Exploring Computational Thinking in Early Childhood: A Game-Based Approach Between Skills and Thinking

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***Abstract*—Current early childhood computational thinking interventions focus mainly on isolated coding activities, leaving foundational cognitive constructs underdeveloped. This study presents a pedagogical framework for children aged 3-7 years integrating narrative-driven instruction with hands-on manipulation to reinforce six computational thinking constructs: Abstraction, Decomposition, Algorithmic Thinking, Pattern Recognition, Error Evaluation and Resolution, and Generalization. Drawing from Bruno Munari's laboratory pedagogy, the intervention employs the SixBricks tool within the adventures of a friendly machine character. Pilot implementations across formal educational settings and informal contexts demonstrated high engagement levels, pedagogical alignment with early childhood practices, and enhanced student performance with subsequent plugged tools. Results show the framework's effectiveness in developing comprehensive computational thinking foundations without requiring digital infrastructure. This provides an accessible alternative to fragmented coding approaches currently prevalent in early childhood education and supports the future Randomized Control Trial to evaluate its impact.**

***Index Terms*—computational thinking, early childhood education, SixBricks, Bruno Munari**

I. Introduction

The increasing recognition of computational thinking as fundamental literacy has prompted educational systems worldwide to integrate these competencies from the earliest learning stages. While Wing's definition positioned computational thinking as problem-solving processes drawing on computer science concepts [1], most early childhood interventions focus on isolated coding activities using digital tools without systematically developing underlying computational thinking constructs that serve as foundational prerequisites [2]. This fragmented approach may introduce technical skills while neglecting the comprehensive cognitive framework necessary for meaningful computational literacy development.

Traditional approaches often assume that abstract computational concepts require formal operational thinking, thereby excluding children below age 7-8 from systematic exposure to these fundamental problem-solving frameworks.

Drawing inspiration from Bruno Munari's educational philosophy, particularly his reflective questions "What have I learned that is new? Can it be done in another way?", this study embraces his vision of the laboratory as a space for direct experimentation, where children discover knowledge through hands-on manipulation and creative problem-solving [3]. This approach recognizes that young children can grasp complex problem-solving concepts when presented through age-appropriate experiences that encourage exploration and discovery through direct contact with materials [4], [5].

This paper presents a comprehensive framework addressing these challenges through innovative integration of narrative-driven instruction and systematic manipulative activities using SixBricks, a globally accessible educational tool, to introduce six fundamental computational thinking constructs through the adventures of a friendly machine character named Matabì.

The paper outlines the theoretical foundation and research objectives (Sect. II), describes the methodology and implementation across contexts (Sect. III), and presents preliminary findings with implications for early childhood computational thinking education (Sect. IV).

II. Study Aims and Framework

This study aims to develop and evaluate a pedagogical framework that integrates computational thinking development with tangible unplugged manipulation in early childhood education. The research addresses a critical gap in current literature where computational thinking interventions primarily target school-age children through digital platforms, leaving younger learners (ages 3-7) underserved despite their demonstrated capacity for complex problem-solving when presented through developmentally appropriate methodologies.

The theoretical foundation builds upon Bruno Munari's laboratory pedagogy, which emphasizes direct experimentation and discovery-based learning through material manipulation. This approach challenges traditional assumptions about young

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children's cognitive limitations, positioning them as capable thinkers who can engage with abstract concepts when mediated through concrete, hands-on experiences [3]. The framework leverages SixBricks as the primary manipulative tool due to its global accessibility and proven educational versatility, particularly in resource-constrained environments where digital alternatives may be unavailable or inappropriate for this age group.

The study's primary objective is to systematically document and evaluate a structured methodology that introduces six fundamental computational thinking constructs (Abstraction, Decomposition, Algorithmic Thinking, Pattern Recognition, Error Evaluation and Resolution, and Generalization) through narrative-driven activities that maintain engagement while developing cognitive skills. Unlike existing unplugged approaches that often fragment computational concepts, this framework embeds all constructs within a coherent adventure storyline, ensuring conceptual continuity and meaningful context for young learners.

A secondary aim involves establishing the feasibility and pedagogical effectiveness of this approach across diverse educational contexts through pilot implementation in formal (kindergarten and primary school) and informal (public workshop) settings. The research methodology prioritizes ecological validity, testing the intervention under authentic classroom conditions with typical early childhood educators rather than specialized researchers, thereby enhancing practical applicability and scalability potential.

The desired goal extends beyond curriculum development to provide empirical evidence supporting the integration of computational thinking in early childhood education without requiring technological infrastructure. This addresses both pedagogical needs for cognitive development and practical constraints faced by educators in diverse socioeconomic contexts, ultimately democratizing access to computational thinking education during critical developmental periods.

III. Project implementation

The intervention was designed as a structured laboratory experience centered on "Matabì", a friendly machine character who guides children through computational problem-solving adventures. In this adventure Matabì helps the mole to find its lost friend Bricky Talp.

The laboratory employs a systematic color-coding scheme that bridges narrative engagement with computational abstraction. The adventure story incorporates five distinct chromatic elements that children must encode into their tower constructions: light blue representing the river that must be crossed, red symbolizing the fish encountered during the journey, yellow indicating the sunflowers marking the path, orange representing Bricky Talp (the lost mole), and green denoting the meadow environment. This color-narrative mapping system serves dual pedagogical functions: maintaining story engagement while simultaneously teaching abstract symbolic representation and systematic encoding processes fundamental to computational thinking.

The pilot implementation targeted children aged 4-7 years across three distinct educational contexts: (1) one kindergarten classroom (n=18 children five years-old), (2) two primary school first-grade classroom (n=20 and n=14 children), and (3) informal workshops during a public science event (n=45 children three to seven years-old across multiple sessions). This diverse sampling strategy ensured cross-contextual validation of the methodological approach.

Each 90-minute session integrates six computational thinking constructs through specific SixBricks activities embedded within this coherent storyline.

Decomposition is introduced through the bridge construction challenge, where children must help the moles cross the river to continue their search. The complex engineering problem is systematically decomposed into manageable subcomponents: children learn to break down the overall construction task into sequential building phases, identifying component interdependencies and resource allocation strategies.

Abstraction emerges through the creation of a "mission summary tower" that captures the essential narrative elements while filtering out irrelevant details. The story's color palette becomes a systematic coding scheme where children construct towers reflecting these core story elements, learning to extract salient features and ignore non-essential narrative details such as character dialogue or temporal sequences.

Algorithmic Thinking develops through systematic creation of movement commands for Matabì navigation. Children design step-by-step instruction sequences using directional vocabulary and gesture-based commands, subsequently translating these into a simplified programming language using bricks as visual command. The activity emphasizes logical ordering, conditional statements, and iterative processes.

Pattern Recognition is cultivated through visual commands' observation, where children identify recurring sequences. For example turn and one step forward can be substituted by a new integrated command. This develops visual-spatial pattern detection skills and encourages systematic comparison of algorithmic outputs.

Generalization occurs through code-to-music transformation exercises, where movement algorithms developed for Matabì are translated into rhythmic and melodic patterns. This cross-domain transfer demonstrates that computational thinking principles transcend specific contexts and can be applied across different representational systems.

Error Evaluation and Resolution is systematically integrated throughout all activities. During tower comparisons, children engage in collaborative debugging sessions to identify color sequence inconsistencies, trace construction errors to their sources, and implement corrective modifications.

The pilot study employed a mixed-methods observational framework without standardized assessment instruments, as quantitative effectiveness evaluation will be conducted in the planned randomized controlled trial. Data collection included: (1) structured behavioral observations with session field notes, recording engagement levels and collaborative dynamics (2) interviews with classroom teachers focusing on pedagogical alignment and implementation feasibility, and (3) photographic documentation of student constructions for pattern analysis. All sessions were conducted by trained facilitators following standardized protocols to ensure consistent implementation across contexts together with an observer, with activity materials standardized using SixBricks sets and session timing maintained within 5-minute variations.

The laboratory culminates in a collaborative mission completion phase where children synthesize all computational thinking components to help Matabì reach Bricky Talp. Teams combine their algorithmic movement commands, verify tower color-coding accuracy against narrative requirements, and collectively debug any identified inconsistencies. As a concluding generalization activity, each child designs and constructs their own "helping machine" using SixBricks, applying learned computational thinking principles to solve self-identified problems or assist imaginary characters. This open-ended construction task encourages creative transfer of computational concepts beyond the structured laboratory context, reinforcing both abstraction and generalization skills while maintaining the playful, discovery-oriented approach characteristic of Munari's educational philosophy.

IV. Preliminary Findings and Discussion

Pilot studies across formal and informal educational contexts revealed distinct implementation patterns that provide valuable insights for scalable deployment. In formal educational settings, the intervention was structured as an extended sequence where each computational thinking construct received dedicated instructional time within separate class periods, allowing for in-depth exploration and metacognitive reflection. This extended format enabled teachers to facilitate meaningful discussions about problem-solving strategies, encouraging children to articulate their thinking processes and make explicit connections between different computational approaches.

Conversely, the informal context compressed the entire laboratory experience into a single session, functioning as an introductory 'taste' of computational thinking for participating children. While children successfully completed Matabì's mission and demonstrated engagement with the narrative framework, they focused primarily on task completion rather than construct-specific learning objectives. The informal setting proved particularly valuable for parent engagement, as computational thinking concepts were simultaneously explained to accompanying adults, providing them with concrete strategies for extending learning through home-based play activities using SixBricks materials.

The differential implementation revealed complementary educational affordances. Formal contexts supported deeper metacognitive development, with children demonstrating increased ability to verbalize problem-solving strategies and recognize computational patterns across different activities. Teachers reported enhanced student performance when subsequently introducing robotic computational tools such as Bee-Bots, suggesting that the unplugged foundation strengthened children's conceptual understanding of algorithmic thinking and spatial reasoning. This transfer effect indicates that hands-on manipulation with SixBricks may serve as effective scaffolding for more complex technological interactions.

Observational data confirmed high engagement levels across both contexts, with children maintaining focused attention throughout sessions and demonstrating collaborative problem-solving behaviors. The narrative-driven approach successfully motivated participation while the systematic color-coding scheme facilitated abstract thinking without overwhelming cognitive load. Teacher feedback consistently highlighted the framework's intuitive design and seamless integration with existing early childhood pedagogical practices. Both observations and teacher interviews confirmed that the laboratory structure is perfectly scalable across the considered age range (3-7 years) by appropriately modulating cognitive loads, suggesting robust developmental adaptability of the methodological framework.

These preliminary findings support the framework's adaptability to diverse educational contexts while highlighting the importance of context-appropriate implementation strategies. The planned Randomized Controlled Trial will be conducted exclusively in formal educational settings, targeting children in their final year of kindergarten and first year of primary school to systematically measure cognitive benefits of unplugged activities on individual computational thinking constructs. This focused approach will enable rigorous assessment of construct-specific learning outcomes and developmental trajectories. Meanwhile, informal laboratory implementations demonstrate particular effectiveness for family sensitization regarding the role and structure of computational thinking, serving as an accessible entry point for broader community engagement and home-based reinforcement of computational concepts.

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