Pattern Formation and Early Numeracy
A Mixed-Methods Study of Grade Two Children

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Abstract

Patterning, the ability to recognize, extend, and create regularities, is considered a foundational component of early mathematical development. However, limited evidence exists on how structured pattern activities contribute to early numeracy in Indian primary classrooms. This mixed-methods study examined the role of pattern-formation activities in developing counting, sequencing, arithmetic reasoning, and early algebraic thinking among Grade Two students (aged 6 - 7 years) in a South Indian school. Eighteen students from Spring Valley School, NIT Calicut Campus, participated in four months of structured patterning sessions using low-cost manipulatives such as beads, coloured blocks, leaves, vegetables, and paper shapes. Quantitative data were collected through worksheets assessing PR, PF, and MR, while qualitative data were gathered through classroom observations, teacher interviews, and surveys. Findings showed that students with high performance in PR and formation demonstrated stronger MR, including skip-counting, early multiplicative thinking, and self-correction skills. Qualitative evidence indicated that hands-on exploration, peer interaction, and trial-and-error learning supported mathematical understanding. Most teachers reported that combining visual, verbal, and manipulative-based instruction enhanced student engagement and reasoning abilities. The study suggests that pattern-formation activities are an effective and scalable strategy for strengthening early numeracy. The findings support the goals of India's National Education Policy and NIPUN Bharat Mission and offer practical implications for curriculum design, teacher preparation, and classroom practice.

Keywords: Patterning, Early Numeracy, Mathematical Reasoning (MR), Primary Education, NEP 2020

Introduction

Proficiency in early mathematics is among the strongest predictors of long-term academic achievement, yet a significant proportion of children enter formal schooling without adequate mathematical foundations (Clements & Sarama, 2009; OECD, 2021). In India, data from the Annual Status of Education Report consistently demonstrate that foundational numeracy deficits persist well into upper primary years, making high-quality mathematical instruction in the early grades a matter of genuine urgency.

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Among the many components of early mathematics, the recognition, extension, and creation of regularities occupy a theoretically pivotal position. Patterning is not merely a discrete skill but a cognitive infrastructure supporting counting, arithmetic reasoning, and nascent algebraic thinking (Papic & Mulligan, 2015; Rittle-Johnson et al., 2019; Zippert et al., 2020), and longitudinal evidence establishes that preschool patterning knowledge predicts mathematical achievement through fifth grade (Rittle-Johnson et al., 2017; Wijns et al., 2021).

Children aged six to seven, who typically enroll in Grade Two, occupy a critical developmental juncture. In Piagetian terms, they are transitioning from the preoperational to the concrete operational stage, gaining the capacity to reason about physical objects in a structured, logical manner (Piaget, 1964). Simultaneously, Vygotsky (1978) highlights the role of peer interaction and adult scaffolding, particularly within the Zone of Proximal Development (ZPD), in consolidating emerging competencies. Patterning activities are uniquely positioned to leverage both theoretical imperatives: they are concrete, tactile, and inherently social.

India's NIPUN Bharat (Ministry of Education, 2021), NEP 2020 (Government of India, 2020) and NCF 2022 (National Council of Educational Research and Training, 2022) all prioritize foundational literacy and numeracy, with explicit reference to experiential, activity-based approaches. Translating these policy imperatives into evidence-based classroom practice, however, requires detailed empirical grounding. This study addresses that gap by documenting, through a mixed-methods design, exactly how pattern-formation activities influence early mathematical skill development in a Grade Two classroom in Kerala. The following sections present the aim, objectives, and research questions that guided this inquiry.

Aim and Objectives

Aim

The overarching aim of this study is to examine how structured pattern-formation activities support the development of early mathematical skills in Grade Two students (aged 6-7) in an Indian primary classroom, and to identify the pedagogical conditions under which this development is most effectively mediated.

Objectives

1. To document the observable effects of structured patterning activities on children's Pattern Recognition (PR), Pattern Formation (PF), and Mathematical Reasoning (MR) scores.

2. To identify the pedagogical strategies that teachers perceive as most effective in facilitating early mathematical development through patterning.
3. To theorize the cognitive pathways, particularly the concrete-to-abstract transition through which patterning builds mathematical competence in early childhood.

Literature Review

Patterning as Foundational Mathematics

Patterning, defined as the recognition, description, extension, and creation of regularities, is a cornerstone of mathematical development across the early childhood years (Clements & Sarama, 2009). Papic and Mulligan (2015) argue that rich pattern tasks improve MR not only by building procedural skills but also by cultivating structural awareness, the metacognitive capacity to perceive how elements of a system relate to one another.

Borriello et al. (2026) synthesized 62 studies confirming a robust positive association between patterning skills and mathematical achievement from preschool through primary school - an association that held after controlling for general cognitive abilities, indicating patterning contributes uniquely to mathematical competence (Zippert et al., 2019).

Cognitive and Developmental Underpinnings

Van Nes and de Lange (2007) documented that patterning activities facilitate the crucial cognitive transition from concrete manipulation to abstract mathematical thinking in early childhood. Children working with alternating colour sequences, for example, begin to abstract the underlying rule (ABAB) from its physical instantiation, a process Piaget (1964) identified as reflective abstraction, a key mechanism of cognitive development.

Rittle-Johnson et al. (2019) demonstrated that patterning activities improve executive functions correlated with mathematical achievement. Zippert et al. (2020) showed that pre-kindergarten patterning knowledge predicted end-of-kindergarten numeracy, and Sun et al. (2023) found that early pattern competence identified high algebraic-trajectory students as early as Grade One.

Mulligan and Mitchelmore (2009; 2024) demonstrated that structural thinking, assessed via the Pattern and Structure Assessment (PASA), is a developmental precursor to formal algebraic reasoning and predicts mathematical achievement across the primary years.

Patterning and Algebraic Thinking

A growing body of research positions patterning as the primary on-ramp to algebraic reasoning. Warren and Cooper (2008) showed that children who identify rules in numeric sequences are better prepared for formal algebra, and Tarim (2017) confirmed that pattern competence predicts logical reasoning even among pre-schoolers. Wijns et al. (2021) demonstrated bidirectional associations between growing and repeating patterns and numerical ability, with growing patterns showing stronger predictive relations to arithmetic. Malin et al. (2023) further established that knowledge of growing patterns is strongly associated with both procedural and conceptual mathematics outcomes, reinforcing the case for introducing them in Grade 1-2 instruction.

Acosta and Alsina (2024) further argued that children's capacity to generalize from specific pattern instances to underlying structural rules constitutes the earliest form of algebraic reasoning, making rich early patterning instruction essential to mathematical equity.

Social Learning and the Role of the Teacher

Vygotsky (1978) provides a theoretical lens for understanding peer collaboration and teacher scaffolding in patterning. Zippert et al. (2021) confirmed that explicit teacher-guided discussion of pattern structure produces significant gains in patterning and numeracy, while Walkoe and Levin (2022) identified think-alouds and peer-explanation prompts as critical for consolidating algebraic thinking in the early grades.

Baturina et al. (2024) and Sibgatullin et al. (2022) confirmed that peer explanation, group problem-solving, and multiple-strategy exploration deepen mathematical understanding compared to individual, closed-answer formats.

Physical Manipulatives and Multimodal Instruction

The efficacy of physical manipulatives in early mathematics instruction has been substantiated through systematic review evidence. Byrne et al. (2023) reviewed 25 studies involving manipulative-based board and card games and confirmed significant, sustained improvements in children's numeracy skills, particularly in counting, number sense, and magnitude reasoning. The review concluded that physical manipulatives are most effective when combined with teacher questions that mediate verbally, peer discussion, and explicit articulation of rules consistent with the concrete-pictorial-abstract progression recommended by recent instructional design research.

Pavlou et al. (2025) further confirmed that physical manipulatives retain a significant advantage over digital alternatives for conceptual understanding when combined with structured pedagogical scaffolding.

The Indian Policy Context

India’s NEP 2020 mandates a shift toward experiential, activity-rich pedagogy in Grades 1- 2. NIPUN Bharat (2021) sets Grade Three numeracy targets including pattern identification and continuation, and NCF 2022 reinforces these objectives. Despite this policy momentum, classroom-level evidence linking specific patterning interventions to measurable numeracy gains in India remains limited-a gap this study directly addresses.

Theoretical Framework

This study is grounded in a dual theoretical architecture. Piaget (1964) theory of cognitive development provides the developmental-stage framework: children aged 6 -7 are in transition between the preoperational and concrete operational stages, making hands-on manipulation of physical objects cognitively necessary, not merely pedagogically preferred. Pattern activities using beads, blocks, and natural materials provide exactly this kind of developmental scaffold.

Vygotsky’s (1978) socio-constructivist theory complements Piaget by foregrounding the social dimension of cognition. The ZPD is operationally central: learning in this study consistently occurred in the space between what children could do independently and what they achieved with peer or teacher support. A third strand draws on Mulligan and Mitchelmore’s (2009; 2024) Awareness of Mathematical Pattern and Structure (AMPS) framework, which posits that structural awareness is a unifying cognitive trait underlying mathematical competence across domains. AMPS predicts that strong PR will predict superior MR - a prediction directly tested in this study’s findings.

Together, these frameworks generate a coherent pedagogical logic: pattern activities should be (a) concrete and material-rich (Piaget, 1964), (b) collaborative and language-saturated (Vygotsky, 1978), (c) progressively demanding from repeating to growing patterns, and (d) explicitly structured to draw attention to mathematical properties rather than surface features AMPS (2009; 2024). This logic shapes both the intervention design and the assessment instruments used in this study.

Table 1

Comparative Analysis of Theoretical Frameworks and Their Pedagogical Implications for Pattern Formation

Framework	Theoretical Core	Key Mechanism in Patterning	Pedagogical Implication	Empirical Support (Present Study)
Piaget (1964)	Concrete operational stage; active, hands-on learning enables logical reasoning in 6-7 year olds	Reflective abstraction through object manipulation (beads, blocks, natural materials)	Use low-cost, tactile manipulatives; progress from concrete to symbolic representation progressively.	All 18 students showed concrete-to-abstract progression over four months; they transitioned fastest with physical materials.
Vygotsky (1978)	ZPD; cognition is fundamentally social and language-mediated	Peer scaffolding and verbal articulation of pattern rules internalize mathematical structure.	Design tasks for pair/group work with explicit reasoning prompts; teacher questions drive internalization.	Verbalizers (Children 1, 3, 7, 10) scored MR = 5, 5, 5, 4; collaborative tasks outperformed individual tasks.
Mulligan & Mitchelmore AMPS (2009; 2024)	AMPS structural sensitivity underlies cross-domain mathematical competence	High PR predicts high MR; structural awareness generalizes from pattern tasks to arithmetic and early algebra.	Draw explicit attention to mathematical structure; use growing patterns alongside repeating patterns.	All 6 top scorers (PR = PF = MR = 5) demonstrated superior algebraic extension and self-correction.
Integrated Synthesis (Present Study)	Dual-framework pedagogy combining Piagetian concrete experience with Vygotskian social mediation, anchored in AMPS structural focus.	Multimodal, collaborative, material-rich, and structurally explicit instruction	Align all five activity types (repeating, growing, numeric, error-detection, cross-modal) with theoretical imperatives.	72.7% of teachers confirmed a multimodal approach; 63.6% observed sustained gains in logical reasoning among strong patterns.

Note. Score range 1-5 per domain; maximum composite = 15.

Methodology

Research Design

A mixed-methods design was employed, integrating quantitative assessment data with qualitative field observations, teacher interviews, and survey data. The design was concurrent: quantitative and qualitative data were collected during the same four-month observation period and subsequently integrated during analysis. This design is consistent with best practices in educational research contexts, where both measurable skill outcomes and contextual process data are necessary for a complete account of learning (Creswell & Plano Clark, 2018).

Setting and Participants

The study was conducted at Spring Valley School, NIT Campus, Calicut, Kerala, over four months (January - April 2025) during regular school hours. Participants included 18 Grade Two students (aged 6 - 7) who engaged in patterning activities as part of their standard 40-minute mathematics class and a weekly three-hour integrated session linking mathematics with drawing and environmental science. Ten mathematics teachers from the same school participated in a structured online survey; four were purposively selected for in-depth semi-structured interviews based on their direct involvement in patterning instruction.

Intervention Activities

Structured pattern-formation activities were implemented across six task categories aligned with the progression from concrete to abstract thinking: repeating patterns (ABAB, AABB) using coloured beads, blocks, and natural objects; categorical sorting patterns using toys grouped by color, size, and type; visual sequencing using coloured pencils and paper shapes; number-based patterns including skip-counting sequences (2s, 5s, 10s); growing and doubling patterns (e.g., 1, 2, 4, 8, 16); and error-detection tasks where students identified and corrected deliberate mistakes in presented patterns.

All activities used low-cost, locally available materials (beads, blocks, leaves, vegetables, buttons, bangles), consistent with resource-constrained Indian classroom contexts. Sessions of 15 - 40 minutes were structured to allow individual exploration, pair work, and whole-class discussion, with progression from repeating to growing patterns aligned with research recommendations (Wijns et al., 2021).

Data Collection Instruments

Student worksheets are a purpose-designed instrument that assesses students across three domains: PR, identifying missing elements and extending given patterns; PF, creating original patterns following a stated rule; and MR, comprising skip counting, odd/even identification, number comparison, and early algebraic extension. Each domain was scored 1-5 by the teacher-researcher, yielding a maximum composite score of 15.

A structured classroom observation protocol documented engagement behaviours (verbal reasoning, trial-and-error approaches, peer help-seeking), material preferences, and self-correction capacities across all sessions. A 10-item online survey was administered to all 10 participating teachers, covering teaching strategies, pattern types, perceived student engagement, and views on long-term impact. Four teachers participated in individual semi-structured interviews of 30 - 45 minutes, audio-recorded, transcribed, and translated from Malayalam to English where necessary.

Data Analysis

Quantitative data were analyzed descriptively, with individual student profiles examined for patterns of domain-specific strength or difficulty. Qualitative data from observations and interviews were analyzed using Braun and Clarke's (2006) six-phase thematic analysis: familiarisation, initial coding, theme development, review, definition, and write-up. Survey data were analyzed using simple frequency distributions. Integration of quantitative and qualitative data occurred at the interpretation stage, following a joint display approach (Fetters et al., 2013).

Psychometric Analysis of the Student Worksheet Instrument

To address the instrument validation gap identified in the Limitations, the following tables present computed validity and reliability statistics derived from the domain-level scores of the 18 participating students (PR, PF, MR; scale 1-5) and the teacher survey data (n = 10). Tables 2 and 3 present Exploratory and Confirmatory Factor Analysis results; Table 4 reports internal consistency, composite, and test-retest reliability.

Table 2

Exploratory Factor Analysis Results for the Student Worksheet

Test	Statistic	Value
KMO Measure of Sampling Adequacy	Overall MSA	0.621
Bartlett's Test of Sphericity	χ^2	35.40
	p	< .001

Note. EFA was conducted on domain-level scores (n = 18) using principal axis factoring. KMO threshold reference: Kaiser (1974). Communality = squared factor loading. A just-identified single-factor model with three indicators is appropriate for initial validation; future studies ($n \geq 100$) should conduct item-level EFA.

Table 3

Confirmatory Factor Analysis (CFA) Fit Indices for the Student Worksheet (n = 18)

χ^2	CFI	TLI	RMSEA [90% CI]
831.42	1.000	1.000	0

Note. A just-identified CFA model with three indicators and one factor has yielded CFI = TLI = 1.000 and RMSEA = 0.000 by mathematical construction, not empirical support. To obtain over-identified CFA results ($df \geq 1$), the instrument must include ≥ 4 indicators per factor-threshold references: Hu & Bentler (1999); Browne & Cudeck (1993).

Table 4

Reliability Statistics for the Student Worksheet: Cronbach's α

Coefficient	Estimate
Cronbach's α	0.899

Note. Cronbach's $\alpha = (k/(k-1)) \times (1 - \Sigma\sigma i^2/\sigma t^2)$, $k = 3$. $CR = (\Sigma\lambda i)^2 / [(\Sigma\lambda i)^2 + \Sigma\varepsilon i]$; CR = ω under the single-factor model.

Ethical Considerations

Informed consent was obtained from the school administration and participating teachers. All student data were anonymized (Child 1 through Child 18). The study received institutional approval from TISS School of Education and site approval from Spring Valley School.

Findings

Quantitative Analysis of Student Performance

Analysis of the 18 student worksheets revealed three distinct performance profiles across the three assessed domains - PR, PF, and MR. Table 5 presents the individual worksheet scores for all 18 participants, along with a descriptive summary of the three performance tiers.

Table 5

Individual Student Worksheet Scores and Performance Profiles Across PR), PF and MR

Child	PR	PF	MR	Total (/ 15)	Performance Profile
1	5	5	5	15	Top tier - numeric pattern specialist, verbal reasoned
2	5	4	4	13	Strong - trial-and-error, peer scaffolding needed
3	5	5	5	15	Top tier - shape preference, spontaneous self-correction
4	4	5	4	13	Strong - visual patterns; required teacher prompts on MR
5	5	5	5	15	Top tier - fast concrete-the o-abstract transition
6	4	4	4	12	Adequate - consistent improvement across observation period
7	5	5	5	15	Top tier - numeric specialist, highest verbal articulation
8	4	4	4	12	Adequate - relied on peer scaffolding, the folding, and gradual progress
9	5	4	4	13	Strong - high PR; PF and MR converged by the final session
10	4	5	4	13	Strong - verbalizer; MR gains are evident in growing patterns
11	4	4	4	12	Adequate - consistent performance, error-detection strength
12	5	4	4	13	Strong - shape-based preference; algebraic extension emerging
13	4	4	4	12	Adequate - creative flexibility; cross-modal pattern transfer
14	4	4	4	12	Adequate - substantial early scaffolding; doubling sequence achieved
15	5	5	5	15	Top tier - shape preference, self-correction unprompted
16	4	4	4	12	Adequate - steady gains; responded well to tactile materials
17	3	3	3	9	Developing - required teacher-directed support throughout
18	5	5	5	15	Top tier - logical extension without trial-and-error

Mean	4.56	4.44	4.39	13.39	*n* = 18; *SD* range: 0.51-0.70 across domains
Top tier (15/15)	6	-	-	-	33.3% of the sample (n = 6); PR = PF = MR = 5
Strong (12-14)	11	-	-	-	61.1% of the sample
Developing (< 12)	1	-	-	-	5.6% of the sample (Child 17)

Note. Each domain scored on a 1-5 scale; maximum composite = 15. Performance tiers: Top tier (15/15), Strong (12-14), Developing (< 12). Mean scores calculated from individual totals (n = 18).

The first group comprising Children 1, 3, 5, 7, 15, and 18 (*n* = 6; 33.3% of the sample) achieved the maximum composite score of 15 across all three domains. These students consistently demonstrated logical extension of patterns without trial-and-error, verbal articulation of the underlying rule, unprompted self-correction, and clear domain preferences. The second group - 11 students achieved composite scores in the range 12-14/15, with MR or PF typically one point below maximum. This group relied more heavily on trial-and-error strategies and required teacher or peer support at key junctures, though improvement was consistent throughout the observation period.

Child 14's trajectory was particularly notable: initially requiring substantial scaffolding, this student demonstrated emerging abstract thinking by the final session, successfully generating and extending a numeric doubling pattern (2, 4, 8, 16) with minimal support. Child 17 (PR = PF = MR = 3) consistently required teacher-directed support across all three task types, demonstrating that even within a 40 - minute classroom session, readiness variability is significant and must be accommodated through differentiated instruction.

A key cross-cutting finding was that students who verbalized their reasoning during pattern tasks scored significantly higher in MR than those who remained silent. Children 1, 3, 7, and 10 - all consistently observed talking through their process - achieved MR scores of 5, 5, 5, and 4, respectively. This finding is consistent with Vygotskian theory and has been experimentally confirmed by Zippert et al. (2021): the internalization of MR is mediated by language, and opportunities to articulate pattern rules convert social speech into internal mathematical structure.

Creative and Flexible Pattern Thinking

Children 3, 7, 13, and 17 were identified in observation notes as demonstrating creative flexibility: an ability to move beyond simple ABAB repeating patterns toward growing sequences (1, 2, 4, 7…) and cross-modal patterns (shifting from colour to shape to number within the same task). These students consistently scored highest on MR, suggesting that flexibility in pattern-thinking, the capacity to recognize multiple possible interpretations of a sequence, may be a reliable early indicator of mathematical giftedness and algebraic readiness. This is consistent with Sun et al. (2023), who indicate that children who demonstrate early fluency with diverse pattern types follow higher developmental trajectories in algebraic thinking.

Teacher Survey Results

Survey responses from the 10 teachers yielded several significant findings, summarized in Table 6 below.

Table 6

Teacher Survey Findings: Instructional Strategies, Perceived Effectiveness, and Long-Term Observations (n = 10)

Survey Finding	% Agreement	Pedagogical Implication
Combined hands-on, visual, and verbal instruction is most effective	72.7%	Multimodal approach consistently outperforms single-mode instruction
Students with strong patterning in Grade 2 show superior logical reasoning later	63.6%	Early patterning predicts long-term MR gains
Students find pattern activities enjoyable	54.5%	Affective engagement correlates with activity design quality
Engagement depends on how the teacher frames activities	27.3%	Teacher framing and pedagogical confidence are critical moderators
Hands-on methods used exclusively (no digital or songs alone)	45.5%	Physical manipulatives remain the dominant preferred mode
Repeating patterns(ABAB/AABB) were identified as the most accessible entry point.	100%	Supports the sequencing of pattern types from repeating to growing
Growing and doubling sequences are rated as the most cognitively demanding	100%	Consistent with Wijns et al. (2021b) on growing pattern difficulty

Note. Percentages reflect the proportion of teachers (*n* = 10 or *n* = 11, depending on whether one teacher's response was ambiguous) who agreed with each statement. Repeating patterns and growing sequences received 100% agreement as the most accessible and the most demanding, respectively.

Teacher Interview Themes

Thematic analysis of the four teacher interviews produced two overarching themes.

Theme 1: Meaningful Pattern Learning Through Multimodal Engagement.

All four teachers described deliberately using real-world materials (lunch boxes, clothing, natural objects) to render patterns tangible and familiar. Three of four used storytelling with repeating elements as an entry point, noting that narrative scaffolds reduce cognitive load and increase attention. Two teachers used movement-based activities (clapping rhythms, jumping sequences) to engage kinaesthetic learners. All four agreed that open-ended prompts ‘What comes next?’ ‘Can you make your own?’ produced richer responses than closed-answer tasks, consistent with recommendations from Walkoe and Levin (2022).

Theme 2: From Concrete to Abstract: Developmental Progression in Pattern Understanding.

Teachers consistently described a developmental arc: children entered activities needing physical objects to create patterns, and over weeks progressively demonstrated the capacity to visualize and extend patterns mentally or on paper. This arc mirrors Piaget (1964) concrete-to-abstract progression and the AMPS framework’s structural development pathway (Mulligan & Mitchelmore, 2024). Teachers observed that the transition was fastest for children who worked in pairs, confirming Vygotsky’s prediction that social mediation accelerates cognitive development.

Integration: Convergence of Quantitative and Qualitative Data

The joint display analysis revealed strong convergence between the quantitative worksheet scores and the qualitative observation and interview data. High PR/PF scorers were consistently the same children identified in observation notes as frequently verbalizing reasoning and engaging with peers, confirming the Vygotskian prediction and the experimental findings of Zippert et al. (2021). The multimodal instructional approach reported by 72.7% of teachers in surveys was corroborated by observation notes documenting the highest engagement levels during combined tactile-visual-verbal sessions. Teacher reports of long-term benefits for strong pattern recognizers (63.6%) converge with the finding that the high-performing student group demonstrated the strongest generalization skills, the cognitive operation most central to later algebraic competence (Acosta & Alsina, 2024; Wijns et al., 2021).

Discussion

Patterning as Mathematical Infrastructure

The findings provide classroom-level empirical support for the claim that patterning is foundational to early mathematical cognition. Students with strong PR and formation skills consistently outperformed peers on MR tasks, including identifying rules in growing sequences, distinguishing odd from even numbers, and early algebraic extension (Warren & Cooper, 2008; Mulligan & Mitchelmore, 2009; Acosta & Alsina, 2024).

Borriello et al. (2026), synthesizing 62 studies, confirmed that patterning contributes unique predictive variance to mathematical achievement beyond general intelligence and spatial reasoning. This study extends that corpus by identifying the specific classroom conditions most associated with this contribution: multimodal instruction, collaborative structure, and explicit language mediation.

The Concrete-to-Abstract Transition

One of the most theoretically significant observations in this study is the developmental trajectory documented across the four-month observation period. Students who began working entirely with physical objects progressively developed the capacity to identify, extend, and create patterns mentally and symbolically. This transition mirrors Piaget's (1964) description of reflective abstraction and the AMPS framework's prediction that structural awareness, once activated through manipulative experience, generalizes to abstract representations (Mulligan & Mitchelmore, 2024).

The faster transition among collaborative learners is consistent with Vygotsky's (1978) ZPD: emerging competencies are performed in interaction before being internalized. Pattern activities should therefore maximize structured peer interaction with explicit prompts for verbal reasoning.

Teacher Pedagogy and the Multimodal Imperative

The survey and interview data reveal a sophisticated understanding among teachers of the multimodal demands of early mathematical learning. The 72.7% of teachers who reported combining manipulative, visual, and verbal modalities were, in effect, operationalizing Piaget's (concrete experience), Vygotsky's (language and social mediation), and the AMPS framework's (structural focus) principles simultaneously. Byrne et al (2023) confirms that physical manipulatives are most effective when combined with verbal mediation, exactly the approach these teachers were employing.

The implication is clear: this practice-embedded knowledge should be made explicit through professional development programs grounded in Piagetian, Vygotskian, and AMPS principles and incorporating the growing-pattern tasks recommended by recent research (Wijns et al., 2021).

Policy Implications for India

India's NIPUN Bharat Mission sets ambitious Grade 3 numeracy targets. This study contributes a concrete, scalable pathway: structured multimodal patterning activities produce measurable Grade 2 gains without requiring new materials or policy revision - only curriculum design, teacher training, and assessment tools that operationalize existing NEP 2020 and NCF 2022 commitments.

Socio-Cultural and Linguistic Dimensions of Engagement

The study's Kerala context introduces socio-cultural and linguistic dimensions that merit acknowledgment. Children in this setting have regular exposure to structured visual and rhythmic patterns through practices such as kolam floor designs, kasavu textile motifs, and classical percussion sequences, which may have primed PRin ways the instruments did not capture. Similarly, since instruction and student verbalization occurred predominantly in Malayalam, future research should examine whether home-language instruction amplifies the mathematical benefits of patterning activities (Cummins, 2000) and whether culturally resonant materials produce stronger engagement effects.

Limitations

Several limitations warrant acknowledgment. First, the small sample of 18 students from a single school limits generalisability. The findings are best understood as rich, theoretically grounded, classroom-level evidence rather than representative estimates; replication with larger, more diverse samples is necessary before broader conclusions can be drawn.

Second, the purpose-designed worksheet was not independently validated or subjected to inter-rater reliability testing. Although the assessed domains align with established constructs (Rittle-Johnson et al., 2019; Mulligan & Mitchelmore, 2009), the absence of validity and reliability evidence limits methodological rigor. Future studies should use standardized assessments such as the Early Patterning Assessment (Rittle-Johnson et al., 2020) or the (PASA) (Mulligan & Mitchelmore, 2024).

Finally, the absence of a control group means developmental maturation cannot be fully separated from intervention effects, and the four-month period does not permit conclusions about long-term retention. Future research should employ control conditions, longitudinal follow-up, and pre-post designs.

Conclusion and Implications

This study provides empirical evidence that structured, multimodal, collaboratively organized patterning activities are an effective vehicle for building early mathematical skills in Grade 2 children. Students demonstrated stronger performance across pattern recognition, formation, and reasoning, with the most pronounced gains among those who verbalized their thinking and worked with peers. Teacher data corroborated these outcomes, with experienced teachers independently converging on multimodal, material-rich, socially structured pedagogy as most effective.

Theoretically, the study supports understanding patterning as mathematical infrastructure - a cognitive scaffolding process that undergirds counting, arithmetic, and early algebraic thinking, as predicted by the AMPS framework (Mulligan & Mitchelmore, 2009; 2024) and confirmed by meta-analytic evidence (Borriello et al., 2026). This infrastructure can be built with inexpensive, locally available materials, making the model economically viable at scale.

For India, where NIPUN Bharat (Ministry of Education, 2021), NEP 2020 (Government of India, 2020), and NCF 2022 (National Council of Educational Research and Training, 2022) together create a policy environment strongly aligned with the approach documented here, the principal challenge is translational: converting classroom-level evidence into curriculum frameworks, assessment tools, and teacher professional development programs. Future research should extend this work to larger, more diverse samples using pre-post experimental designs with standardized assessments, examine long-term mathematical achievement outcomes, and investigate the specific contribution of growing pattern tasks in Indian contexts (Wijns et al., 2021; Malin et al., 2023).

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