentally sustainable healthcare," *Front Med (Lausanne)*, vol. 12, p., 2025, doi: 10.3389/fmed.2025.1446569.

[61] A. Rico, E. Agirre-Basurko, A. Ruiz-González, I. Palacios-Agúndez, and D. Zuazagoitia, "Integrating Mathematics and Science Teaching in the Context of Education for Sustainable Development: Design and Pilot Implementation of a Teaching-Learning Sequence about Air Quality with Pre-Service Primary Teachers," *Sustainability*, vol. 13, p. 4500, 2021, doi: 10.3390/su13084500.

[62] G. Geitz and J. De Geus, "Design-based education, sustainable teaching, and learning," *Cogent Education*, vol. 6, p., 2019, doi: 10.1080/2331186x.2019.1647919.

[63] R. Shadiev, B. Reynolds, and R. Li, "The Use of Digital Technology for Sustainable Teaching and Learning," *Sustainability*, p., 2024, doi: 10.3390/su16135353.

[64] S. Wilhelm, R. Förster, and A. Zimmermann, "Implementing Competence Orientation: Towards Constructively Aligned Education for Sustainable Development in University-Level Teaching-And-Learning," *Sustainability*, p., 2019, doi: 10.3390/su11071891.

[65] A. Melinder, H. K. Kierulf, and P. Ulleberg, "Towards Higher Quality in Expert Reports in Child Protection: Why Emphasizing Limitations and Alternative Explanations Matters," *Int J Child Maltreat*, p., 2025, doi: 10.1007/s42448-025-00226-2.

[66] P. Rohmadheny and Y. Laila, "Expert Judgment of Learning Achievements Evaluation Instrument for Children Age 4-5 Years Old," vol. 5, pp. 168–176, 2020, doi: 10.31004/obsesi.v5i1.524.

[67] M. N. Sitorus, A. Yus, and D. Saragi, "Development of Computer-Based Kindergarten Children's Creativity Portfolio Assessment Instruments," vol. 3, pp. 1421–1427, 2020, doi: 10.33258/birle.v3i3.1207.

[68] R. N. Xasanovna, "The Effectiveness Of Game-Based Learning In Teaching Arithmetic Operations To Primary School Students," *International Journal Of Science And Technology*, p., 2025, doi: 10.70728/tech.v2.i05.076.

[69] J. A. Cayang and E. M. Ursabia, "https://www.jippublication.com/leveling-up-mathematical-skills-the-effectiveness-of-game-based-learning," *Journal of Interdisciplinary Perspectives*, p., 2024, doi: 10.69569/jip.2024.0087a.

[70] O. Al-Hassan, L. M. Alhasan, R. AlAli, A. Al-Barakat, K. Al-Saud, and N. Ibrahim, "Enhancing Early Childhood Mathematics Skills Learning through Digital Game-Based Learning," *International Journal of Learning, Teaching and Educational Research*, p., 2025, doi: 10.26803/ijlter.24.2.10.

[71] M. Ismaiel, Q. A. Rauf, R. Bibi, R. Siddique, and S. Ali, "The effectiveness of game-based learning in improving fractions mastery among 5th-grade students, comparing it with traditional teaching methods.," *Social Science Review Archives*, p., 2025, doi: 10.70670/sra.v3i1.424.

[72] S. Mawalia and H. A. Setiaji, "Experimentation Of Video Based Learning Methods With Game Based Learning In Improving Students' Understanding Of Mathematical Concepts," *Mathline : Jurnal Matematika dan Pendidikan Matematika*, p., 2025, doi: 10.31943/mathline.v10i2.942.