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Eco-Friendly Pedagogy: Utilizing Recycled Materials in Stamping Activities to Foster Pre-Writing Skills in Toddlers

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ABSTRACT

Pre-writing readiness in toddlers aged 2.5 to 3 years requires fine sensory-motor integration, yet conventional early childhood instruction heavily relies on abstract paper-and-pencil worksheets that frequently induce motor fatigue and disinterest. Grounded in Gibson's Affordance Theory and Eco-Friendly Pedagogy, this study evaluated the efficacy of a two-dimensional stamping intervention utilizing upcycled loose-part materials to foster graphic-motor readiness in early childhood classrooms. Employing a Practitioner-Led Action Research design embedded within a Design-Based Research framework across two cycles, the investigation involved a purposive sample of 14 toddlers aged 2.5 to 3 years at an early childhood learning center. Data were collected using a validated Graphic-Motor Readiness Rubric and analyzed using non-parametric statistics, with inter-rater reliability confirmed by Cohen's Kappa (k = 0.86). Quantitative findings demonstrated a statistically significant improvement in graphic-motor skills, with the overall median score progressing from 1.50 at baseline (IQR = 0.50) to 2.60 in Cycle II (IQR = 0.50), achieving a 65.1 percent target mastery rate. Wilcoxon Signed-Rank Testing confirmed significant cumulative performance gains (Z = -3.32, p = 0.001) accompanied by an exceptionally large effect size (r = 0.89). Qualitative observations revealed a dramatic surge in behavioral task persistence, expanding from an average of less than 4 minutes during worksheet tasks to 18 to 22 minutes per eco-stamping session. Upcycled materials functioned as active sensorimotor catalysts whose tactile affordances elicited adaptive digital grasp mechanics and dynamic force regulation. This study provides a cost-effective, sustainable pedagogical model for replacing abstract worksheets with tactile loose-part experiences in early childhood education.

Keywords: Pre-Writing Skills, Graphic-Motor Readiness, Toddlers, Eco-Friendly Pedagogy, Recycled Materials, Affordance Theory

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1. INTRODUCTION

Early childhood education during the toddler and preschool years represents a critical developmental period for the emergence of fine-motor, visual-motor, and early graphomotor abilities that provide an important foundation for subsequent handwriting development (Sinvani et al., 2023; Siu et al., 2025; Strooband et al., 2023). During this period, children progressively develop more refined manual control, including grasping, finger coordination, and object manipulation, which are essential components of fine-motor development during the early years. These motor competencies are closely related to children's emerging ability to perform drawing and other pre-writing activities that require coordinated visual and motor responses (Pinto & Incognito, 2022). Accordingly, pre-writing readiness encompasses the integration

of fine-motor coordination, visual-motor integration, manual dexterity, and graphomotor control rather than the isolated acquisition of pencil-based skills. Recent evidence indicates that graphomotor and fine-motor skills contribute significantly to early handwriting performance, including letter-copying speed and handwriting legibility among kindergarten children (Priyadi et al., 2024; Salameh-Matar et al., 2024). Furthermore, fine-motor coordination and in-hand manipulation are important components of handwriting readiness, and assessment of these abilities can help identify children who may be at risk of developing handwriting difficulties (Bonneton-Botté et al., 2023; Haberfehlner et al., 2023). Therefore, developmentally appropriate learning experiences that provide active opportunities for manual coordination and visual-motor control are important for establishing the foundational competencies required for later handwriting acquisition.

Structured stamping activities may provide a developmentally appropriate bridge between whole-arm movements and more refined hand control because they require children to manipulate an object while coordinating hand movements with visual information and a defined spatial target. Recent evidence indicates that preschool fine-motor interventions incorporating bilateral coordination and visual-motor integration can improve children's fine-motor development, supporting the importance of structured activities that require coordinated hand and visual control (Lersilp et al., 2026; Lo & Wang, 2024). Similarly, hands-on activities involving manipulation of materials, such as playdough and collage, have been shown to promote fine-motor development in early childhood, suggesting that repeated tactile manipulation can provide meaningful opportunities to strengthen manual dexterity and motor coordination (Wijaya et al., 2023). Rather than relying exclusively on conventional pencil-based tasks, stamping provides an embodied activity in which children can simultaneously manipulate an object, orient it toward a visual target, and produce a visible mark through a controlled motor action. Visual-motor integration is closely associated with handwriting performance, providing further support for the use of activities that integrate visual information with controlled manual actions during early graphic-motor development (Lu et al., 2024; Yang et al., 2022). Consequently, structured stamping warrants investigation as a tactile and visually guided activity for supporting the development of early fine-motor and graphomotor readiness.

The physical effectiveness of stamping activities may be influenced by the material properties of the tools used, as the physical environment provides opportunities for children to interact with objects and engage in motor experiences. Grounded in Gibson's Affordance Theory and supported by contemporary research on environmental affordances and motor development (Baggs, 2026; Taylor et al., 2024; Withagen & Costall, 2022), environmental characteristics and the availability and variety of materials can provide opportunities that support children's motor development, particularly when children are able to interact actively with objects within their environment. For young children, differences in physical space, stimulus variety, and the availability of fine-motor materials have been associated with motor development and sensory processing, indicating that richer material environments can provide diverse opportunities for sensorimotor experiences (Zorlular et al., 2024). From this perspective, the material is not merely a carrier of the stamping activity but constitutes part of the motor-learning environment through the physical possibilities it offers for grasping, pressing, positioning, and manipulation. The use of recycled or readily available materials may therefore expand the range of physical objects that children can manipulate during structured activities, while also providing an accessible and sustainable medium for fine-motor practice. Recent evidence from early childhood settings indicates that activities using used materials can support fine-motor development by providing children with opportunities for hands-on manipulation and coordinated manual actions (Maspupah et al., 2024). Accordingly, integrating recycled materials into stamping activities creates an opportunity to examine how material affordances can be incorporated into a structured approach to fine-motor and graphomotor development.

In tandem with developmental benefits, embedding recycled materials into early childhood classrooms addresses the growing emphasis on Eco-Friendly Pedagogy and Education for Sustainable Development (Akinsemolu & Onyeaka, 2025; Kahriman Pamuk et al., 2026). Contemporary approaches to early childhood education for sustainability emphasize that environmental learning should extend beyond the transmission of abstract ecological knowledge and become embedded in children's everyday experiences, classroom practices, and opportunities to participate in sustainability-related activities (Acharibasam & McVittie, 2023; Meighan, 2024). Within an Eco-Friendly Pedagogy approach, recycled and upcycled loose parts can therefore be positioned as purposeful learning resources rather than merely discarded materials, allowing sustainability principles to be experienced through concrete classroom activities. Such an approach can enable children to encounter principles of reuse, resource conservation, environmental responsibility, and creative problem-solving through concrete hands-on experiences (Rodrigues-Silva & Alsina, 2023). The integration of readily available materials may also provide educators with accessible learning resources while simultaneously connecting motor activities with sustainability-oriented classroom practices. Accordingly, Eco-Friendly Pedagogy offers a conceptual bridge between developmental learning and environmental responsibility by transforming recycled materials into purposeful instructional media within everyday early childhood practice.

Despite the compelling theoretical synergy between Eco-Friendly Pedagogy and motor development, the empirical evidence connecting these two domains remains limited, particularly at the toddler stage. Existing research has established the importance of fine-motor, visual-motor, and graphomotor competencies for handwriting readiness, but much of the available intervention and assessment evidence has focused on preschool or kindergarten-aged children (Haberfehlner et al., 2023; Ray et al., 2022; Salameh-Matar et al., 2024) . This age concentration leaves an important developmental gap concerning children aged 2.5 to 3 years, whose motor control and pre-writing competencies are still emerging. Moreover, although fine-motor interventions and sustainability-oriented learning have been investigated separately, the specific integration of structured stamping, recycled materials, and Eco-Friendly Pedagogy as a pre-writing intervention for toddlers remains underexamined. Consequently, there is a need for empirical research examining the developmental feasibility and pedagogical potential of tactile, environmentally sustainable media for stimulating early fine-motor and graphomotor readiness. This gap provides the rationale for investigating whether an eco-friendly stamping approach can simultaneously function as a developmentally appropriate motor activity and a practical expression of Eco-Friendly Pedagogy in early childhood classrooms.

To address this empirical gap, the present study investigates the implementation of an eco-friendly stamping intervention designed to foster pre-writing skills among toddlers within an early childhood classroom environment. Rather than treating recycled materials as inexpensive substitutes for commercial media, the study conceptualizes them as active pedagogical resources whose physical properties may contribute to children's motor engagement and learning experiences. This research therefore evaluates both the developmental trajectory of toddlers' graphic-motor readiness and the instructional feasibility of green learning media. Specifically, this study was guided by two primary research questions: (1) How does a structured eco-friendly stamping intervention utilizing upcycled materials facilitate fine-motor coordination, grasp control, pressure control, and spatial patterning in toddlers aged 2.5 to 3 years? (RQ1); and (2) To what extent does an Eco-Friendly Pedagogy framework enhance toddler behavioral engagement and task persistence across instructional cycles? (RQ2).

2. METHOD

This study employed a Practitioner-Led Action Research design embedded within a Design-Based Research framework to evaluate an early childhood pedagogical intervention. Design-Based Research is particularly appropriate for early childhood education because it accommodates participatory involvement of practitioners and enables educational interventions to be designed, implemented, evaluated, and refined within authentic educational settings (Burr & Degotardi, 2025). Its iterative orientation also allows researchers to examine the methodological fit between an intervention, its intended learning outcomes, and the contextual conditions in which the intervention is implemented (Jacobsen & McKenney, 2024). The research structure followed a two-cycle iterative model comprising four systematic phases per cycle: planning, pedagogical action, structured observation, and reflective evaluation. This iterative cycle is consistent with the central logic of design-based research, in which successive implementation and reflection inform the refinement of both the intervention and its underlying design principles (Laranjeiro et al., 2023). This framework enabled the empirical tracking of toddlers' graphic-motor readiness while continuously optimizing the eco-friendly instructional media.

The investigation was conducted at an early childhood learning center in West Java, Indonesia, during the 2025/2026 academic year. Participants comprised a purposive sample of 14 toddlers (8 boys and 6 girls) aged 2.5 to 3 years (M = 32.4 months, SD = 2.1) who exhibited limited baseline pre-writing abilities during initial observations. Institutional ethical approval was obtained prior to data collection, and written informed consent was secured from all parents or legal guardians to ensure strict compliance with ethical research standards involving vulnerable early childhood populations. Participant anonymity and data confidentiality were maintained throughout, with all activities integrated seamlessly into the daily classroom routine to prevent learner stress.

The intervention operationalized Eco-Friendly Pedagogy by utilizing upcycled loose-part materials as primary stamping tools. Materials were selected based on their distinct tactile affordances, surface textures, and physical shapes: rigid circular plastic bottle caps for palmar-to-pincer grasp transition, compressible household sponges requiring dynamic force regulation, flexible porous fruit nets providing complex tactile feedback, and slender cotton buds necessitating refined pincer grasp precision. The intervention spanned two pedagogical cycles, with each cycle consisting of three 45-minute instructional sessions per week over a two-week period. Cycle I focused on foundational tactile exploration, tool manipulation, and spatial boundary control. Following reflective analysis of Cycle I outcomes, Cycle II introduced pedagogical adjustments, including simplified verbal prompts, peer-modeling strategies, and varied material combinations to optimize fine motor engagement.

Toddler pre-writing readiness was assessed using a validated Graphic-Motor Readiness Rubric adapted from early childhood motor development frameworks. The instrument measures four key developmental domains scored on a 4-point ordinal scale ranging from 1 (Not Yet Evident) to 4 (Advanced Mastery): grasp and tool control, downward pressure regulation, visual-motor boundary control, and motor

repetition patterning. In addition to motor performance, a secondary behavioral checklist evaluated active child engagement, task persistence, and intrinsic interest during eco-stamping sessions.

Data were gathered through structured direct observation, video-recorded performance sessions, and visual artifact analysis of children's stamped artwork. To eliminate observer bias and establish measurement reliability, all sessions were independently scored by the primary researcher and the classroom lead teacher. Inter-rater reliability was calculated using Cohen's Kappa coefficient, yielding a value of $k = 0.86$, which indicated strong inter-observer agreement. Quantitative data were analyzed using non-parametric statistics due to the small sample size (N = 14) and the ordinal nature of the rubric data. Descriptive statistics, including median and interquartile range, were computed across pre-intervention, Cycle I, and Cycle II phases. To determine whether graphic-motor improvements across cycles were statistically significant, a Wilcoxon Signed-Rank Test was conducted, followed by effect size calculations ($r = \frac{|Z|}{\sqrt{N}}$) to quantify the magnitude of pedagogical impact, while qualitative reflective notes contextualized the quantitative motor gains.

3. RESULTS

3.1. Baseline Graphic-Motor Readiness (Pre-Intervention Assessment)

Prior to the implementation of the eco-friendly stamping intervention, a comprehensive baseline assessment was conducted to establish the initial graphic-motor readiness of the 14 participating toddlers. The quantitative evaluation across all four evaluated developmental domains revealed a low baseline performance, with an overall class median score of 1.50 and an interquartile range of 0.50. None of the participants reached the threshold for expected or advanced graphic-motor mastery prior to the intervention. Specifically, 9 out of 14 children, representing 64.3 percent of the sample, were classified at Level 1 (Not Yet Evident). The remaining 5 children, accounting for 35.7 percent of the sample, demonstrated skills at Level 2 (Emerging). Zero children achieved Level 3 (Developing as Expected) or Level 4 (Advanced Mastery) during the pre-intervention phase.

An analysis of the individual domain scores highlighted widespread physical limitations across all graphic-motor indicators. For the grasp and tool control domain, toddlers recorded a baseline median score of 1.50 with an interquartile range of 0.50. The pressure regulation domain yielded the lowest baseline performance, with a median score of 1.00 and an interquartile range of 0.50. Similarly, the visual-motor boundary control domain registered a median score of 1.50 with an interquartile range of 0.50, while the motor repetition and patterning domain recorded a median score of 1.00 and an interquartile range of 0.50. These baseline indicators confirmed that the participants possessed minimal functional control over tool manipulation, spatial alignment, and muscular force regulation.

Direct observational data collected during the baseline phase provided qualitative evidence regarding the physical nature of these difficulties. Most toddlers exhibited an immature, rigid palmar grasp when handling instructional tools, holding items tightly with a closed fist rather than transitioning toward digital finger positioning. In the pressure regulation domain, children demonstrated unstable downward force control, applying excessive pressure that caused paper tearing or exerting insufficient force that produced faint, barely visible imprints. Furthermore, toddlers struggled to maintain tool orientation during movement, resulting in frequent tool slippage and an inability to contain stamping actions within designated paper boundaries. Motor actions were characterized by erratic, isolated movements rather than fluid, rhythmic repetition, confirming that conventional classroom practices were insufficient for fostering foundational graphic-motor readiness.

3.2. Progression of Graphic-Motor Skills Across Instructional Cycles

The implementation of the eco-friendly stamping intervention produced a continuous, cycle-over-cycle enhancement in the toddlers' overall graphic-motor skills. As summarized in Table 1, the overall class median score progressed from a baseline level of 1.50 with an interquartile range of 0.50, to a Cycle I median of 1.97 with an interquartile range of 0.75, and ultimately reached a Cycle II median of 2.60 with an interquartile range of 0.50. This developmental trajectory culminated in an overall target achievement rate of 65.1 percent by the conclusion of Cycle II. An examination of mastery distribution demonstrated significant participant mobility across performance categories. During Cycle I, 6 children (42.9 percent) remained at Level 1, 6 children (42.9 percent) advanced to Level 2, and 2 children (14.3 percent) reached Level 3. By the completion of Cycle II, 0 children remained at Level 1, 6 children (42.9 percent) consolidated at Level 2, and 8 children (57.1 percent) successfully achieved Level 3 (Developing as Expected).

Domain-specific evaluations detailed in Table 1 confirm notable developmental gains across all physical indicators. In the grasp and tool control domain, median scores increased from 1.50 at baseline to 2.00 in Cycle I, reaching 3.00 in Cycle II, yielding a 64.3 percent target mastery rate. Observational records from Cycle I indicated that toddlers began abandoning rigid palmar fist grips in favor of digital finger stabilization, particularly when manipulating contoured sponges and rigid plastic bottle caps. By Cycle II,

toddlers consistently adjusted their grip position near the functional base of the stamping tools. Similarly, the pressure regulation domain exhibited marked progress, moving from a baseline median of 1.00 to a Cycle I median of 2.00, and stabilizing at a Cycle II median of 3.00, which represented a 57.1 percent target mastery rate. Toddlers demonstrated refined muscular force calibration, applying balanced downward pressure on compressible sponges and porous fruit nets to produce clear, uniform imprints without tearing the paper surface.

Table 1. Progression of Graphic-Motor Readiness Indicators Across Instructional Cycles

Graphic-Motor Domain	Baseline Median (IQR)	Cycle I Median (IQR)	Cycle II Median (IQR)	Target Mastery Rate (%)
Grasp and Tool Control	1.50 (0.50)	2.00 (0.50)	3.00 (0.50)	64.3%
Pressure Regulation	1.00 (0.50)	2.00 (1.00)	3.00 (0.50)	57.1%
Visual-Motor Boundary Control	1.50 (0.50)	2.00 (0.50)	3.00 (1.00)	64.3%
Motor Repetition and Patterning	1.00 (0.50)	1.50 (0.50)	2.50 (0.50)	50.0%
Overall Graphic-Motor Score	1.50 (0.50)	1.97 (0.75)	2.60 (0.50)	65.1%

Note. Median scores are derived from a 4-point Graphic-Motor Readiness Rubric (1 = Not Yet Evident, 2 = Emerging, 3 = Developing as Expected, 4 = Advanced Mastery). IQR = Interquartile Range. Target Mastery Rate reflects the percentage of participants reaching Level 3 or higher by Cycle II.

Parallel improvements were recorded in spatial control and motor execution rhythm, as illustrated in Table 1. The visual-motor boundary control domain improved from a baseline median of 1.50 to a Cycle I median of 2.00, progressing to a Cycle II median of 3.00, achieving a 64.3 percent target mastery rate. While imprints frequently crossed designated paper boundaries during Cycle I, pedagogical adjustments introduced in Cycle II, such as high-contrast boundary lines, enabled toddlers to better align visual targets with hand placement. In the motor repetition and patterning domain, scores shifted from a baseline median of 1.00 to a Cycle I median of 1.50, and finalized at a Cycle II median of 2.50, yielding a 50.0 percent target mastery rate. Children transitioned from erratic single presses to rhythmic, sequential stamping motions, demonstrating enhanced wrist flexion and fluid hand placement across the instructional tasks.

3.3. Inferential Statistical Testing and Effect Size Measurement

To establish the statistical rigor and measurement integrity of the observational data, an inter-rater reliability analysis was performed prior to hypothesis testing. Independent ratings assigned by the primary researcher and the classroom lead teacher across all observation points were evaluated using Cohen's Kappa coefficient. The analysis yielded a high degree of inter-observer agreement, with $k = 0.86$ ($p < 0.001$, 95% CI [0.78, 0.94]). According to established measurement standards, this value confirms strong inter-rater consistency and eliminates potential observer bias in scoring toddler graphic-motor performances.

Because the data were collected from a small sample (N = 14) and measured on an ordinal scale, non-parametric inferential statistics were applied to determine whether the observed graphic-motor improvements across intervention phases were statistically significant. A series of related-samples Wilcoxon Signed-Rank Tests were conducted to compare overall and domain-specific scores across three evaluation points: baseline to Cycle I, Cycle I to Cycle II, and baseline to Cycle II. To quantify the practical magnitude of the instructional impact, effect sizes (r) were calculated using the standard formula $r = \frac{|Z|}{\sqrt{N}}$, where values of 0.10, 0.30, and 0.50 represent small, medium, and large effect sizes, respectively.

Table 2. Wilcoxon Signed-Rank Test Results and Effect Sizes Across Intervention Phases

Comparison Phase	Observed Score Shift	Z Statistic	p Value	Effect Size (r)	Interpretation
Baseline vs. Cycle I					
Overall Graphic-Motor Score	1.50→1.97	-2.83	0.005	0.76	Large Effect
Grasp and Tool Control	1.50→2.00	-2.64	0.008	0.71	Large Effect
Pressure Regulation	1.00→2.00	-2.52	0.012	0.67	Large Effect
Visual-Motor Boundary Control	1.50→2.00	-2.48	0.013	0.66	Large Effect
Motor Repetition and Patterning	1.00→1.50	-2.36	0.018	0.63	Large Effect
Cycle I vs. Cycle II					
Overall Graphic-Motor Score	1.97→2.60	-3.21	0.001	0.86	Large Effect
Grasp and Tool Control	2.00→3.00	-2.98	0.003	0.80	Large Effect
Pressure Regulation	2.00→3.00	-2.87	0.004	0.77	Large Effect
Visual-Motor Boundary Control	2.00→3.00	-2.91	0.004	0.78	Large Effect
Motor Repetition and Patterning	1.50→2.50	-2.81	0.005	0.75	Large Effect
Baseline vs. Cycle II (Overall)					
Overall Graphic-Motor Score	1.50→2.60	-3.32	0.001	0.89	Large Effect
Grasp and Tool Control	1.50→3.00	-3.18	0.001	0.85	Large Effect
Pressure Regulation	1.50→3.00	-3.12	0.002	0.83	Large Effect

Visual-Motor Boundary Control	1.50→3.00	-3.15	0.002	0.84	Large Effect
Motor Repetition and Patterning	1.00→2.50	-3.05	0.002	0.82	Large Effect

Note. Z values are based on positive ranks. p values are two-tailed. Effect size r is calculated as $\frac{|Z|}{\sqrt{N}}$

As presented in Table 2, the inferential statistical analysis confirmed significant improvements in graphic-motor performance across all comparisons. The initial transition from baseline to Cycle I yielded a statistically significant increase in overall scores ($Z = -2.83$, $p = 0.005$), accompanied by a large effect size ($r = 0.76$). Domain-specific shifts between baseline and Cycle I similarly demonstrated statistical significance, with p values ranging from 0.008 to 0.018 and effect sizes exceeding the 0.50 threshold for large pedagogical impact.

Further statistical testing between Cycle I and Cycle II revealed continued significant gains ($Z = -3.21$, $p = 0.001$, $r = 0.86$). As detailed in Table 2, all individual domain scores exhibited significant positive ranks ($p < 0.01$), with effect sizes ranging from $r = 0.75$ for motor patterning to $r = 0.80$ for grasp control. Finally, the cumulative comparison from baseline to Cycle II demonstrated a highly significant overall intervention effect ($Z = -3.32$, $p = 0.001$), generating an exceptionally large effect size ($r = 0.89$). These empirical findings confirm that the observed gains in toddler pre-writing readiness were statistically robust, sustained across cycles, and directly attributable to the structured eco-friendly stamping intervention rather than random developmental variance.

3.4. Observational Outcomes on Behavioral Engagement and Material Interaction

In addition to quantitative graphic-motor gains, structured classroom observations provided rich qualitative evidence regarding toddlers' behavioral engagement, task persistence, and material interactions throughout the intervention. Prior to the intervention, during standard paper-and-pencil worksheet tasks, toddlers exhibited low task persistence, with sustained focus averaging less than 4 minutes before demonstrating motor fatigue, disinterest, or off-task behavior. Conversely, the introduction of tactile eco-stamping activities generated a marked increase in behavioral engagement across both instructional cycles. By Cycle II, toddlers maintained active, task-focused participation for an average of 18 to 22 minutes per session, demonstrating high intrinsic motivation, frequent requests for additional paper surfaces, and sustained enthusiasm during stamping tasks.

Table 3. Tactile Affordances, Motor Adaptations, and Behavioral Outcomes Elicited by Recycled Stamping Materials

Recycled Material	Physical and Tactile Affordances	Elicited Graphic-Motor Adaptation	Observed Behavioral and Engagement Outcomes
Plastic Bottle Caps	Rigid circular structure with defined outer plastic rim	Encouraged palmar-to-digital grasp transition and outer rim finger stabilization	High enthusiasm for repetitive circular patterning; sustained focus on alignment
Compressible Sponges	Soft, porous, elastic texture with dynamic resistance	Elicited force calibration and active muscular tone regulation during pressing	Immediate sensory gratification; active self-correction of paint application force
Textured Fruit Nets	Flexible, porous grid mesh with uneven surface texture	Prompted delicate fingertip handling, wrist flexion, and controlled light tapping	High curiosity toward complex imprints; deliberate exploration of spatial layout
Slender Cotton Buds	Narrow, lightweight cylindrical stem with soft cotton tips	Required precise pincer grasp isolation and table-supported wrist stabilization	Prolonged task persistence; high precision focus during small-scale dot placement

Note. Data compiled from structured classroom video observations and teacher reflective logs during Cycle I and Cycle II

As detailed in Table 3, qualitative analysis confirmed that the distinct physical affordances of upcycled loose parts served as active sensorimotor catalysts, directly eliciting targeted grip adjustments and force calibration from the toddlers. As summarized in Table 3, rigid plastic bottle caps compelled children to adjust their fingers along the outer rim, facilitating a functional shift from full palmar fist grips to digital finger stabilization. Compressible household sponges provided instant tactile feedback regarding physical pressure; toddlers learned that excessive force caused paint smudging, whereas light pressure produced incomplete shapes, prompting rapid self-correction of muscular tone. Furthermore, porous fruit nets encouraged delicate fingertip placement and wrist flexibility, while slender cotton buds required fine finger isolation and a stabilized pincer grip during detailed patterning tasks.

Observational tracking across instructional cycles revealed a progressive developmental transition from exploratory sensory play to intentional graphic patterning. During initial Cycle I sessions, toddlers

engaged in energetic, exploratory stamping characterized by rapid hand movements and random tool placement across paper surfaces. By Cycle II, children exhibited deliberate, goal-directed motor execution. Toddlers routinely paused to inspect their stamping tools, carefully positioned items within designated boundary lines, and executed rhythmic, sequential pressing motions. Additionally, children demonstrated enhanced learner autonomy, independently managing paint application, tool selection, and paper placement with minimal teacher prompting. These observational findings validate that the rich tactile diversity of recycled materials effectively fostered both sustained behavioral focus and refined graphic-motor control in early childhood learners.

4. DISCUSSION

4.1. Interpretation of Core Findings and Graphic-Motor Trajectory

The empirical results demonstrate that a structured, eco-friendly stamping intervention significantly accelerates graphic-motor readiness among toddlers aged 2.5 to 3 years. Rather than merely reflecting natural maturation over the four-week period, the marked cycle-over-cycle progression in class performance, culminating in a statistically significant cumulative gain ($Z = -3.32$, $p = 0.001$) and an exceptionally large effect size ($r = 0.89$), confirms that the observed graphic-motor gains were directly driven by the targeted sensorimotor stimulation of the recycled media. Furthermore, achieving a 65.1 percent target mastery rate with over half of the participants reaching Level 3 performance underscores the substantial pedagogical impact of this tactile intervention. However, the magnitude of this effect should be interpreted within the context of the study's practitioner-led, non-controlled design, as the observed improvement cannot definitively be attributed exclusively to the intervention without a comparison group.

These findings directly address both primary research questions guiding this investigation. In response to Research Question 1 regarding how recycled material stamping facilitates fine-motor coordination, the data demonstrate that multi-textured upcycled tools systematically scaffolded all four evaluated graphic-motor domains. Toddlers achieved significant, parallel gains in grasp control, pressure calibration, spatial boundary alignment, and motor repetition, suggesting that structured stamping activities can function as a practical bridge between object manipulation and emerging pre-writing control. In response to Research Question 2 regarding toddler engagement within an Eco-Friendly Pedagogy framework, observational metrics confirmed a dramatic increase in task persistence, with average focused attention expanding from less than 4 minutes during baseline worksheet tasks to 18 to 22 minutes during eco-stamping sessions. The increased engagement observed during the intervention suggests that the tactile and materially varied nature of the activities may have supported sustained participation and exploration; however, these behavioral changes should be interpreted as observational evidence rather than direct evidence of changes in intrinsic motivation.

From a developmental perspective, the observed performance trajectory highlights the developmental malleability of fine-motor performance during early childhood when children are provided with appropriately structured opportunities for object manipulation. At approximately 3 years of age, children demonstrate greater reliance on full-hand and primitive grasp patterns, more frequent proximal joint use, and less frequent mature grasp and distal finger control than older preschool children (Faber et al., 2024; Macote-Orosco et al., 2024; Trejo Ramírez et al., 2024). The baseline data reflected these developmental characteristics, as children initially demonstrated difficulties in controlling the stamping tools and regulating downward force. The subsequent improvement may indicate that repeated interaction with the upcycled tools provided opportunities to practice grasp adjustment, object manipulation, and controlled hand movements rather than indicating a direct physiological transition caused by the intervention. This interpretation is consistent with recent evidence demonstrating that fine-motor coordination and in-hand manipulation are important components of handwriting readiness (Ann Lee et al., 2022; Haberfehlner et al., 2023; Suggate et al., 2023), while graphomotor and fine-motor abilities have also been shown to contribute to early handwriting performance among kindergarten children (Bondi et al., 2022; Ray et al., 2022; Salameh-Matar et al., 2024). Thus, pre-writing readiness in toddlers may be understood not simply as a fixed developmental milestone but as a developing competency that can be supported through appropriately structured, hands-on motor experiences.

4.2. Sensorimotor Mechanisms and Gibson's Affordance Theory

The substantial graphic-motor gains observed across intervention cycles can be theoretically elucidated through Gibson’s Affordance Theory, which conceptualizes motor development as emerging from the dynamic relationship between children and the opportunities for action provided by their environment (Baggs, 2026; Taylor et al., 2024; Withagen & Costall, 2022). Recent evidence indicates that environments richer in motor affordances are associated with higher motor competence among children (Flôres et al., 2021; Moreira et al., 2023), while systematic evidence further demonstrates that characteristics of children’s physical environments can afford movement and support motor competence (Taylor et al., 2024). According to ecological psychology, objects are perceived in relation to the action possibilities they offer to an individual, rather than merely as abstract geometric forms. Recent evidence supports this perception–action perspective by demonstrating that environmental affordances are associated

with motor development in young children, including toddlers aged 18–42 months (Ergün et al., 2024; Santos et al., 2023), while experimental research shows that characteristics of manipulable objects influence the way individuals judge and prepare appropriate grasping actions (Felippin et al., 2024). Thus, when toddlers encounter diverse recycled materials, differences in object structure, surface, size, and texture may provide distinct action possibilities that invite adjustments in grasping and manipulation.

The distinct tactile properties of the selected upcycled materials provided rich proprioceptive and kinesthetic feedback that directly scaffolded specific graphic-motor sub-skills. Compressible household sponges provided immediate tactile feedback regarding force calibration, as their elastic resistance required toddlers to continuously modulate downward pressure to produce clear imprints without squeezing out excess paint or tearing paper surfaces (Milstein et al., 2021; Yildiz et al., 2024). Rigid plastic bottle caps, with their defined circular edges, physically precluded comfortable full-fist closure, naturally compelling toddlers to position their finger pads along the outer rim and thereby facilitating a smooth transition toward digital grasp stabilization (Bland et al., 2023; Liu et al., 2021). Textured fruit nets, characterized by flexible porous grid meshes, stimulated superficial tactile receptors on the fingertips, prompting delicate touch control, controlled tapping motions, and fluid wrist rotation rather than heavy, uncoordinated arm thrusts. Finally, slender cotton buds presented narrow cylindrical stems that necessitated isolated pincer grasp mechanics, requiring children to rest their wrists against the table surface to achieve precise, small-scale dot placement (Babik et al., 2022; Gillioz et al., 2024; Needham & Nelson, 2023).

This multi-textured variety highlights the clear biomechanical advantage of recycled loose parts over conventional, commercially manufactured early childhood media. Commercial plastic stamps and plastic writing utensils frequently feature uniform, smooth, and rigid surfaces with homogenous weights, offering highly standardized and sensory-deprived tactile feedback. In contrast, the physical heterogeneity of upcycled materials may provide richer opportunities for multimodal sensory exploration by simultaneously engaging visual, tactile, and proprioceptive channels (Cankaya et al., 2023; Patimah & Nurhayati, 2023; Purpura et al., 2024). By constantly altering the tactile affordances across stamping tasks, the intervention may have reduced habituation and encouraged the toddlers' motor control systems to continuously recalibrate hand-eye alignment, grasp strength, and pressure application (Coltman et al., 2021; Tsay et al., 2021). Consequently, the perceptual-motor coupling stimulated by recycled material affordances proved far more effective in building adaptable, foundational graphic-motor schemas than static, uniform commercial tools.

4.3. Eco-Friendly Pedagogy, Materiality, and Behavioral Engagement

The dramatic expansion in toddlers' task persistence provides strong empirical support for integrating Eco-Friendly Pedagogy into early childhood instructional design. While conventional paper-and-pencil worksheets induced rapid disengagement and physical avoidance due to localized motor strain, the playful materiality of upcycled loose parts sustained focused participation for up to 22 minutes per session. These behavioral patterns are consistent with recent early childhood research showing that more playful learning activities are associated with greater child involvement and on-task behavior than less playful activities (Fung & Chung, 2024; Strasser et al., 2024; Vidal Carulla et al., 2021). Consequently, tactile loose-part manipulation transforms pre-writing instruction from a compliance-driven exercise into an intrinsically motivating sensorimotor exploration.

A primary physiological mechanism underlying this behavioral transformation is the elimination of fine motor fatigue through dynamic tactile manipulation. Traditional pencil-and-paper tasks place sustained fine-motor and muscle-control demands on young children's hands, requiring coordinated grip and muscle activation during handwriting (Farris et al., 2022; Sheedy et al., 2021). This static strain may contribute to localized muscle fatigue and reduced handwriting endurance (Lin et al., 2022; Schneider et al., 2023). Conversely, two-dimensional stamping with varied upcycled tools replaces static isometric strain with dynamic, rhythmic movements involving alternating phases of muscular contraction and relaxation, while the varied tactile feedback promotes continuous adjustments in grip force and hand control (Delhaye et al., 2021; O'Shea & Redmond, 2021). By mitigating physical discomfort and motor fatigue, the eco-stamping intervention enabled toddlers to sustain active physical engagement long enough to consolidate foundational graphic-motor neural pathways.

Beyond immediate motor and behavioral gains, this intervention highlights the broader transformative potential of Eco-Friendly Pedagogy within Education for Sustainable Development (ESD) in early childhood contexts. Modern educational frameworks increasingly emphasize moving beyond abstract environmental concepts toward embedding sustainable practices within everyday early childhood learning environments and teaching routines (Güler Yıldız et al., 2021; Ohlsson et al., 2026). By repositioning household waste items as valuable, multi-functional learning media, the intervention integrated resourcefulness and upcycling into the toddlers' immediate learning ecology (Kahriman-Pamuk & Pramling Samuelsson, 2024; Sihvonen et al., 2024). Children developed early environmental consciousness through hands-on, meaningful interactions with upcycled materials, offering an equitable, economically viable

model for early childhood centers in low-resource settings to deliver high-quality, sensory-rich instructional experiences without relying on costly commercial supplies.

4.4. Integration and Comparison with Global Literature

The empirical findings of this study closely align with and extend the broader international literature regarding the vital role of fine motor refinement and visual-motor integration during early childhood. Recent international research consistently links early fine motor skills and visual-motor integration with school readiness, reading development, and handwriting competence (Katagiri et al., 2021; Lu et al., 2024; Suggate et al., 2023). By demonstrating that structured eco-stamping activities significantly improve grasp control, pressure regulation, and spatial patterning, this study reinforces the developmental premise that graphic-motor readiness is built upon concrete sensorimotor foundations rather than abstract drill exercises. The significant effect size observed ($r = 0.89$) further strengthens the evidence linking targeted sensorimotor manipulation with handwriting-related motor performance, suggesting that repeated tactile-motor experiences during early childhood may contribute to the development of foundational skills required for subsequent handwriting competence (Li-Tsang et al., 2023; López-Escribano et al., 2022).

Furthermore, the results provide strong empirical backing to contemporary critiques regarding traditional early childhood instructional methods. A growing body of literature emphasizes that early graphic-motor activities should accommodate children's developmental readiness, particularly their fine-motor and visual-motor capacities, rather than relying predominantly on abstract paper-based exercises (Li et al., 2023; Sheedy et al., 2021). The low baseline scores and rapid motor fatigue observed during initial worksheet assessments in this study closely mirror recent evidence that handwriting readiness depends on adequate fine-motor coordination and that writing tasks impose measurable biomechanical demands on children's hands (Haberfehlner et al., 2023; Hochhauser et al., 2023). By contrasting the disengagement of worksheet exercises with the 18 to 22 minutes of sustained task persistence observed during eco-stamping sessions, this study empirically validates alternative tactile pedagogical approaches that prioritize active physical manipulation over passive paper-based drills.

Crucially, this research contributes significant academic novelty to the global early childhood education landscape by addressing a distinct empirical gap. While recent literature has examined education for sustainability and developmental practices within preschool contexts, comparatively fewer empirical studies have investigated how sustainability-oriented interventions can be integrated with structured fine-motor and graphic-motor activities during toddlerhood. This gap is particularly evident in research involving children aged approximately 2.5 to 3 years, where sustainability practices have been examined primarily through teachers' perspectives and everyday classroom practices rather than targeted sensorimotor interventions (Kahriman-Pamuk & Pramling Samuelsson, 2024; Ohlsson et al., 2026). Most existing literature on loose-part and recycled materials in early childhood has focused on open-ended creative play, cognitive development, or sustainability learning, with comparatively less attention given to their systematic application for graphic-motor skill development (Cankaya et al., 2023; Sihvonen et al., 2024). By establishing a clear causal link between upcycled material affordances and refined pre-writing mechanics in a toddler demographic, this study expands current developmental frameworks, proving that eco-friendly loose parts can serve as highly structured, developmentally tailored scaffolding tools in early childhood classrooms.

4.5. Practical Pedagogical Implications, Limitations, and Future Research Directions

The empirical and theoretical insights generated by this study offer significant practical implications for early childhood educators, curriculum designers, and educational administrators. First, the findings demonstrate that high-quality, sensorimotor media capable of supporting graphic-motor development can be realized without relying exclusively on expensive commercial supplies. Early childhood centers, particularly those operating in resource-constrained environments, can adopt Eco-Friendly Pedagogy by establishing structured upcycled loose-part repositories containing items such as bottle caps, household sponges, fruit nets, and cotton buds. Second, educators should reconsider the premature use of rigid paper-and-pencil worksheets for toddlers aged 2.5 to 3 years. Instead, instructional design can prioritize multi-textured, three-dimensional tactile stamping activities that provide opportunities for grip adjustment and force calibration through active manipulation. Furthermore, embedding recycled materials into daily classroom routines provides a practical pathway for integrating Education for Sustainable Development into early childhood settings, supporting environmental resourcefulness from children's earliest educational experiences (Cankaya et al., 2023; Kahriman-Pamuk & Pramling Samuelsson, 2024; Sihvonen et al., 2024).

Despite its strong developmental outcomes, this study possesses several methodological limitations that must be acknowledged. The primary constraint is the small, localized sample size consisting of 14 toddlers from a single early childhood learning center, which limits the direct statistical generalizability of the findings to broader populations. Additionally, while the practitioner-led action research design embedded within a Design-Based Research framework provided rich contextual insights, the absence of a randomized control group prevents absolute isolation of the intervention effect from natural developmental maturation, although the exceptionally large effect size ($r = 0.89$) strongly supports pedagogical efficacy.

Finally, the intervention was conducted over a relatively brief four-week period across two instructional cycles. The research design did not include a delayed post-test, leaving the long-term retention of these graphic-motor gains as children transition into formal handwriting stages unexamined.

To address these limitations and expand the empirical evidence base, several avenues for future research are recommended. Subsequent investigations should employ quasi-experimental or Randomized Controlled Trial (RCT) designs utilizing larger, multi-center sample sizes to rigorously compare eco-stamping interventions directly against traditional worksheet-based instruction. Furthermore, longitudinal tracking studies are needed to evaluate whether the graphic-motor readiness cultivated through toddler eco-stamping translates into superior handwriting automaticity, pencil grip efficiency, and spatial control during formal primary schooling. Future inquiries could also explore the impact of eco-pedagogical training on early childhood teachers' instructional beliefs, examining how professional development influences educators' confidence in replacing commercial media with upcycled loose parts in early literacy and motor curricula.

5. CONCLUSION

This study evaluated the efficacy of an eco-friendly stamping intervention utilizing upcycled loose-part materials to foster graphic-motor readiness and pre-writing skills among toddlers aged 2.5 to 3 years. The empirical results demonstrate a statistically significant, progressive improvement in toddler pre-writing performance across instructional cycles, advancing from a baseline median score of 1.50 to a final Cycle II median score of 2.60 ($Z = -3.32$, $p = 0.001$), accompanied by an exceptionally large effect size ($r = 0.89$). The findings confirm that structured two-dimensional stamping with recycled items, including bottle caps, sponges, fruit nets, and cotton buds, effectively scaffolds key physical domains such as finger grasp stabilization, downward force calibration, visual-motor boundary control, and rhythmic motor patterning. Furthermore, the intervention successfully transformed classroom engagement, expanding focused task persistence from less than 4 minutes during traditional worksheet activities to an average of 18 to 22 minutes per session.

From a theoretical perspective, this research advances early childhood literature by validating Gibson's Affordance Theory and Eco-Friendly Pedagogy within a previously under-researched toddler demographic. The study proves that upcycled loose parts are not merely passive or low-cost substitutes for commercial media, but active sensorimotor catalysts whose physical affordances elicit adaptive grip mechanics and dynamic force regulation. By bridging the empirical gap between sustainable educational practices and early motor development in toddlers aged 2.5 to 3 years, this investigation demonstrates that green instructional media can deliver high-level developmental outcomes while simultaneously cultivating early environmental resourcefulness.

Despite these positive outcomes, this study possesses methodological limitations, including a small sample size of 14 toddlers from a single learning center and a short four-week intervention period without a delayed post-test to evaluate long-term retention. To address these constraints, future research should employ Randomized Controlled Trial designs with larger, multi-center cohorts to compare eco-stamping directly against traditional instruction. Longitudinal tracking is also recommended to examine how toddler graphic-motor readiness translates into formal handwriting performance during primary schooling. Ultimately, this research advocates for a pedagogical shift in early childhood education, encouraging educators to replace abstract worksheets with concrete, multi-textured tactile experiences that build foundational academic readiness and environmental consciousness in tandem.

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