



## EFFECTS OF RECYCLING-BASED MATHEMATICAL TASKS ON PRESCHOOL CHILDREN'S PATTERN RECOGNITION

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### Abstract

Pattern recognition is an important component of early mathematical development and provides a foundation for later algebraic and relational thinking. This study examined whether recycling-based mathematical tasks improve preschool children's pattern recognition performance more effectively than traditional manipulative-based instruction. A randomized pre-test/post-test experimental design was used with 60 preschool children assigned to experimental and control groups. The experimental group participated in an eight-week intervention involving structured mathematical tasks with recycled materials, organized according to the Eco-Mathematical Embodied Learning framework, whereas the control group received traditional patterning instruction using standard classroom manipulatives. Children's pattern recognition performance was assessed using a researcher-developed assessment, and teacher-rated engagement scores were used to document participation. Results showed that the experimental group demonstrated greater improvement than the control group. Repeated measures ANOVA indicated a significant group by time interaction, and teacher-rated engagement scores were higher in the experimental group. The findings suggest that recycled materials, when used within a structured instructional sequence, may serve as accessible, sensory-rich resources for supporting early mathematical learning in sustainability-related classroom practices.

**Keywords:** early childhood mathematics, pattern recognition, recycled materials, sustainability education, preschool children

### INTRODUCTION

Early mathematical development provides an important foundation for children's later learning, problem solving, and participation in formal mathematics education. Among early mathematical competencies, pattern recognition has a central role because it supports children's ability to identify regularities, compare relationships, extend sequences, and develop early forms of algebraic and relational thinking (Bakker et al., 2024; Rizos & Gkrekas, 2024). Research has shown that preschool children's patterning abilities are associated with later mathematical achievement and broader cognitive development, making pattern recognition a meaningful focus for early childhood mathematics instruction (Coolen et al., 2023; Ling & Loh, 2023). Evidence from primary school samples reinforces this continuity. A recent meta-analysis of 81 effect sizes reported a moderate positive association between patterning skills and mathematical achievement across early childhood and the primary grades (Zhang et al., 2026), and a large-scale study of first- to fourth-grade students showed that pattern recognition continues to develop, and to pose difficulty, well beyond the preschool years (Reuter & Reinhold, 2025). Strengthening pattern recognition before school entry is therefore relevant not only for preschool mathematics but also for the mathematical demands children meet in primary education.

In preschool classrooms, patterning activities are commonly supported through traditional classroom manipulatives such as blocks, beads, counters, and colored shapes, and prior research has emphasized that the transfer of learning depends partly on how knowledge is connected to contexts, materials, and later applications (Barnett & Ceci, 2002). These materials can provide useful opportunities for hands-on learning; however, they may also present mathematical ideas in relatively uniform and decontextualized ways. In contrast, everyday materials may offer children more familiar, authentic,



and sensory-rich opportunities to explore mathematical relationships. Recycled materials such as bottle caps, cardboard tubes, egg cartons, fabric scraps, and packaging materials vary naturally in color, shape, size, texture, and sound. These properties can support classification, comparison, sequencing, and pattern construction while also connecting mathematical activity to children's everyday experiences.

The use of recycled materials may also help situate early mathematics instruction within sustainability-related classroom practices, which are increasingly emphasized in preschool education as part of meaningful, developmentally appropriate learning experiences (Ohlsson et al., 2024a; Watt & Frydenberg, 2025). Early childhood education increasingly emphasizes the importance of helping young children engage in environmental issues through concrete, age-appropriate experiences. When children use discarded or reusable materials in mathematical tasks, they encounter mathematics not only as an abstract skill but also as part of meaningful activity connected to reuse, waste reduction, and care for the environment. Such integration may be especially valuable in early childhood settings, where learning is often grounded in play, sensory exploration, social interaction, and familiar objects.

Although research has separately examined embodied mathematics learning, material-based instruction, and sustainability education in early childhood, fewer studies have investigated how recycled materials can be systematically used to support specific mathematical competencies such as pattern recognition. In particular, limited experimental evidence is available on whether recycling-based mathematical tasks can produce stronger gains in preschool children's pattern recognition than traditional manipulative-based instruction. Addressing this gap is important because recycled materials may offer a low-cost and accessible way to enrich early mathematics learning while connecting classroom activities to sustainability-related practices.

This study draws on the Eco-Mathematical Embodied Learning (EMEL) framework as an instructional design structure for organizing recycling-based mathematical tasks. In this study, EMEL is used to sequence children's experiences across four phases: environmental engagement, mathematical mapping, cognitive construction, and environmental integration. Rather than treating recycled materials only as substitutes for traditional classroom manipulatives, the framework positions them as authentic learning resources that can support embodied engagement, pattern recognition, and sustainability-related meaning making.

The purpose of this study was to examine whether recycling-based mathematical tasks designed within the EMEL framework improve preschool children's pattern recognition performance more effectively than conventional instruction using standard classroom manipulatives. The study also examined children's engagement during recycling-based mathematical activities through structured teacher observations. By focusing on pattern recognition in preschool classrooms, this study aimed to contribute to early childhood mathematics education by exploring how low-cost, familiar, and sustainability-related materials can be used to support children's mathematical learning.

## **Literature Review**

This section reviews the literature informing the design and focus of the present study. It first discusses pattern recognition as a foundational component of early mathematical development. It then considers material-based and embodied approaches to early mathematics learning, with particular attention to the role of authentic and sensory-rich materials. The next section examines sustainability-related learning in early childhood education and the potential of recycled materials to connect mathematical activity with everyday environmental practices. Finally, it presents the Eco-Mathematical Embodied Learning framework as the instructional design structure used to organize the recycling-based mathematical tasks in this study.

## **Pattern Recognition in Early Childhood Mathematics**

Pattern recognition is a foundational component of early mathematical thinking. It involves children's ability to notice regularities, identify repeating units, compare relationships, complete sequences, and extend patterns into new cases. These abilities are closely related to classification, seriation,



correspondence, relational reasoning, and early algebraic thinking (Papic et al., 2011; Björklund & Pramling, 2014). For preschool children, patterning activities provide opportunities to move beyond simple matching toward more flexible forms of mathematical reasoning, such as predicting what comes next, explaining a pattern rule, and recognizing the same structure across different materials or representations.

Pattern recognition is also developmentally appropriate for preschool classrooms because it can be explored through play, movement, talk, visual arrangements, and hands-on manipulation. Children can construct repeating patterns, growing patterns, and spatial patterns using objects that differ in color, shape, size, or texture. These activities support children's attention to structure and regularity, which are important for later mathematical learning.

Recent work has also highlighted the value of sequenced, multimodal, play-based experiences for supporting young children's attribute-based reasoning and classification. For example, Hainaut (2026) found that coordinated multimodal guided play supported pre-kindergarten children's movement from global recognition toward more analytic reasoning focused on defining attributes. This is relevant to pattern recognition because children's ability to attend to attributes is central to identifying, constructing, and extending patterns. For this reason, pattern recognition provides a useful context for examining how instructional materials shape early mathematical thinking. When children use objects to build or extend patterns, they must attend to both visible attributes and underlying structures. This makes patterning an appropriate focus for investigating whether recycled materials, with their natural variation and everyday familiarity, can support early mathematical learning differently from uniform traditional classroom manipulatives.

### **Material-Based and Embodied Mathematics Learning**

Embodied perspectives on mathematics education emphasize that mathematical understanding develops through action, perception, gesture, spatial experience, and interaction with physical tools and materials (Abrahamson et al., 2022; Alberto et al., 2022; Shvarts & Abrahamson, 2023; Way & Ginns, 2024). From this perspective, young children learn mathematical ideas not only through verbal explanation or symbolic representation, but also by building understanding through touching, moving, comparing, arranging, and transforming objects. This view is especially relevant in early childhood education, where learning is often grounded in sensory experience, play, and social interaction.

Manipulatives are commonly used in early mathematics instruction because they allow children to represent mathematical relationships concretely. Traditional classroom manipulatives can be helpful because they are durable, visually clear, and designed for repeated classroom use. However, their uniformity may sometimes limit opportunities for children to work with naturally varied materials. Recycled materials offer a different type of material experience, extending embodied and action-based views of mathematics learning beyond purpose-designed manipulatives toward familiar classroom materials (Alberto et al., 2022; Abrahamson et al., 2022). Variations in texture, size, color, shape, sound, and prior use can invite children to compare attributes, make decisions about relevant and irrelevant features, and construct patterns across less standardized objects. In this sense, recycled materials may provide a rich context for embodied mathematical activity.

The authenticity of materials may also influence children's engagement with mathematical tasks. Situated learning perspectives suggest that learning becomes more meaningful when it is connected to familiar objects, everyday practices, and socially relevant purposes (Lave & Wenger, 1991). Recycled materials are recognizable objects from children's homes, classrooms, and communities. When these materials are used in mathematical activities, children may connect patterning tasks to familiar experiences with consumption, reuse, sorting, and caring for shared spaces. This connection can make mathematical exploration more meaningful than activities that rely solely on purpose-designed materials. Recent early childhood research has also emphasized the importance of structured, hands-on experiences that connect cognition, action, and meaning. In a study on toy repair as engineering learning, Peleg and Levy (2026) showed that structured repair activities supported young children's functional understanding, design-oriented problem solving, and emotionally engaged



learning while also introducing values of sustainability and care. Although their study focused on engineering rather than mathematics, it supports the broader argument that authentic materials and meaningful object-based activity can bridge cognitive, affective, and practical dimensions of early learning. This perspective aligns with the present study's use of recycled materials as meaningful resources for mathematical exploration.

### **Sustainability-Related Learning in Early Childhood**

Sustainability education in early childhood has moved beyond simple nature appreciation toward broader attention to children's participation in environmentally meaningful practices. Research in early childhood education suggests that young children can engage with sustainability through concrete, developmentally appropriate experiences such as sorting materials, reusing objects, caring for classroom environments, and discussing everyday choices related to waste and resources (Hedefalk et al., 2015; Ernst & Burcak, 2019). Experimental and practice-oriented studies have also shown that sustainability-related early childhood experiences can support children's environmental understanding, social-emotional learning, and teacher-guided classroom participation (Kornilaki et al., 2022; Ohlsson et al., 2024b; Watt & Frydenberg, 2025). Such activities can help children begin to understand environmental responsibility in ways that are accessible and connected to daily life.

However, sustainability-related activities are often implemented separately from core academic learning, although recent preschool research emphasizes the need for intentional pedagogical planning and integrated learning environments in education for sustainability (Ohlsson et al., 2024b). Mathematics activities may be treated as one part of the curriculum, while environmental education is addressed through separate projects or thematic activities. This separation can limit opportunities for integrated learning. Recycling-based mathematical tasks offer one way to connect these domains by using sustainability-related materials and practices to support mathematical thinking. For example, children can sort recycled materials by attributes, create repeating or growing patterns with reused objects, and apply patterning skills to organize classroom recycling systems.

Recent studies suggest that sustainability in early childhood education is increasingly approached through pedagogical design, teacher practice, and meaningful classroom participation. Koşan and Güler-Yıldız (2026), for example, examined professional development designed to support preschool teachers' sustainability-related views and practices, showing that sustainability can be strengthened through intentional pedagogical planning. In addition, research on early childhood repair activities suggests that reuse and care for objects can provide concrete ways for children to participate in sustainability-related practices (Peleg & Levy, 2026). These studies support the relevance of positioning recycled materials not only as inexpensive resources, but also as objects that can connect classroom learning with sustainability-related meanings.

In this study, sustainability is not treated as a separate outcome measured independently from mathematics performance. Rather, it provides a meaningful classroom context for organizing mathematical activity. This distinction is important because the primary outcome of the study is children's pattern recognition performance. Sustainability-related practices are used to enrich the learning context, support engagement, and position recycled materials as authentic resources for early mathematical exploration.

### **The EMEL Framework as an Instructional Design Structure**

The Eco-Mathematical Embodied Learning framework was used in this study as an instructional design structure for sequencing recycling-based mathematical tasks. The framework brings together three complementary ideas: children learn mathematical concepts through embodied interaction with materials (Abrahamson et al., 2022; Alberto et al., 2022); learning becomes more meaningful when it is connected to familiar and socially relevant contexts (Barnett & Ceci, 2002; Lave & Wenger, 1991); and sustainability-related practices can provide concrete experiences for young children (Kornilaki et al., 2022; Ohlsson et al., 2024b). In this study, the framework guided how recycled materials were introduced, explored, mathematically structured, and connected to classroom practices.



The framework includes four phases. In the Environmental Engagement Phase, children explore recycled materials through sensory engagement, discussion of material origins, and classification activities. This phase is intended to activate children's familiarity with materials and support attention to attributes such as color, shape, size, texture, and function. In the Mathematical Mapping Phase, children begin to connect these material attributes to mathematical structures by creating simple patterns such as AB and AAB sequences or arranging objects by size, color, or quantity. In the Cognitive Construction Phase, children work with more complex patterning tasks, including completing, extending, and constructing patterns using varied recycled materials. In the Environmental Integration Phase, children apply patterning ideas to sustainability-related classroom practices, such as organizing recycling systems or explaining patterns to peers. Using EMEL as an instructional structure helped ensure that the intervention moved gradually from informal exploration toward more explicit mathematical reasoning and application. The framework also helped distinguish the experimental intervention from traditional manipulative-based instruction. In the experimental group, recycled materials were not used only as replacement objects; they were embedded within a sequence of tasks that connected sensory exploration, pattern construction, mathematical explanation, and sustainability-related classroom activity. This study therefore examines whether such a structured use of recycled materials can support preschool children's pattern recognition more effectively than conventional instruction using standard classroom manipulatives.

### Research Questions

This study used a randomized pre-test/post-test experimental design supplemented by structured teacher observations. Guided by the Eco-Mathematical Embodied Learning framework as an instructional design structure, the study addressed the following research questions:

1. To what extent do recycling-based mathematical tasks improve preschool children's pattern recognition performance compared with traditional manipulative-based instruction?
2. How do children's engagement levels during recycling-based mathematical tasks compare with those observed during traditional manipulative-based mathematics instruction?

The first research question examined the effect of the recycling-based intervention on children's pattern recognition performance through pre-test and post-test comparisons between the experimental and control groups. The second research question examined children's engagement during mathematics activities using structured teacher observation scores. Together, these questions focused on both learning outcomes and observed engagement while maintaining pattern recognition as the primary outcome of the study.

## METHOD

### Participants

The participants were 60 preschool children aged 4 to 6 years who were enrolled in three early childhood education centers. The centers had not previously implemented a systematic recycling-based mathematics curriculum. Children were assigned to either the experimental group ( $n = 30$ ) or the control group ( $n = 30$ ). Stratified random assignment was used to support balance across age and gender.

The experimental group included 16 girls and 14 boys, with a mean age of 5.2 years ( $SD = .7$ ). The control group included 15 girls and 15 boys, with a mean age of 5.1 years ( $SD = .8$ ). The age range was 4.1 to 6.0 years in the experimental group and 4.0 to 5.9 years in the control group. Table 1 presents the demographic characteristics of the participants.

**Table 1.** Demographic characteristics of participants

| Characteristic      | Experimental Group (n=30) | Control Group (n=30) |
|---------------------|---------------------------|----------------------|
| Gender (Girls/Boys) | 16/14                     | 15/15                |
| Mean Age (years)    | 5.2 (SD = .7)             | 5.1 (SD = .8)        |
| Age Range (years)   | 4.1 - 6.0                 | 4.0 - 5.9            |

Inclusion criteria required that children were enrolled in preschool, were between 4 and 6 years of age, had no prior systematic exposure to recycling-based mathematics activities, and followed typical developmental trajectories according to school records and teacher reports. Children with diagnosed developmental or learning disabilities that required individualized instructional adaptations were not included in the final sample. Children who missed more than 20% of the intervention sessions were also excluded from the final analysis to support consistency in intervention exposure.

### Research Design

The study used a randomized pre-test/post-test experimental design to examine the effects of recycling-based mathematical tasks on preschool children's pattern recognition performance. The independent variable was the type of mathematics instruction. Children in the experimental group participated in recycling-based mathematical tasks structured through the Eco-Mathematical Embodied Learning framework, whereas children in the control group received conventional patterning instruction using standard classroom manipulatives. The primary dependent variable was children's pattern recognition performance, measured through a researcher-developed pattern recognition assessment administered before and after the intervention. Children's engagement during mathematics activities was also documented through structured teacher observations.

The intervention lasted eight weeks and was organized according to the four phases of the EMEL framework. The Environmental Engagement Phase was implemented during weeks 1–2, the Mathematical Mapping Phase during weeks 3–4, the Cognitive Construction Phase during weeks 5–6, and the Environmental Integration Phase during weeks 7–8. This sequence was designed to move children gradually from informal exploration of recycled materials toward more explicit pattern construction, pattern extension, and application of patterning ideas within sustainability-related classroom practices.

In the experimental condition, recycling-based mathematical tasks were designed around four instructional principles. First, environmental embeddedness was supported by introducing tasks through brief discussions about where materials came from, how they are commonly used, and how they can be reused. Second, multi-sensory engagement was encouraged through children's tactile, visual, and auditory exploration of recycled materials. Third, material familiarity was emphasized by using objects drawn from children's everyday environments, such as bottle caps, cardboard tubes, egg cartons, packaging materials, and fabric scraps. Fourth, mathematical progression was built into the intervention by increasing the complexity of patterning tasks across the eight-week sequence.

During the Environmental Engagement Phase, children participated in activities such as "Treasure Sort," in which they sorted recycled materials by origin or observable attributes, such as household use, color, size, texture, and shape. The mathematical focus of this phase was classification and attribute recognition. In another activity, "Eco-Detective," children identified regularities, and repeated structures already present in recycled materials, such as ridges on bottle caps, compartments in egg cartons, or repeated shapes in packaging. During the Mathematical Mapping Phase, children began to use recycled materials to construct more explicit mathematical patterns. In "Green Sequences," children created AB and AAB patterns using sorted recycled materials. In "Recycling Line-Up," children arranged materials by size, color, or quantity to create simple growing patterns. The mathematical focus of this phase was connecting material attributes to pattern structures, including repeating units, order, and gradual change. During the Cognitive Construction Phase, the tasks involved more complex patterning demands. In "Pattern Puzzles," children completed and



extended patterns such as ABC, ABBC, and growing patterns using varied recycled materials. In “Eco-Engineering,” children used pattern principles to design simple structures or arrangements with recycled materials. The mathematical focus of this phase was pattern completion, pattern extension, spatial organization, and relational reasoning. During the Environmental Integration Phase, children applied patterning ideas to classroom-based sustainability practices. In “Community Helpers,” children created patterned labels, signs, or arrangements for classroom recycling systems. In “Pattern Ambassadors,” children explained simple patterning ideas using recycled materials in peer-sharing activities. The mathematical focus of this phase was transfer, mathematical communication, and the application of pattern recognition in meaningful classroom contexts.

The control condition addressed similar patterning objectives but used traditional classroom manipulatives rather than recycled materials. Children in the control group completed patterning activities involving blocks, counters, beads, or colored shapes. These activities focused on identifying, completing, and extending patterns, but they did not include the structured sustainability-related context or the four-phase recycled-material sequence used in the experimental condition.

### **Materials and Instruments**

Children’s pattern recognition performance was assessed using a 30-item pattern recognition assessment developed for the present study based on existing research on early childhood patterning (Papic et al., 2011; Wijns et al., 2019). The assessment included three subscales: pattern identification, pattern completion, and pattern extension, with 10 items in each subscale. Pattern identification items required children to recognize repeated units in visual or object-based sequences. Pattern completion items required children to identify the missing element in a partially completed pattern. Pattern extension items required children to continue a repeating or growing pattern according to its underlying structure.

For example, a pattern identification item asked children to identify what repeated in a sequence such as red circle–blue circle–red circle–blue circle. A pattern completion item asked children to select the missing element in a sequence such as triangle–square–triangle–. A pattern extension item asked children to continue a growing pattern such as one block–two blocks–three blocks–. Each item was scored on a 0–3 scale. A score of 0 indicated an incorrect or no response; 1 indicated a partially correct response showing limited recognition of the pattern; 2 indicated a correct response with minimal support or limited explanation; and 3 indicated a correct and independent response demonstrating recognition of the underlying pattern structure. Each subscale therefore ranged from 0 to 30. Total pattern recognition scores ranged from 0 to 90, with higher scores indicating stronger pattern recognition performance. To reduce overlap between the assessment and the intervention, the assessment items used neutral visual and object-based prompts rather than the recycled materials used in the experimental activities. This distinction was intended to ensure that the post-test measured children’s pattern recognition performance rather than familiarity with the specific materials used during the intervention. Evidence for content validity was established through expert review. Two experts in early childhood mathematics education evaluated the pattern recognition assessment in terms of developmental appropriateness, clarity of instructions, alignment with the three intended subscales, and suitability for children aged 4 to 6 years. Revisions were made based on their feedback to improve item clarity, visual presentation, and balance across difficulty levels.

Children’s engagement during mathematics activities was documented using a structured teacher observation checklist developed for the present study. The checklist was informed by observational approaches to involvement and engagement in early childhood education, particularly the Leuven Involvement Scale for Young Children (Laevers, 1994). The Leuven approach conceptualizes involvement as the degree to which children are focused, interested, mentally active, and engaged in an activity. In the present study, the checklist included 10 behavioral indicators rated on a 10-point scale, focusing on sustained attention, active participation, peer interaction, persistence, responsiveness to teacher prompts, and involvement with task materials.



The teacher observation checklist was used as a supplementary process measure rather than as a primary outcome measure. Teachers recorded children's engagement during designated mathematics activity sessions in both experimental and control conditions. The engagement scores were used to compare children's observed participation in recycling-based and traditional manipulative-based mathematics activities and were interpreted in relation to the pattern recognition findings. Before the intervention, teachers were oriented to the indicators and scoring procedures to support consistent use of the checklist across activity sessions. Internal consistency was examined for the total pattern recognition assessment, its three subscales, and the engagement checklist in the present sample before conducting the main analyses. Cronbach's alpha coefficients indicated acceptable to good reliability for all measures. For the total pattern recognition assessment (30 items), alpha was .87 at pre-test and .89 at post-test. At the subscale level (10 items each), alpha values were .78 (pre-test) and .81 (post-test) for pattern identification, .80 and .84 for pattern completion, and .82 and .85 for pattern extension. The 10-item teacher observation checklist yielded an alpha of .86 across the eight-week implementation period. All coefficients exceeded the conventional threshold of .70, indicating that both instruments produced internally consistent scores in the present sample.

For the experimental intervention, a diverse set of recycled materials was used to support patterning activities. These materials included plastic containers of different sizes and colors, bottle caps varying in size, color, and texture, cardboard packaging pieces, fabric scraps, paper tubes, egg cartons, and selected natural materials such as pinecones, shells, and stones. Materials were selected based on their suitability for classification, comparison, sequencing, and pattern construction. Before use, all materials were cleaned, inspected, and organized. Items with sharp edges, unsafe surfaces, or small detachable parts that could pose choking hazards were removed. The remaining materials were grouped according to relevant mathematical attributes, including color, shape, size, texture, quantity, and potential use in repeating or growing patterns.

The control group used traditional classroom manipulatives commonly available in preschool classrooms, including blocks, counters, beads, and colored shapes. These materials were used to address similar patterning objectives, including pattern identification, completion, and extension, but without the recycled-material context or sustainability-related task sequence used in the experimental condition.

### **Data Collection and Analysis**

Data were collected at three levels: children's pattern recognition performance, teacher-recorded engagement during mathematics activities, and demographic information. Pattern recognition data were collected at two time points. The pre-test was administered during the week before the intervention began, and the post-test was administered during the week following the completion of the eight-week intervention. The pattern recognition assessment was administered individually to each child in a quiet space adjacent to the classroom. Scripted instructions and standardized administration procedures were used at both time points to ensure consistency across children and groups.

The researchers who administered and scored the pattern recognition assessment were blind to the children's group assignments. This procedure was used to reduce potential assessment bias. Children's responses were scored according to the predetermined 0–3 scoring rubric. A score of 0 indicated an incorrect or no response; 1 indicated a partially correct response showing limited recognition of the pattern; 2 indicated a correct response with minimal support or limited explanation; and 3 indicated a correct and independent response demonstrating recognition of the underlying pattern structure. Subscale scores were calculated separately for pattern identification, pattern completion, and pattern extension. A total pattern recognition score was calculated by summing the scores across all 30 items.

Teacher-recorded engagement observations were conducted weekly throughout the intervention period during designated mathematics activity sessions. Before the intervention began, teachers were oriented to the observation checklist and scoring procedures. They were instructed to rate children's engagement based on observable behaviors, including sustained attention, active participation,



persistence, peer interaction, responsiveness to prompts, and involvement with task materials. Engagement scores were recorded for children in both experimental and control groups during comparable mathematics activity periods.

All quantitative data were analyzed using SPSS version 27.0. Descriptive statistics were calculated to summarize demographic characteristics, pre-test and post-test pattern recognition scores, subscale scores, and teacher-recorded engagement scores. Internal consistency coefficients were examined for the pattern recognition assessment and the engagement checklist in the present sample before the main analysis. Cronbach's alpha was computed for the total assessment, for each of its three subscales, and for the observation checklist; these coefficients are reported in the Materials and Instruments section. Independent samples t-tests were used to examine baseline equivalence between the experimental and control groups. Paired-samples t-tests were conducted to examine within-group changes from pre-test to post-test.

Repeated measures ANOVA was used to examine the group  $\times$  time interaction and determine whether changes in pattern recognition performance differed between the experimental and control groups. Multiple regression analysis was conducted to examine whether group assignment predicted post-test pattern recognition scores after controlling for pre-test scores, age, and gender. Effect sizes were reported using Cohen's d for t-tests and partial eta squared ( $\eta^2$ ) for ANOVA. Statistical significance was set at  $p < .05$ .

## RESULTS

This section presents the quantitative findings of the study in relation to children's pattern recognition performance and teacher-rated engagement during mathematics activities. First, baseline equivalence between experimental and control groups is reported. Next, pre-test and post-test changes in overall pattern recognition performance are presented, followed by the results of the repeated measures ANOVA examining the group  $\times$  time interaction. Subscale-level findings for pattern identification, pattern completion, and pattern extension are then reported. Finally, regression results and teacher-rated engagement scores are presented as supplementary evidence regarding children's participation during mathematics activities.

### Preliminary Analyses and Baseline Equivalence

The demographic characteristics of the participants are reported in Table 1 in the Participants section. The experimental and control groups were comparable in terms of age and gender distribution. Before the intervention, an independent-samples t-test was conducted to examine whether the groups differed in pattern recognition performance. The results showed no statistically significant difference between the experimental group ( $M = 45.3$ ,  $SD = 7.2$ ) and the control group ( $M = 44.8$ ,  $SD = 6.9$ ),  $t_{(58)} = .27$ ,  $p = .785$ . This finding indicated baseline equivalence in pattern recognition performance before the intervention.

### Effects on Total Pattern Recognition Performance

Descriptive statistics for pre-test and post-test pattern recognition scores are presented in Table 2. The experimental group increased from a pre-test mean of 45.3 ( $SD = 7.2$ ) to a post-test mean of 60.5 ( $SD = 6.8$ ). The control group increased from a pre-test mean of 44.8 ( $SD = 6.9$ ) to a post-test mean of 47.2 ( $SD = 7.1$ ).

Paired-samples t tests were conducted to examine within-group changes from pre-test to post-test. The experimental group showed a statistically significant increase in pattern recognition scores,  $t_{(29)} = 9.87$ ,  $p < .001$ , Cohen's  $d = 1.80$ . The increase observed in the control group was not statistically significant,  $t_{(29)} = 1.65$ ,  $p = .110$ , Cohen's  $d = .30$ . These results indicate that children in the experimental group showed greater improvement in pattern recognition performance than children in the control group.


**Table 2.** Pre-test and post-test pattern recognition scores by group

| Group                 | Pre-test M | Pre-test SD | Post-test M | Post-test SD |
|-----------------------|------------|-------------|-------------|--------------|
| Experimental (n = 30) | 45.3       | 7.2         | 60.5        | 6.8          |
| Control (n = 30)      | 44.8       | 6.9         | 47.2        | 7.1          |

Note. Total pattern recognition scores ranged from 0 to 90. Higher scores indicate stronger pattern recognition performance.

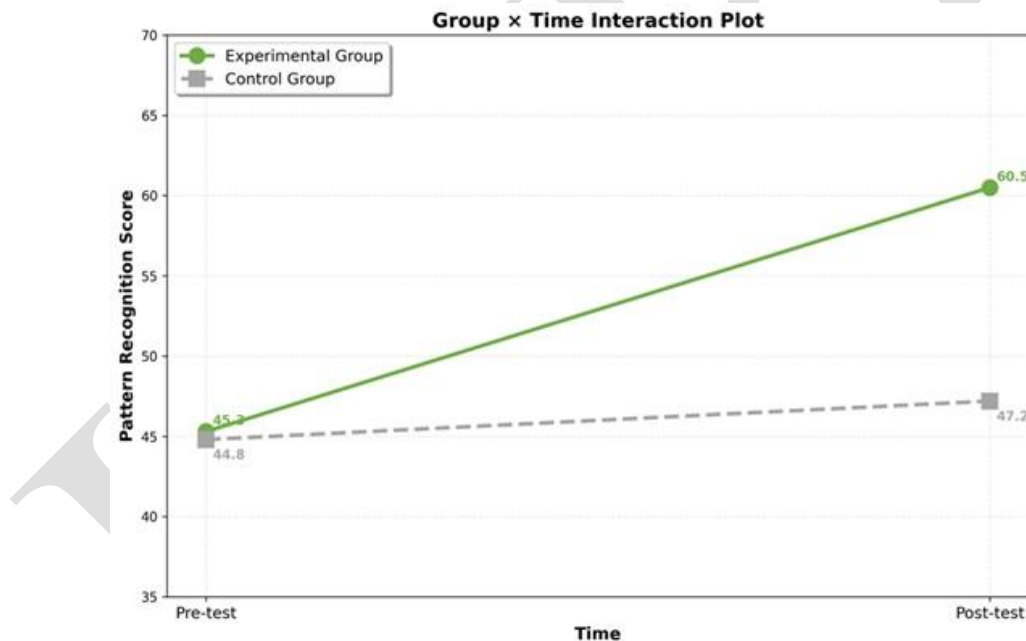
### Group × Time Interaction

A repeated measures ANOVA was conducted to determine whether changes in pattern recognition performance differed between the experimental and control groups over time. The analysis revealed a significant main effect of group,  $F_{(1, 58)} = 25.43$ ,  $p < .001$ ,  $\eta^2 = .305$ , and a significant main effect of time,  $F_{(1, 58)} = 37.87$ ,  $p < .001$ ,  $\eta^2 = .395$ . More importantly, the group × time interaction was statistically significant,  $F_{(1, 58)} = 32.15$ ,  $p < .001$ ,  $\eta^2 = .356$ . This interaction indicated that the magnitude of change from pre-test to post-test differed significantly between the experimental and control groups.

**Table 3.** Repeated measures ANOVA summary for pattern recognition scores

| Source       | df    | F     | p      | $\eta^2$ |
|--------------|-------|-------|--------|----------|
| Group        | 1, 58 | 25.43 | < .001 | .305     |
| Time         | 1, 58 | 37.87 | < .001 | .395     |
| Group × Time | 1, 58 | 32.15 | < .001 | .356     |

Note.  $\eta^2$  = partial eta squared. The group × time interaction represents the differential change in pattern recognition scores from pre-test to post-test across the experimental and control groups.


**Figure 1.** Group × time interaction for pattern recognition scores

Mean pattern recognition scores are shown for the experimental and control groups at pre-test and post-test. The steeper increase in the experimental group indicates a larger gain in pattern recognition performance following the recycling-based mathematical task intervention.

### Subscale-Level Pattern Recognition Outcomes

Subscale-level descriptive statistics are presented in Table 4. The experimental group showed increases across all three pattern recognition subscales. Pattern identification scores increased from 15.2 (SD = 2.4) to 19.3 (SD = 2.1), pattern completion scores increased from 14.7 (SD = 2.6) to 20.2 (SD = 2.4), and pattern extension scores increased from 15.4 (SD = 2.8) to 21.0 (SD = 2.5). In the control group, changes were smaller across the three subscales. Pattern identification scores increased from 15.0 (SD = 2.3) to 16.1 (SD = 2.5), pattern completion scores increased from 14.9 (SD = 2.5) to



16.1 (SD = 2.6), and pattern extension scores changed only slightly from 14.9 (SD = 2.7) to 15.0 (SD = 2.8).

**Table 4.** Pattern recognition subscale scores by group and time

| Subscale               | Experimental Pre-test<br>M (SD) | Experimental Post-test<br>M (SD) | Control Pre-test M<br>(SD) | Control Post-test M<br>(SD) |
|------------------------|---------------------------------|----------------------------------|----------------------------|-----------------------------|
| Pattern identification | 15.2 (2.4)                      | 19.3 (2.1)                       | 15.0 (2.3)                 | 16.1 (2.5)                  |
| Pattern completion     | 14.7 (2.6)                      | 20.2 (2.4)                       | 14.9 (2.5)                 | 16.1 (2.6)                  |
| Pattern extension      | 15.4 (2.8)                      | 21.0 (2.5)                       | 14.9 (2.7)                 | 15.0 (2.8)                  |

Note. Each subscale score ranged from 0 to 30. Higher scores indicate stronger performance in the corresponding pattern recognition dimension. Values are presented as means with standard deviations in parentheses.

### Predictors of Post-Test Pattern Recognition Performance

A multiple regression analysis was conducted to examine whether group assignment predicted post-test pattern recognition scores after controlling for pre-test score, age, and gender. The regression model was statistically significant,  $F_{(4, 55)} = 28.15$ ,  $p < .001$ , and explained 67% of the variance in post-test scores,  $R^2 = .67$ , adjusted  $R^2 = .65$ . Group assignment was a significant predictor of post-test pattern recognition performance,  $B = 9.80$ ,  $SE = 1.16$ ,  $t = 8.42$ ,  $p < .001$ . Pre-test score was also a significant predictor,  $B = .45$ ,  $SE = .09$ ,  $t = 4.87$ ,  $p < .001$ . Neither age,  $B = .12$ ,  $SE = .11$ ,  $t = 1.05$ ,  $p = .299$ , nor gender,  $B = .08$ ,  $SE = .11$ ,  $t = .70$ ,  $p = .487$ , was a significant predictor. Unstandardized coefficients and their standard errors are reported in Table 5.

**Table 5.** Regression analysis predicting post-test pattern recognition scores

| Predictor        | B    | SE   | t    | p      |
|------------------|------|------|------|--------|
| Group assignment | 9.80 | 1.16 | 8.42 | < .001 |
| Pre-test score   | .45  | .09  | 4.87 | < .001 |
| Age              | .12  | .11  | 1.05 | .299   |
| Gender           | .08  | .11  | .70  | .487   |

Note.  $R^2 = .67$ , adjusted  $R^2 = .65$ ,  $F(4, 55) = 28.15$ ,  $p < .001$ . Group assignment was coded to compare the experimental and control conditions. Gender was entered as a control variable. B = unstandardized regression coefficient; SE = standard error of B.

### Teacher-Rated Engagement During Mathematics Activities

Teacher-rated engagement scores were compared between the experimental and control groups. As shown in Table 6, the experimental group had a higher mean engagement score ( $M = 8.2$ ,  $SD = 1.1$ ) than the control group ( $M = 6.3$ ,  $SD = 1.3$ ). This difference was statistically significant,  $t_{(58)} = 6.93$ ,  $p < .001$ , Cohen's  $d = 1.67$ . These results suggest that children in the experimental group were rated as more engaged during mathematics activities than children in the control group.

**Table 6.** Teacher-rated engagement scores by group

| Group                 | Mean | SD  |
|-----------------------|------|-----|
| Experimental (n = 30) | 8.2  | 1.1 |
| Control (n = 30)      | 6.3  | 1.3 |

Note. Engagement was rated by teachers using a structured observation checklist. Scores were based on a 10-point scale, with higher scores indicating greater observed engagement during mathematics activities.

## DISCUSSION, CONCLUSION, and RECOMMENDATIONS

The purpose of this study was to examine whether recycling-based mathematical tasks support preschool children's pattern recognition performance more effectively than traditional manipulative-based instruction. The findings indicated that children in the experimental group showed greater improvement from pre-test to post-test than children in the control group. The significant group  $\times$  time interaction suggests that the recycling-based intervention was associated with stronger gains in pattern recognition performance. These findings provide initial evidence that recycled materials, when used within a structured instructional sequence, may serve as meaningful and sensory-rich resources for early mathematics learning. The improvement observed in the experimental group is consistent with embodied perspectives on early mathematics learning, which emphasize the role of action,



perception, gesture, and material interaction in children's mathematical understanding (Shvarts & Abrahamson, 2023; Way & Ginns, 2024). In the present study, children worked with recycled materials that varied naturally in color, shape, size, texture, and form. These variations may have encouraged children to compare attributes, attend to regularities, and construct patterns across less uniform materials. Unlike traditional classroom manipulatives, which are often designed to be visually consistent and predictable, recycled materials provided opportunities for children to identify relevant pattern features while managing natural variation. This may have supported more flexible forms of pattern recognition.

The subscale findings provide further insight into how children's pattern recognition developed during the intervention. The experimental group showed gains across pattern identification, pattern completion, and pattern extension. The increases in pattern completion and pattern extension are particularly important because these tasks require children to move beyond recognizing surface-level repetition and to reason about the underlying structure of a pattern. Previous research suggests that early patterning is closely related to relational reasoning, structural awareness, and later mathematical development (Mulligan & Mitchelmore, 2009; Papic et al., 2011; Wijns et al., 2019). The stronger gains observed in the experimental group suggest that recycling-based tasks may be especially useful for supporting children's ability to complete and extend patterns. The findings also align with research emphasizing the value of play-based, multimodal, and material-rich learning experiences in early childhood education. Young children often develop mathematical ideas through active exploration, visual comparison, movement, and interaction with concrete materials. Recent work has shown that structured multimodal experiences can support children's attention to attributes and their movement toward more analytic forms of reasoning (Hainaut, 2026). In this study, the recycling-based tasks required children to sort, compare, arrange, complete, and extend patterns using familiar objects. Such activities may have helped children connect mathematical thinking with everyday material experiences.

The sustainability-related context of the intervention may also have contributed to children's engagement with mathematical tasks, as recent early childhood sustainability research indicates that meaningful environmental practices can support children's participation, attitudes, and social-emotional engagement (Kornilaki et al., 2022; Ohlsson et al., 2024b; Watt & Frydenberg, 2025). Recycled materials were not used simply as low-cost substitutes for traditional classroom manipulatives; rather, they were embedded in activities involving reuse, sorting, and classroom-based sustainability practices. This connection may have made the tasks more meaningful for children by linking mathematical activity to familiar objects and everyday environmental routines. Research in early childhood education increasingly suggests that young children can participate in sustainability-related practices through concrete and developmentally appropriate classroom experiences (Hedefalk et al., 2015; Ernst & Burcak, 2019). However, in the present study, sustainability was used as a meaningful instructional context rather than as a separately measured outcome. Therefore, the findings should be interpreted primarily in relation to children's pattern recognition performance and engagement.

Teacher-rated engagement scores were higher in the experimental group than in the control group. This finding suggests that children were perceived by their teachers as more engaged during recycling-based mathematical activities. The tactile variety, novelty, and everyday familiarity of recycled materials may have contributed to sustained attention and participation. This interpretation is consistent with early childhood research showing that meaningful object-based activities can support children's active involvement, problem solving, and affective engagement (Peleg & Levy, 2026). At the same time, engagement was measured through teacher ratings rather than independent observational coding. Therefore, this result should be interpreted as supplementary evidence about children's participation during the intervention.

The regression findings further support the association between group assignment and post-test pattern recognition performance after controlling for pre-test scores, age, and gender. Group



assignment remained a significant predictor, suggesting that the observed differences in post-test scores were not explained only by initial performance or demographic characteristics. The non-significant effects of age and gender indicate that the intervention may have provided accessible entry points for children across the 4- to 6-year age range represented in the sample. This is important for early childhood classrooms, where children often differ in developmental level, language use, attention span, and prior mathematical experiences. The study contributes to early childhood mathematics education by showing how recycled materials can be used within a structured sequence of mathematical tasks. The EMEL framework was used in this study as an instructional design structure rather than as a fully validated theoretical model. Its four phases helped organize the intervention from initial material exploration to explicit pattern construction and application in classroom practices. This structure may be useful for teachers who wish to integrate mathematical learning with familiar, low-cost, and sustainability-related materials. The findings suggest that carefully sequenced recycling-based tasks can support pattern recognition while also providing a meaningful context for classroom participation. Taken together, the findings indicate that recycled materials can enrich early mathematics learning when they are embedded within a structured and developmentally appropriate instructional sequence.

This study suggests that recycling-based mathematical tasks may provide a low-cost, accessible, and developmentally appropriate approach for enriching early childhood mathematics instruction. When carefully planned, recycled materials can support children's pattern recognition while also situating mathematical learning within meaningful classroom practices related to reuse, care for materials, and sustainability. The study also offers a practical example of how early mathematics instruction can be connected to sustainability-related classroom practices without treating sustainability as a separate measured outcome. Because patterning knowledge remains linked to mathematical outcomes well into the primary years (Borriello et al., 2023), preschool gains of this kind are best understood as part of a longer developmental trajectory rather than as isolated outcomes. At the same time, recent reviews caution that gains from training general skills do not transfer automatically to broader mathematical achievement (Fyfe & Borriello, 2025), which supports the view that recycling-based tasks should be embedded in mathematics instruction rather than treated as a substitute for it.

Several suggestions can be offered based on these findings. First, early childhood teachers may use familiar materials such as bottle caps, cardboard tubes, egg cartons, packaging pieces, and fabric scraps to design patterning tasks involving classification, comparison, sequencing, completion, and extension. Such materials may enrich early mathematics activities because they are concrete, sensory-rich, accessible, and connected to children's everyday experiences. Second, sustainability-related classroom practices may be used as a meaningful context for early mathematical learning. In this study, sustainability served as a context for organizing mathematical tasks around reuse, sorting, and care for materials. Therefore, the findings do not show that children's environmental awareness increased. Instead, they suggest that pattern recognition activities can be situated within sustainability-related practices in developmentally appropriate ways. For early childhood teachers, this means that mathematical learning and sustainability-related routines do not need to be treated as separate classroom domains. Third, the EMEL framework may be used as an instructional planning structure. Its four-phase sequence—environmental engagement, mathematical mapping, cognitive construction, and environmental integration—offers a way to move from informal exploration of recycled materials toward explicit mathematical reasoning and application. For example, children may first explore and classify materials, then use their attributes to create simple patterns, later complete and extend more complex patterns, and finally apply patterning ideas in classroom routines. This progression may help teachers design tasks that are not only hands-on but also mathematically focused and developmentally progressive, consistent with research emphasizing intentional pedagogical design in preschool sustainability education (Ohlsson et al., 2024b).

Finally, careful material selection and classroom organization are important for implementing recycling-based mathematical tasks. Materials should be clean, safe, age-appropriate, and sufficiently varied to support mathematical comparison and pattern construction. Teachers need to consider which



material attributes are mathematically relevant, such as color, shape, size, texture, quantity, and order. Family participation in collecting reusable materials may further support the approach, but such participation should be organized carefully to ensure safety, hygiene, and consistency across activities.

### **Limitations of the Research**

Several limitations should be considered when interpreting the findings. First, the sample size was relatively small and included children from three preschool centers. Although the experimental and control groups were comparable at pre-test, larger studies are needed to examine whether similar results can be obtained across different early childhood settings. Second, the intervention lasted eight weeks and did not include a delayed post-test. Therefore, the study does not provide evidence about the long-term maintenance of children's pattern recognition gains. Future research should examine whether the gains observed after recycling-based mathematical tasks are sustained over longer periods. Third, the study focused only on pattern recognition. Although patterning is an important component of early mathematical development, the findings cannot be generalized directly to other mathematical domains. Future research should examine whether recycling-based mathematical tasks can support areas such as number sense, measurement, geometry, spatial reasoning, and data representation. Different mathematical domains may require different types of recycled materials, task structures, and teacher guidance.

A further limitation concerns the possible influence of a novelty effect. Children in the experimental group worked with recycled materials that were new to them and that differed from their usual classroom manipulatives in texture, sound, shape, and origin, whereas children in the control group used standard and highly familiar materials. It is therefore possible that part of the higher engagement and the larger performance gains observed in the experimental group reflected the unfamiliarity and sensory richness of the materials rather than the eco-mathematical pedagogy itself. This is consistent with what is commonly described as a novelty or Hawthorne effect, and the present design cannot separate the two influences. Future research could address this issue by including a second comparison condition in which children use novel but non-recycled materials, by extending the intervention so that initial novelty declines, or by measuring engagement repeatedly across the implementation period to examine whether group differences persist once the materials are no longer new.

A further limitation concerns measurement. The pattern recognition assessment and teacher-rated engagement checklist were developed for the present study and informed by existing literature. Although expert review was used to support content validity, further validation studies are needed with larger samples. Future research should examine the psychometric properties of these instruments in greater depth, including internal consistency, inter-rater reliability where applicable, and evidence of construct validity. Finally, engagement was assessed through teacher ratings. These scores provided useful supplementary information about children's observed participation, but they may also be influenced by teacher perceptions. Future studies should include independent observers, video-based coding, or systematic field notes to examine children's engagement processes more deeply. Research should also examine implementation conditions, including teacher preparation, implementation fidelity, classroom discourse, and children's mathematical explanations. The implications of this study should therefore be interpreted as promising but preliminary.

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### **Ethics and Conflict of Interest**

Ethical approval for the study was obtained from the Human Research Ethics Committee of Dokuz Eylül University with decision number 36 dated December 3, 2025. The official approval document was issued by Dokuz Eylül University Buca Faculty of Education on December 16, 2025, with document number E-10042736-204.01.07-1644970. The research was conducted in accordance with ethical principles, and the author declares that there is no conflict of interest. Written informed



consent was obtained from the children's parents or legal guardians before participation. Children's participation was voluntary, and all data were anonymized to protect confidentiality. All recycled materials used in the intervention were cleaned, inspected, and selected according to age-appropriate safety criteria. The author declares that there is no conflict of interest regarding the publication of this study.

### Data Availability

The data that support the findings of this study are available on request from the author.

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