Developing Creative and Playful Computational Thinking with LEGO Robotics in Upper Primary Education: Practical Experiences and Pedagogical Innovations

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Abstract

In digital transformation, computational thinking (CT) is fundamental for creative problem-solving. This presentation examines LEGO robotics (EV3, SPIKE Prime, WeDo) in primary and elementary education, focusing on play and creativity in CT acquisition. Research shows LEGO robotics with visual programming effectively develops algorithmic thinking, problem-solving, and teamwork. Playful approaches enhance student motivation and foster creativity during programming tasks. Robots aid in understanding physics principles and boost STEM interest. Teacher preparation for CT pedagogical integration is crucial, enhancing confidence and methodological knowledge, addressing knowledge gaps and technical challenges. The presentation showcases practical experiences and pedagogical innovations supporting students' creative and playful CT through LEGO robotics.

Keywords: *computational thinking, LEGO robotics, playful pedagogy, creative problem solving, teacher training*

1. Introduction

In the age of digital transformation, the key task of education is to prepare students for the challenges of the 21st century. At the heart of this preparation is computational thinking (CT), which goes beyond programming and has become a fundamental skill for critical problem solving and algorithmic thinking.

The concept of computational thinking is broader than programming. It is a mental process aimed at problem solving and a related set of transversal competencies that uses the principles of computer science and the tools of the digital ecosystem to solve problems effectively. As a mental process, it involves breaking things down into their basic components, pattern recognition, abstraction, and the application of algorithms. As a set of competencies, it integrates mathematical, learning, and creative thinking competencies (Csernai & Racsko, 2024: 9).

LEGO robotics systems (Mindstorms EV3, SPIKE Prime, WeDo) offer an ideal, practical platform for developing these skills in upper grades. The combination of visual (Scratch-based) programming and hands-on robot building allows students to develop their algorithmic thinking, problem-solving skills, and teamwork in a playful, creative environment (Reinhold, 2025; Ardito et al., 2020; Chalmers, 2018).

This study examines the pedagogical application of LEGO robots in upper elementary school, presenting practical experiences and methods for developing creative and playful computational thinking. Special attention is given to the importance of teacher training, which is essential for the confident and effective introduction of computational thinking pedagogy.

2. The theoretical foundations of computational thinking and creativity

2.1. Computational thinking and creative problem solving

In a technology-driven society, computational thinking is a fundamental cognitive tool for solving complex problems. The concept goes beyond mere programming skills; it involves abstracting problems, identifying key elements, and developing algorithmic strategies that provide an effective and transferable method of problem solving in STEM and beyond (Reinhold, 2025; Anastasiou et al., 2024).

Computational thinking is closely intertwined with creative problem solving. As a framework based on algorithms, logical reasoning, and abstraction, it provides structure and preconditions for creativity, which manifests itself in the ability to generate new and effective solutions. According to Paper's theory, computers can serve as catalysts for creativity, which is supported by current empirical research (Israel-Fishelson et al., 2020). LEGO robotics, combined with visual programming, provides a concrete context for creative problem solving, where students must generate new, original solutions and iterate their designs (Ana et al., 2016). The iterative cycle (design, build, test, and refine) models the creative problem-solving process, with computational thinking providing the underlying structure. Transferability is one of the characteristics of computational thinking and creative thinking, suggesting that developing one is likely to benefit the other.

2.2. The role of playful learning and pedagogical frameworks

Play and playful learning play a key role in developing computational thinking and creativity. LEGO robotics systems, combined with visual programming, provide a low-risk environment for intellectual risk-taking and experimentation (Reinhold, 2025). This free exploration encourages students to test hypotheses, be flexible, and be resilient in the face of failure (Ardito et al., 2020). The collaborative approach also develops teamwork and communication, which are fundamental parts of computational thinking.

The use of reliable pedagogical frameworks is essential for successful integration. The TPACK (Technological Pedagogical Content Knowledge) model is particularly important in this context, as it emphasizes the synthesis of technological, pedagogical, and content knowledge. The structure of the TPACK model and its fundamental role in robotics education are presented in detail in Chapter 6 and Figure 3. Teachers need to understand not only the technical details of robotics, but also the developmental aspects that develop computational thinking skills (Chalmers, 2018).

3. LEGO Robotics: Pedagogical Tools and Visual Programming

LEGO Robotics (Mindstorms EV3, SPIKE Prime, WeDo) systems are key tools for developing creative computational thinking in primary school education. These platforms integrate modular hardware (programmable bricks, motors, sensors) with intuitive visual programming environments (e.g., Scratch-based block programming). This combination lowers the entry threshold even for the youngest learners, allowing them to focus on algorithmic logic and problem solving rather than complex syntax (Chaudhary et al., 2017; Vallance and Towndrow, 2018; Reinhold, 2025).

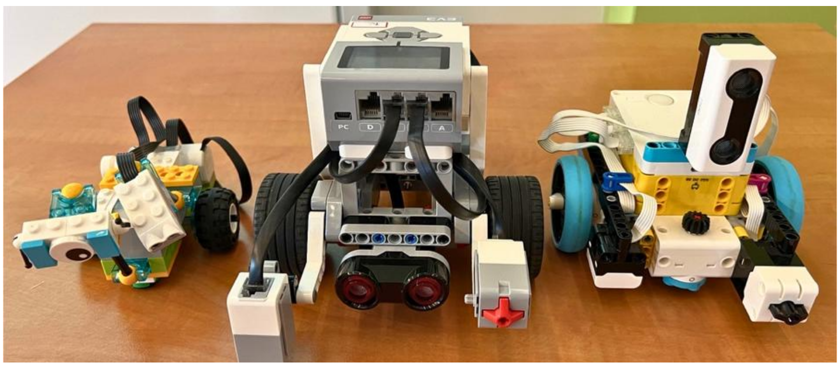

Figure 1: *LEGO robotics educational platforms (WeDo, Mindstorms EV3, SPIKE Prime)*
(Source of the image: Own source)

The use of LEGO robots provides a unique, hands-on learning experience that sets them apart from traditional, textbook-based methods. Physical construction and programming create a direct feedback loop: students immediately see the results of their code in the robot's behavior (Ardito et al., 2020). This iterative process of building and testing supports computational thinking skills (e.g., decomposition, debugging) while mirroring authentic engineering practice, reinforcing teamwork and communication (Chaudhary et al., 2017).

Thanks to the versatility of these platforms, educators can apply robotics to a wide range of learning objectives:

1. WeDo: Suitable for introducing early, basic programming and STEM concepts, minimizing cognitive load (Anastasiou et al., 2024).

2. EV3/SPIKE: Supports more complex challenges and helps students apply mathematical, physical, and computer science concepts in a single interdisciplinary task. This type of method not only develops computational thinking but also positively influences motivation for STEM (Addido et al., 2023; Leonard et al., 2016).

Visual programming environments not only facilitate coding, but also develop spatial reasoning and problem solving, as students must visualize the robot's movements in 3D space. The success of integration depends on the preparedness of teachers, whose TPACK knowledge (technological, pedagogical, and content knowledge) is essential for the effective introduction of computational thinking pedagogy (Chalmers, 2018; Leonard et al., 2016).

4. Playful learning: Intrinsic motivation and creative self-confidence in robotics

4.1. The scientific basis and application of intrinsic motivation

Playful learning methodologies are key to the effective development of computational thinking among upper-grade students. This pedagogical approach allows LEGO robotics tools (Mindstorms EV3, SPIKE Prime) to be used to stimulate intrinsic motivation, as the activity stems from internal joy for the sake of the activity itself.

Intrinsic motivation is an internal drive to act that occurs when the learner performs the activity for its own sake – for enjoyment, satisfaction, or to increase their sense of competence (Hunter, 2008; Di Domenico and Ryan, 2017). Its fundamental characteristics are autonomy, competence, and relatedness, which are essential for promoting intrinsic motivation (Hunter, 2008; Moy et al., 2016). This motivation is critical for supporting sustained engagement in STEM fields in education (Moy et al., 2016; Santos et al., 2020; Schüler et al., 2023).

The effectiveness of robotic interventions stems from their simultaneous reinforcement of key elements of motivation: open-ended tasks support students' autonomy and sense of competence. Immediate physical feedback reinforces the sense of efficacy, which deepens engagement (Reinhold, 2025; Ana et al., 2016).

4.2. The role of playful learning and pedagogical frameworks

Creative confidence is the belief of learners that they are capable of generating and implementing new, innovative ideas and coping with failure.

LEGO robotics project work supports:

1. Divergent thinking and abstraction: Open-ended robotics challenges require the development of multiple possible algorithmic solutions (Israel-Fishelson et al., 2020).

2. Debugging and resilience: During iterative code refinement, errors are treated as a natural part of the learning loop, which strengthens students' resilience (Addido et al., 2023).

The role of the teacher is critical in using the TPACK framework to create a safe, supportive environment where students dare to take risks and think creatively (Chalmers, 2018).

5. Interdisciplinary applications of LEGO Robotics in STEM education

LEGO Robotics (Mindstorms EV3, SPIKE Prime, WeDo) and visual programming provide a unique platform for building interdisciplinary bridges between STEM disciplines (science, technology, engineering, and mathematics) in upper grades (Reinhold, 2025). The physical construction and programming of robots allows students to learn abstract principles through experience.

The use of LEGO robots authentically supports the understanding of physical concepts such as the principles of Newtonian mechanics. Students must design and program robots for tasks such as moving objects or navigating slopes. This allows them to directly observe the effects of force, motion, mass, and acceleration, linking algorithmic thinking with scientific reasoning (Reinhold, 2025; Chalmers, 2018).

During the implementation of each project, engineering principles (e.g., mechanical design, structural stability) provide immediate feedback (Addido et al., 2023).

To illustrate interdisciplinary learning, Figure 2 shows various real-world STEM challenges that require a synthesis of programming, physics, and mechanical design.

Figure 2: *Various LEGO robotics STEM tasks: Practical application of algorithmic thinking to physical and engineering challenges*
(Source of the image: Vallance and Towndrow, 2018; adapted)

Robotics projects also seamlessly integrate mathematical concepts into practice. When programming, students must apply the principles of sequencing, measurement (e.g., distance, angle), and logical reasoning. Calculating and modeling the movements of robots makes mathematical relationships tangible and relevant (Reinhold, 2025).

It is essential for success that teachers are able to facilitate inquiry-based and playful challenges (Chalmers, 2018). This cross-disciplinary approach has been shown to improve cognitive and social skills (Reinhold, 2025; Chalmers, 2018).

6. Teacher training, TPACK, and the integration of computational thinking pedagogy

The introduction of computational thinking and robotics into education requires a clear pedagogical paradigm shift (Reinhold, 2025), in which teacher training is a fundamental prerequisite for successful implementation. The rise of computational thinking as a 21st-century basic skill requires educators to abandon traditional didactic methods and adopt inquiry-based, student-centered approaches that leverage the playful, exploratory potential of robotics (Reinhold, 2025). Teachers' confidence and proficiency in these areas directly determines the quality of learning outcomes.

A central element in building methodological knowledge and teacher confidence is the TPACK (Technological Pedagogical and Content Knowledge) framework. The model is based on the triad of content, pedagogical, and technological knowledge, which „defines the different types of knowledge and skills that teachers are expected to have in order to successfully plan and implement technology-based learning, emphasizing the importance of the intersection of Technological Knowledge, Pedagogical Knowledge, and Content Knowledge" (Turcsányi-Szabó, 2011).

Figure 3 shows a visual representation of the TPACK model.

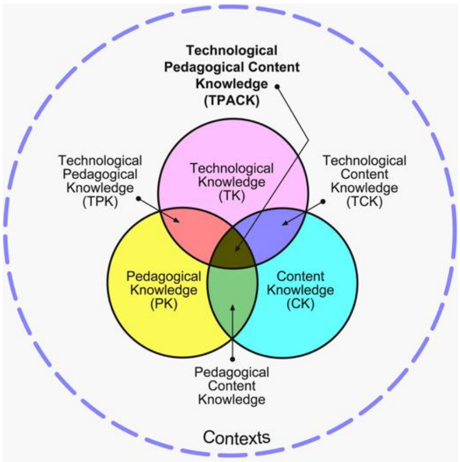

Figure 3: *Elements of the TPACK model (Technological Pedagogical Content Knowledge)*
(Source of the image: Kurt, 2018; adapted)

Knowledge organized along these intersections is critical in robotics education, as it ensures that educators not only acquire technical skills, but also gain a deep understanding of theoretical concepts in computer science and the pedagogical strategies that can be used to integrate the content most effectively into existing curricula (Chalmers, 2018).

The TPACK dimensions in the pedagogy of computational thinking include the following:

1. Pedagogical Content Knowledge (PCK): Methodological knowledge related to a given subject, which is necessary for the effective teaching of concepts related to computational thinking (e.g., abstraction, algorithmization).

2. Technological Content Knowledge (TCK): Technological knowledge that helps to present and understand specific content (e.g., robot movements, sensor operation).

3. Technological Pedagogical Knowledge (TPK): Effective use of various technologies (e.g., LEGO platforms, visual programming interfaces) to support teaching and learning, taking into account student assessment and curriculum design.

The strength of the model is that it takes into account that a number of factors (e.g., school type, grade level, demographic characteristics) influence the emphasis on TPACK elements. Longterm, systematic training development is essential for successful integration, which requires the use of technology (ICT) for student assessment, content comprehension, curriculum planning, and the application of technology-based teaching strategies (Lengyelné et al., 2015).

Professional development must also emphasize collaborative learning. Professional learning communities (PLCs), based on Social Interdependence Theory and Vygotsky's zone of proximal development, enable teachers to share best practices, support each other, and collectively overcome emerging technological and curricular barriers (Anastasiou et al., 2024).

There are a bunch of hurdles during implementation that are super important to get over for sustainability. These include teachers' attitudes and beliefs about technological complexity, lack of alignment with curriculum and assessment, and resource constraints (e.g., time, tools, technical support). For innovation to be sustainable, professional development must be ongoing and embedded in the school culture. Institutional leadership must provide long-term commitment and support for cross-disciplinary planning, ensuring that computational thinking is not isolated but is an integral part of STEM and other subjects (Ardito et al., 2020; Reinhold, 2025). Continuous professional development helps teachers adapt to new tools and methods, ensuring momentum for pedagogical innovation (Chalmers, 2018).

7. Evaluating computational thinking and creativity

In LEGO robotics-based interventions, measuring computational thinking and creativity requires a synthesis of quantitative and qualitative approaches for a holistic understanding. Quantitative methods (e.g., performance-based tasks, pre- and post-tests) support learning outcomes with numerical data, measuring the correctness and efficiency of algorithms and coding skills (Reinhold, 2025; Addido et al., 2023). In contrast, qualitative methods (e.g., student journals, observations, interviews) provide rich insights into processes, teamwork, debugging strategies, and nuances of creativity (Chaudhary et al., 2017). Combining the two methods (mixed methodology) increases the validity of research results.

Figure 4 shows the LEGO robotics-based curriculum design cycle and the mixed evaluation approach, which consists of initial evaluation, curriculum implementation, and continuous measurement of results.

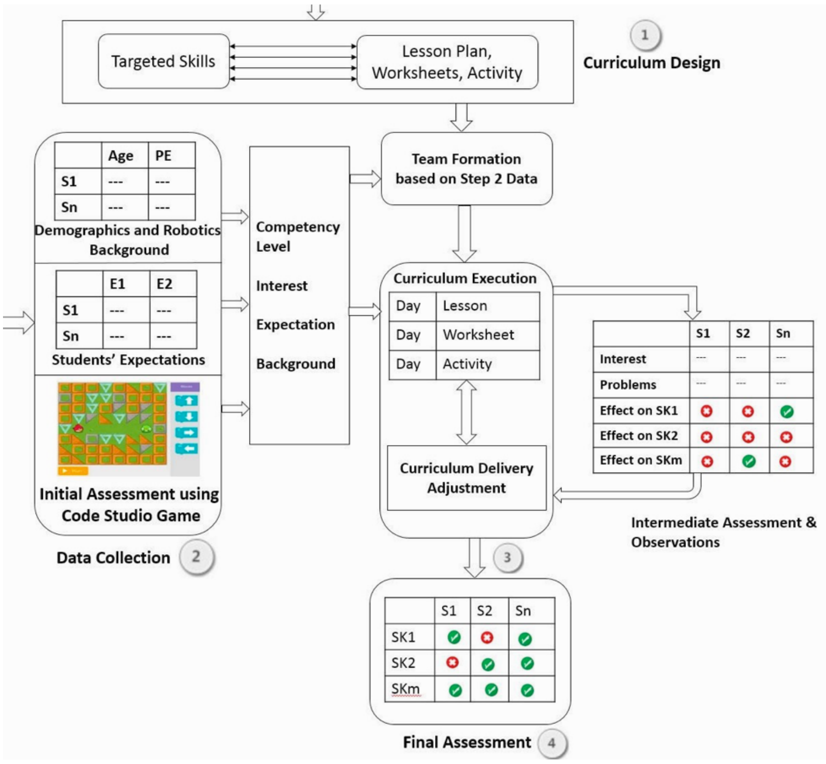

Figure 4: *LEGO robotics computational thinking curriculum design and evaluation process (Source of the image: Chaudhary et al., 2017; adapted)*

Assessing creativity in robotics focuses not on the correctness of the solution, but on the diversity and originality of ideas and the flexibility shown in overcoming challenges. Assessment should take into account the exploratory nature of playful learning, where making mistakes is part of the process of development. Student journals and reflective practices are excellent qualitative tools as they allow learners to articulate their thought processes, share their solution strategies, and develop metacognitive skills (Ardito et al., 2020).

Gender and diversity should be given special attention during the evaluation process. The inclusion of robotics has the potential to reduce traditional gender stereotypes in STEM. However, to ensure equal opportunities, it is essential that assessment systems are flexible and recognize not only technical proficiency but also different forms of teamwork, leadership, and creative contribution (Ardito et al., 2020). Teacher professional development is key to ensuring that educators evaluate impartially and address differing prior knowledge through differentiated instruction (Chaudhary et al., 2017).

8. Equal opportunities, sustainability, and the future of robotics in education

8.1. Equal opportunities and accessibility

Ensuring equal opportunities and accessibility is a critical challenge in integrating LEGO robotics. Financial barriers (e.g., the cost of kits and compatible devices) are a significant constraint for underfunded schools. In addition, a lack of teacher preparedness or unequal access to professional development can hinder the creation of inclusive learning environments. Collaborative and playful pedagogy has the potential to reduce traditional gender or social stereotypes, but assessment practices must also be flexible to recognize creative contributions and different forms of teamwork in addition to technical proficiency (Reinhold, 2025; Leonard et al., 2016).

8.2. Sustainability and future trends

Systemic and long-term support is needed for the sustainable expansion of robotics programs. Key elements of this include continuous professional development for teachers within the framework of TPACK, the use of cost-effective solutions (e.g., resource sharing), and the organic integration of programs into the curriculum in STEM and other subjects (Chalmers, 2018).

The future of LEGO robotics points towards student-led projects and an emphasis on creativity as an integral part of computational thinking. The goal is not only to transfer skills, but also to maintain students' intrinsic motivation and to create a school culture that values experimentation and innovation.

9. Summary and conclusion

LEGO Robotics and visual programming represent a transformative step in upper elementary school in deepening computational thinking, creativity, and STEM knowledge. The tools provide tangible, playful experiences that support algorithmic thinking, logical reasoning, and collaborative problem solving.

LEGO-based activities increase intrinsic motivation and creative self-confidence. Continuous experimentation and iterative refinement align with constructivist learning theories by emphasizing construction that deepens conceptual understanding and learning from mistakes. Robotics also builds interdisciplinary bridges, connecting computational thinking with physical principles and spatial reasoning.

The success of these programs depends on comprehensive training for educators. Professional development is essential for building TPACK expertise, which combines technological proficiency with appropriate pedagogical methods. Cost-effectiveness and curriculum integration are essential for sustainability.

The assessment of learning outcomes requires a balance of qualitative and quantitative methods. Assessment should include creative contributions and take diversity into account to ensure equal opportunities.

The future of robotics points towards student-led discovery and continuous pedagogical innovation. Education systems must support a culture of creativity in order to nurture agile problem solvers for the challenges of the 21st century.

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