Technological Thinking and 3D Design with LEGO: A Pedagogical Reflection

Yonny Fernando Molina Sandoval[1], Olga Nájar Sánchez[2], Jenny Edith Parada Camargo[3]

[1] Universidad Pedagógica y Tecnológica de Colombia (UPTC). Master's Program in Technology-Mediated Educational Environments (c). Educational Virtual Environments (AVE) Research Group. yonny.molina@uptc.edu.co. ORCID: https://orcid.org/0000-0002-1116-3177
[2] Professor, Universidad Pedagógica y Tecnológica de Colombia (UPTC). Faculty of Education Sciences. Educational Virtual Environments (AVE) Research Group. olga.najar@uptc.edu.co. ORCID: https://orcid.org/0000-0003-1286-7683
[3] Professor, Universidad Pedagógica y Tecnológica de Colombia (UPTC). Faculty of Economic and Administrative Sciences. School of Business Administration. jenny.parada@uptc.edu.co. ORCID: https://orcid.org/0000-0003-2104-3977

Abstract
This reflection article considers the pedagogical potential of LEGO as a teaching aid for developing three-dimensional (3D) design and technological thinking competencies in the school context. The reflection is supported by a documentary review of studies published between 2019 and 2024 on constructionism, technological thinking, 3D design and spatial visualization, design thinking in K–12 education, and educational robotics, supported by classical theoretical references. It is argued that the articulation of physical construction with LEGO, 3D modeling, and problem-solving benefits processes of representation, functional analysis, iteration, evaluation, and improvement of solutions. It is also argued that LEGO promotes spatial reasoning, systems understanding, applied creativity, and technological decision-making when it is used as a teaching device with pedagogical intentionality rather than simply as a playful resource. Finally, teaching guidelines are proposed for designing classroom experiences centered on prototyping and design.
Keywords: LEGO; 3D design; technological thinking; constructionism; technology education; spatial visualization

1. INTRODUCTION

Education currently faces the challenge of preparing students who are able to understand, project, modify, and evaluate artifacts, processes, and systems in environments increasingly mediated by digital technologies. Global analyses of trends reshaping education emphasize the need for educational systems to adapt to changing contexts (OECD, 2019; UNESCO, 2021). In this scenario, technological thinking is configured as a category that transcends an instrumental view of technology. In the Colombian context, technology education has been proposed as a heterogeneous system of actions and practices involving agents, artifacts, knowledge, norms, and values (Monterroza Ríos & Escobar Gómez, 2021). Bibliometric analyses of the field show that research in technology education has increasingly focused on creativity, design, problem solving, and STEM education (Xu et al., 2020).

From this perspective, 3D design and technological thinking have particular contemporary relevance because they articulate conceptual understanding, spatial representation,

creativity, and problem solving. The goal is not merely to incorporate innovative tools into the classroom, but to construct experiences that enable students to think technologically: analyze needs, project solutions, anticipate the behavior of an object, build prototypes, and review their decisions. This concern is consistent with recent debates on computational thinking, which invite us to understand it as a situated and social practice rather than solely as an individual cognitive skill (Kafai & Proctor, 2022).

Within this framework, LEGO is presented as an interesting pedagogical mediation because it makes it possible to move from abstract ideas to constructions that can be touched, tested, and improved. Its relevance does not lie in the attractiveness of the material, but in the possibility of mobilizing sequences of construction, deconstruction, testing, and redesign consistent with constructionism (Papert, 1980) and design-based learning. When these sequences are connected with 3D modeling tasks, students do not simply assemble pieces: they express technical intentionality, contrast alternatives, and understand structural and functional relationships in greater depth. Recent evidence on LEGO structures and robotics supports this potential for spatial reasoning and computational thinking (Kocabas et al., 2023; Leonard et al., 2023); for example, among children aged 7 to 9, LEGO construction skills were associated with mathematical performance, partly through spatial skills (McDougal et al., 2023).

This article proposes an academic reflection on the relationship between LEGO, 3D design, and technological thinking. It is based on the premise that the convergence of physical construction and digital representation can strengthen the cognitive and procedural capacities required for solid technology education, in a Latin American context where the integration of computational thinking in primary and secondary education has relied mainly on educational robotics and block-based programming languages (Quiroz-Vallejo et al., 2021). The purpose is to argue why LEGO, integrated into three-dimensional design experiences, can constitute an effective teaching environment for developing technological thinking in basic and secondary education.

2. THEORETICAL FRAMEWORK

2.1. Technological thinking as an educational category

Technological thinking has been approached as a category that goes beyond the utilitarian conception of technology and understands it as a form of knowledge, action, and transformation. Perceiving technology involves recognizing that artifacts and systems are the consequence of human decisions situated in a context. As proposed by Monterroza Ríos and Escobar Gómez (2021), technical, technological, and engineering levels are differentiated according to the knowledge and innovation capacities involved, which helps clarify what is expected from school-based technology education.

Thinking technologically therefore means analyzing challenges, imagining alternatives, having criteria for judging the feasibility of a solution, and evaluating the extent to which it resolves the situation at hand, rather than merely reproducing procedures or operating tools. This idea is compatible with the recent reframing of computational thinking toward computational literacies, which emphasizes its situated and social nature (Kafai & Proctor, 2022), and with evidence on educational robotics reporting benefits in interest, engagement, and academic achievement in STEM areas (Anwar et al., 2019). In Latin America, STEAM approaches have been associated with strengthening computational thinking, performance, motivation, creativity, and problem solving (Palmera Quintero et al., 2024), while reviews of STEAM and mathematical thinking highlight problem solving

and gamification as central subcategories (Acendra Pertuz & Conde Carmona, 2024). A scoping review of 145 articles on computational thinking and educational technology found that resources with and without technological devices are equally frequent and that primary education is the most common level of application (Acevedo-Borrega et al., 2022), showing that these competencies can be developed with low-technology-cost resources such as blocks.

In the classroom, this entails experiences in which students express a design intention through models, contrast it with constraints, test it, and critically review their results. Technological thinking therefore requires settings that articulate material action, technical language, spatial representation, and reflection on function.

2.2. Constructionism, active learning, and mediation with LEGO

Constructionism holds that learning is strengthened when individuals construct objects that can be shared, reflect on them, and improve them through interaction with others (Papert, 1980). The production of artifacts is not a by-product of learning activity, but rather the means that organizes understanding, creativity, and intellectual autonomy. Vygotsky's (1978) sociocultural perspective complements this approach by highlighting the role of social interaction and mediation in knowledge construction. A critical review of maker education, however, warns that producing an artifact is not enough to guarantee knowledge construction; this occurs when students represent and explain the actions, concepts, and strategies they use while building (Valente & Blikstein, 2019). In digital fabrication settings, evidence indicates potential for developing competencies and computational thinking, particularly creativity, collaboration, and problem solving, although teachers show limited knowledge of computational-thinking concepts and face time constraints (Iwata et al., 2020), while reviews of teacher education in creation-centered learning grounded in constructionism emphasize the need for professional support for teachers (Caratachea et al., 2023).

LEGO naturally fits this framework because it provides a material construction language that makes spatial relationships, assembly sequences, and functional criteria explicit. Building allows students to experiment with stability, symmetry, coupling, support, movement, and modularity. Practice, however, is not limited to manipulation: conversation about what has been built, justification of decisions, analysis of failures, and redesign transform the resource from material support into cognitive mediation. An exploratory study with students from kindergarten through second grade showed that debugging a LEGO structure mobilized strategies similar to those used in programming, such as pattern comparison and error tracing (Kocabas et al., 2023). In primary education, a ten-week after-school LEGO robotics program showed evidence of computational thinking and computational participation among fifth- and sixth-grade students (Leonard et al., 2023). On a broader scale, a systematic review of 22 studies with students from preschool through sixth grade identified LEGO Mindstorms as the predominant robotics kit and collaborative learning, project-based learning, and embodied learning as the most frequent pedagogical strategies (Ching & Hsu, 2024). A meta-analysis of 27 experimental and quasi-experimental K–12 studies found a positive effect of educational robots on computational thinking (DME = 0.558), with stronger results when design-based instructional approaches were used and when students worked in small groups (Hong, 2024). Manipulation of physical objects also appears as a central element of tangible experiences; reviews of tangible programming languages point to their contribution to collaborative learning, problem solving, and creative expression in early childhood (Funk et al., 2021), and an experience with an embodied computer-free kit showed that algorithmic thinking and debugging

emerged prominently (Hu et al., 2024). With 51 kindergarten children, an 11-session robotics intervention showed that task engagement was central to gains in computational thinking (Gerosa et al., 2022).

These characteristics are especially valuable when the work is directed toward real design problems rather than the reproduction of closed models. In that case, LEGO ceases to be a playful resource and becomes a mediation that articulates construction, reflection, and meaningful learning.

2.3. 3D design and spatial visualization in technology education

Three-dimensional design makes it possible to represent, explore, modify, and visualize objects before building them. Cognitive load theory, updated by Sweller et al. (2019), reminds us that these representations should be appropriately graduated so that task complexity does not exceed students' processing capacity.

Spatial visualization, understood as the ability to mentally represent rotations, perspectives, proportions, and structures in three dimensions, is central to this process. A recent meta-analysis associates spatial training with improvements in mathematical performance (Hawes et al., 2022), and training with physical materials produced broader and more consistent gains in mathematics than non-embodied, computer-based training (Gilligan-Lee et al., 2023). In the specific case of LEGO, the mediating effect of mental rotation was greater in concrete construction tasks than in digital tasks (McDougal et al., 2023), supporting the complementarity of physical and digital approaches. Reviews of spatial-skill development in authentic STEM contexts indicate that spatial training has moderate positive effects on spatial skills and mathematical performance, moderated by gender and socioeconomic status, so interventions should be designed inclusively (Zhu et al., 2023). In 3D modeling, a 30-hour SketchUp course significantly improved the spatial thinking of lower-secondary students (Šafhalter et al., 2022), and secondary students perceived that 3D modeling strengthens design, communication, collaboration, creativity, and problem solving (Coşkun & Deniz, 2022). A scoping review of 3D printing in mathematics education, in turn, indicates that project-based learning and maker approaches predominate and that this technology improves spatial reasoning and geometric understanding (Ng et al., 2022). Teaching these skills nevertheless faces barriers and dispositions. A narrative review identifies systematic curricular design, the use of spatial technologies, hands-on activities, and assessment as pedagogical practices, and identifies insufficient time and failure to account for student complexity as difficulties, with teacher education playing a fundamental role (Bufasi et al., 2024). The qualification of technology teachers, incorporation of spatial illustration, and development of sketches were associated with significant progress in spatial rotation and minimal failure rates (Lane & Sorby, 2022). In Germany, only 22% of surveyed teachers had integrated 3D printing into their teaching although approximately 45% had access to printers, and those with greater expertise recognized a broader range of competencies and methodological uses (Thyssen & Meier, 2023).

From a didactic perspective, the contribution of 3D design is not limited to improving cognitive performance. Its greatest value is that students must transform concepts into formal decisions: proportions, assembly, volume, orientation, compatibility between pieces, and anticipation of functioning. When modeling, students organize information, establish relationships, anticipate results, and structure an object according to a design intention. Therefore, three-dimensional representation acts as a bridge between imagination and technical judgment and places decision-making at the center of education.

2.4. Design thinking, project-based learning, and collaboration

Design thinking helps students better understand problems, identify needs, and find solutions. In seventh grade, its incorporation into a technology course supported both basic learning and the development of original digital products compared with traditional teaching (Lin et al., 2020); in a short workshop with young people, it increased interest in engineering, creative confidence, and positive perceptions of STEM (Kijima et al., 2021). In a 3D modeling curriculum with 90 sixth-grade students, a three-stage design-thinking framework produced significantly greater improvements in work performance, operational skills, and creativity than traditional teaching, although not in basic knowledge (Tan et al., 2024). A systematic review of 229 articles on K–12 STEM education also found that design-based learning is adopted more frequently than other approaches, mainly to achieve STEM literacy (Halawa et al., 2024). In early childhood, its relationship with craft, design, and technology education has been discussed (Grönman et al., 2024). In turn, the review by Nazlidou et al. (2024) shows that innovative and interactive technologies expand the possibilities of design education.

Project-based learning shares with these proposals an emphasis on authentic problems; a meta-analysis reports a positive effect on academic achievement, with differences according to moderating variables (Chen & Yang, 2019). A meta-analysis of 26 studies on informal project-based learning in STEM found a moderate effect compared with traditional teaching, influenced by the teaching approach, assessment, group composition, and program duration (Santhosh et al., 2023). In the field of design thinking, a bibliometric analysis of 99 publications shows its growing relevance for developing capacities required in digitalized environments, such as interdisciplinary collaboration and the articulation of human and technological perspectives (Dragicevic et al., 2023). Collaboration, finally, cuts across these strategies: a meta-analysis of 40 studies on computer-supported collaborative learning found a mean effect of 0.523 on academic achievement, influenced by intervention duration (Talan, 2021).

Design thinking and technological thinking are related, but they are not equivalent; the former is a creative problem-solving process, whereas the latter focuses on the creation and understanding of objects and systems. Tools such as LEGO combined with 3D design can articulate both approaches by allowing students to explore, design, test, and improve ideas.

3. METHODOLOGY

This is a reflection article based on a documentary review, understood as the analytical and critical reading of academic literature to support an argued position (Xiao & Watson, 2019). The review was organized into five thematic areas: technological thinking, constructionism, 3D design and spatial visualization, design thinking in K–12 education, and experiences in robotics or construction with LEGO. Empirical studies and reviews published between 2019 and 2024 were prioritized; the classic works of Papert (1980) and Vygotsky (1978) were retained as theoretical foundations.

The review does not seek to be exhaustive, but rather to establish theoretical and pedagogical convergences among categories that are often treated separately, avoiding reducing LEGO construction to a playful resource or 3D design to an instrumental competency. For the analysis, findings from the sources were coded and compared and grouped into thematic categories (Braun & Clarke, 2019), which structure the results

section: technological thinking as a design practice, LEGO as cognitive mediation, 3D design and spatial reasoning, and physical-digital articulation with collaboration.

4. RESULTS

The analysis of the literature made it possible to identify four thematic categories that synthesize what the reviewed evidence contributes to the development of technological thinking. Each category is presented with its pedagogical interpretation, that is, what it implies for the planning, mediation, and assessment of classroom experiences.

4.1. Technological thinking as a design practice

The literature converges on the idea that technological thinking develops through experiences in which students analyze, create, and evaluate solutions, rather than through simple exposure to tools (Kafai & Proctor, 2022; Monterroza Ríos & Escobar Gómez, 2021). Studies using design thinking show improvements in the production of original outcomes, creativity, and creative confidence (Kijima et al., 2021; Lin et al., 2020; Tan et al., 2024), and design-based learning is a frequent approach in K–12 STEM education (Halawa et al., 2024). Research in technology education confirms that creativity, problem solving, and design are expanding trends in the field (Xu et al., 2020), and in Latin America STEAM strategies are associated with improvements in creativity and problem solving (Acendra Pertuz & Conde Carmona, 2024; Palmera Quintero et al., 2024).

From the pedagogical reflection, this finding shifts the focus from the tool to the task. What is decisive is not whether the classroom has blocks or modeling software, but whether the challenge requires students to identify needs, establish criteria, make decisions, and justify them. The study by Tan et al. (2024) illustrates this idea with sixth-grade students: a design-thinking framework applied to a 3D modeling curriculum improved work performance, operational skills, and creativity, although not basic knowledge, suggesting that design expands the type of learning achieved and not merely its quantity. Along the same lines, the review by Nazlidou et al. (2024) shows that innovative and interactive technologies enrich design education when integrated into value-added experiences for students, and the review by Grönman et al. (2024) places design thinking in dialogue with craft, design, and technology education from early childhood.

4.2. LEGO as cognitive mediation

Research on LEGO structures and robotics reports benefits in debugging, computational thinking, and spatial reasoning (Kocabas et al., 2023; Leonard et al., 2023), consistent with general findings on educational robotics (Anwar et al., 2019; Ching & Hsu, 2024). Constructive skill with LEGO is also associated with mathematical performance through spatial skills (McDougal et al., 2023). These benefits appear in intentional and supported tasks, not in free play. Meta-analyses on educational robots indicate a positive effect on computational thinking, greater with design-based approaches and small groups (Hong, 2024), while tangible and embodied experiences show that algorithmic thinking and debugging emerge from interaction with physical objects (Funk et al., 2021; Hu et al., 2024). However, the simple production of artifacts does not guarantee knowledge construction; it is the representation and explanation of actions that reveals and consolidates understanding (Valente & Blikstein, 2019), and in preschool task engagement conditioned gains (Gerosa et al., 2022).

The systematic review by Ching and Hsu (2024), which analyzed 22 studies with students from preschool through sixth grade, helps clarify this point. It found that the most studied computational-thinking skills were sequencing, conditionals, loops, debugging, and

algorithmic thinking; LEGO Mindstorms was the predominant kit; and the most widely adopted pedagogical strategies were collaborative learning, project-based learning, and learning built through interaction between the body and the environment, that is, embodied learning. Therefore, the effects are not attributed to the material itself, but to the way the activity is organized around it. Pedagogically, this implies that teachers should formulate questions, require justifications, and promote debugging of solutions so that manipulation of the pieces becomes an object of analysis.

4.3. 3D design and spatial reasoning

3D modeling is associated with improvements in spatial thinking in basic and secondary education (Šafhalter et al., 2022) and with positive perceptions of design, communication, and creativity competencies (Coşkun & Deniz, 2022). More broadly, spatial training is linked to mathematical performance (Hawes et al., 2022), with advantages for work with physical materials (Gilligan-Lee et al., 2023), and 3D printing is associated with improvements in spatial reasoning and geometric understanding (Ng et al., 2022). The most recent reviews agree that spatial training produces moderate positive effects, conditioned by gender and socioeconomic status (Zhu et al., 2023), and that teaching it requires systematic curricular design, hands-on activities, and teacher training (Bufasi et al., 2024).

Recent evidence shows the usefulness of combining digital tools with project-based pedagogical design. In a study with 255 engineering students, the integration of augmented reality, virtual reality, and 3D printing in multivariable calculus produced a significant improvement in spatial visualization in the experimental group (a 25% increase, compared with 5% in the control group), with a medium effect size (Medina Herrera et al., 2024). Although this concerns higher education, the result is consistent with what has been observed in basic and secondary education: the benefit comes from articulating the tool with task design that requires mentally manipulating and representing three-dimensional objects. For classroom practice, this means explicitly planning activities involving rotation, views, and comparison between the constructed object and its digital model, rather than assuming that software use alone is sufficient to develop spatial reasoning.

4.4. Physical-digital articulation and collaboration

The integration of physical construction and digital representation makes it possible to move from the idea to the model, from the model to the prototype, and then to evaluation of its functioning, in line with the cycles of design thinking (Lin et al., 2020) and project-based learning (Chen & Yang, 2019). Collaboration strengthens these processes (Talan, 2021; Vygotsky, 1978), and meta-analyses of informal project-based learning in STEM report moderate effects dependent on group composition, assessment, and duration (Santhosh et al., 2023). Design thinking is also recognized as an increasingly relevant approach for developing capacities in digitalized environments (Dragicevic et al., 2023).

The support is intended to create a solid structure. As stated by Özbek et al. (2024), a study with 233 preservice teachers found that inducing learning outcomes did not modify the examples of activities students selected, but it did change the sequential structure of their collaborative work, increasing the knowledge acquired. Transferred to work with LEGO and 3D design, this suggests that stating clear goals for each phase (for example, what criterion the model must meet or what decision the team must justify) can improve the quality of interaction rather than leaving it to group spontaneity.

4.5. Pedagogical implications of the findings

The results are related to four implications for pedagogical mediation. First, task design is more fundamental than the resource; the educational return depends on open challenges with constraints and criteria, rather than on reproducing closed prototypes. Second,

progression should consider cognitive load so that the complexity of modeling and construction increases gradually (Sweller et al., 2019). Third, assessment must take the process into account and not only the product, because the benefits obtained are concentrated in design skills, creativity, and practical performance, as stated by Tan et al. (2024). Fourth, teachers are an essential component; a longitudinal study with 74 secondary teachers showed that their conceptions of 3D modeling and printing change with classroom experience (Anđić et al., 2024), emphasizing the need for training and support. This need is corroborated in other contexts: only a minority of German teachers had integrated 3D printing despite having printers in their schools (Thyssen & Meier, 2023); training in spatial instruction improved the performance of future technology teachers (Lane & Sorby, 2022); and reviews of teacher education in maker education emphasize the importance of professional development (Caratachea et al., 2023).

Based on the review, teaching guidelines are proposed for the classroom to design experiences with LEGO and 3D design (Table 1). These are suggestions derived from the reflection, not an empirically validated protocol.

Table 1. Teaching guidelines for the classroom

Present a design challenge	**Articulate construction and representation**	**Redesign and evaluate**	**Evaluate the process and the outcome**
Initiate with an authentic need or design challenge so that students construct the conditions and requirements that a functional object must meet (Kafai & Proctor, 2022; Tan et al., 2024). Before building, students represent their ideas through drawings, diagrams, or technical conversations, making prior thinking visible and reducing improvisation.	The LEGO-built model is the basis for 3D modeling: students translate dimensions, structure, and assembly sequences, which helps them understand the object's internal logic and not only its appearance. Complexity should be graduated to avoid overloading students (Sweller et al., 2019), include explicit rotation activities and comparisons between what is built and what is modeled (Medina Herrera et al., 2024), and establish goals and roles for collaborative work (Özbek et al., 2024; Talan, 2021).	Redesign and evaluate using explicit criteria such as stability, effectiveness, geometric accuracy, functionality, economy of pieces, and relevance to the challenge. By discussing and applying these criteria, students learn to verbalize their design decisions technically and understand that every design can be improved; error becomes a source of information for improvement, as occurs in debugging tasks (Kocabas et al., 2023; Ching & Hsu, 2024).	Evaluate both the product and the process: the quality of spatial representation, the response to the stated need, the ability to make changes, the use of technical language, and transfer to other physical or digital models, combining knowledge tests with rubrics and design portfolios (Tan et al., 2024). The teacher acts as mediator and guide and requires training and practice in the pedagogical use of these technologies (Anđić et al., 2024).

Note. Prepared by the authors based on the literature reviewed.

The pedagogical and didactic impact is expressed in the formative experience, being as meaningful for students as the education that takes place in the classroom; see Figure 1.



Figure 1. Pedagogical and didactic impact of the teaching guidelines for the classroom

Note. Prepared by the authors based on the literature reviewed.

In the classroom, the guidelines transform the dynamics of teaching centered on transmission into a design space in which design- and project-based learning organizes the instructional sequence (Chen & Yang, 2019; Halawa et al., 2024; Santhosh et al., 2023). The teacher moves from being a transmitter of content to a designer of learning situations and a mediator who asks questions, introduces technical language, and guides reflection. This role requires sustained training and support because teachers' conceptions of 3D modeling and printing evolve with classroom experience (Anđić et al., 2024), and reviews of spatial teaching and teacher education agree that professional development, sufficient time, and systematic curricular design are conditions for success (Bufasi et al., 2024; Caratachea et al., 2023; Lane & Sorby, 2022; Thyssen & Meier, 2023). Assessment expands from the product to the process through rubrics, design portfolios, and oral defenses, since the effects of these strategies are concentrated in skills that content tests do not always capture (Tan et al., 2024). Ultimately, the use of blocks, a low-technology-cost resource, makes it possible to combine activities with and without digital devices, something common in computational-thinking education (Acevedo-Borrega et al., 2022), thereby expanding implementation possibilities in contexts with limited equipment.

Likewise, these guidelines provide a clear structure for rigorously analyzing the development of technological thinking. These phases can be translated into concrete variables and indicators such as the accuracy of prior knowledge, spatial skill, inventiveness, justification of design choices, and teamwork, which can be assessed through comparative, longitudinal, or mixed approaches such as those used in recent research (Anđić et al., 2024; Kijima et al., 2021; Lin et al., 2020; Tan et al., 2024). In this analysis, it is essential to consider moderating factors such as gender, socioeconomic status, or execution time (Santhosh et al., 2023; Zhu et al., 2023), as well as developments in STEAM and computational thinking in Latin America (Acendra Pertuz & Conde Carmona, 2024; Palmera Quintero et al., 2024; Quiroz-Vallejo et al., 2021). In this way, the classroom becomes a space for action research in which teachers systematize and examine students' reflective processes in order to adjust their teaching strategies. It is essential to emphasize

that these results come from the analysis of the literature and educational reflection; therefore, their confirmation in each school requires practice-based research supported by validated tools and continuous measurements over time.

5. DISCUSSION

The review suggests that the educational value of LEGO is greater when it is integrated into design-oriented teaching rather than free or automatic construction. Construction by itself can be motivating, but it contributes to technological thinking when the function, representation, and justification of what has been built are contrasted and evaluated through 3D models. Studies reporting benefits share this characteristic: intentional, sequenced, and supported tasks (Kocabas et al., 2023; Leonard et al., 2023; Lin et al., 2020). The results of Ching and Hsu (2024) strengthen this interpretation, since the most frequent strategies in LEGO educational robotics were collaborative, project-based, and embodied—that is, mediation strategies rather than simple uses of the material. This lesson aligns with Hong's (2024) meta-analysis, according to which design-based approaches and work in small groups produce better results, and with the warning by Valente and Blikstein (2019) that knowledge is constructed when students represent and explain their actions, not merely by manufacturing a product.

Likewise, spatial reasoning appears as a bridge between material construction and technological understanding (Hawes et al., 2022; Šafhalter et al., 2022). 3D modeling helps students think in terms of form, structure, scale, compatibility, and transformation, and is especially powerful when students continuously compare what they imagine, what they model, and what they build. Evidence on physical materials (Gilligan-Lee et al., 2023; McDougal et al., 2023) and on digital tools combined with projects (Medina Herrera et al., 2024) does not suggest competition between physical and digital approaches, but rather an articulation that teaching practice should foster. In this regard, reviews of spatial teaching indicate that the most relevant facilitators are systematic curricular design, hands-on activities, and spatial technologies, while the main barriers are insufficient time and lack of consideration of student diversity (Bufasi et al., 2024; Zhu et al., 2023).

A third implication is that integrating LEGO and 3D design offers an opportunity to overcome common dichotomies in school: theory and practice, play and knowledge, digital and material. When learning revolves around authentic problems, these oppositions lose meaning; building, modeling, and redesigning are rigorous ways of thinking, understanding, and arguing. Technological thinking gains strength in the movement between action, representation, and reflection, redefining the student's role as an active designer and the teacher's role as a designer of learning situations.

From a pedagogical perspective, the teacher's role is decisive. A longitudinal study with 74 secondary teachers showed that their conceptions of 3D modeling and printing change with classroom experience (Anđić et al., 2024), suggesting that teacher education and support condition the scope of these strategies. Similarly, evidence on instructional design in K–12 STEM education indicates that design-based learning is frequently used, mainly to achieve STEM literacy (Halawa et al., 2024), which raises the question of whether, in our contexts, it is being translated into intentional classroom practices or merely isolated activities. In Latin America, the integration of computational thinking has concentrated on educational robotics and block-based programming languages (Quiroz-Vallejo et al., 2021), and studies on STEAM still focus on reporting improvements in motivation, performance,

and creativity (Palmera Quintero et al., 2024), suggesting that the move toward three-dimensional design and technological thinking as a specific construct is still incipient.
Assessment deserves special attention. The results of Tan et al. (2024) show that design thinking in a 3D modeling curriculum improved practical performance and creativity, but not basic knowledge. This does not invalidate the strategy, but it warns that assessments focused only on conceptual content may fail to capture its effects, and that it is advisable to combine knowledge tests with process rubrics, design portfolios, and oral defenses of the decisions made. In addition, the quality of collaboration depends on its scaffolding (Özbek et al., 2024), so group tasks require explicit goals and roles.
In this way, it is useful to point out contextual tensions and conditions. Blocks constitute a low-technology-cost resource compared with other tools, and evidence indicates that resources with and without technological devices are equally frequent in computational-thinking education (Acevedo-Borrega et al., 2022), which can be an advantage in contexts with connectivity or equipment constraints. Nevertheless, the transition to digital tools remains necessary to represent, quantify, and communicate design decisions. As limitations, the reflection is based on a non-exhaustive documentary review and on heterogeneous studies in terms of design, participant age, and duration; several are short-term or exploratory, and some were conducted in higher education. Therefore, their conclusions should be interpreted with caution. Future research should evaluate these strategies in longitudinal studies, analyze their curricular integration in Latin American contexts, and develop validated instruments to assess technological thinking as a complex construct.

6. CONCLUSIONS

The reflection allows us to state that LEGO constitutes a tool for teaching three-dimensional design and technological thinking as long as it is embedded in programs that seek to analyze, represent, prototype, and refine solutions. What makes LEGO useful is not its materiality, but the way it is used in the classroom: an appropriate methodology turns construction into technological learning. Recent evidence on educational robotics with LEGO supports the association of its effects with collaborative, project-based, and embodied strategies (Ching & Hsu, 2024), and that the strongest results are achieved with design-based approaches and small groups (Hong, 2024). Producing artifacts, however, does not by itself guarantee knowledge construction, since this requires students to represent and explain their actions (Valente & Blikstein, 2019).
The combination of LEGO and 3D design helps represent objects in space, understand how they function, and make technological decisions, while allowing solutions to be continuously improved. Thus, technology education is not limited to teaching how to use devices; it teaches students to think about, project, and evaluate technology, and the classroom becomes a design space in which students make sense of what they do while creating. Recent studies suggest that this potential is realized when physical and digital tools are articulated with projects and intentional design tasks (Medina Herrera et al., 2024; Tan et al., 2024).
From a pedagogical perspective, it is concluded that planning should begin with authentic design challenges, graduate task complexity, establish goals and roles for collaborative work (Özbek et al., 2024), and assess the process in addition to the product. It is also concluded that teachers are the agents who transform the resource into mediation; therefore, their training and support are a condition of quality (Anđić et al., 2024), especially in Latin

American contexts where curricular integration of these strategies requires further research (Quiroz-Vallejo et al., 2021). Reviews of spatial teaching and teacher education agree that time, systematic curricular design, and professional development are conditions for these proposals to transcend isolated experiences (Bufasi et al., 2024; Caratachea et al., 2023; Lane & Sorby, 2022; Thyssen & Meier, 2023).

In conclusion, technological thinking finds in the articulation of materiality, modeling, and reflection one of its most promising educational pathways. Integrating LEGO into 3D design sequences contributes to a pedagogy centered on understanding, creating, and consciously improving solutions, and constitutes a relevant strategy for strengthening cognitive and metacognitive skills, problem solving, and meaningful and autonomous learning, consistent with evidence of moderate effects of project-based learning in STEM (Santhosh et al., 2023).

REFERENCES

1. Acendra Pertuz, J. M., & Conde Carmona, R. J. (2024). STEAM for the Development of Mathematical Thinking: A Documentary Review. Praxis, 20(2). https://doi.org/10.21676/23897856.5783
2. Acevedo-Borrega, J., Valverde-Berrocoso, J., & Garrido-Arroyo, M. del C. (2022). Computational thinking and educational technology: A scoping review of the literature. Education Sciences, 12(1), Article 39. https://doi.org/10.3390/educsci12010039
3. Anđić, B., Maričić, M., Weinhandl, R., Mumcu, F., Schmidthaler, E., & Lavicza, Z. (2024). Metaphorical evolution: A longitudinal study of secondary school teachers' concepts of 3D modelling and printing in education. Education and Information Technologies, 29(11), 14091–14126. https://doi.org/10.1007/s10639-023-12408-x
4. Anwar, S., Bascou, N. A., Menekse, M., & Kardgar, A. (2019). A systematic review of studies on educational robotics. Journal of Pre-College Engineering Education Research, 9(2), 19–42. https://doi.org/10.7771/2157-9288.1223
5. Braun, V., & Clarke, V. (2019). Reflecting on reflexive thematic analysis. Qualitative Research in Sport, Exercise and Health, 11(4), 589–597. https://doi.org/10.1080/2159676X.2019.1628806
6. Bufasi, E., Lin, T. J., Benedicic, U., Westerhof, M., Mishra, R., Namsone, D., Dudareva, I., Sorby, S., Gumaelius, L., Klapwijk, R. M., Spandaw, J., Bowe, B., O'Kane, C., Duffy, G., Pagkratidou, M., & Buckley, J. (2024). Addressing the complexity of spatial teaching: A narrative review of barriers and enablers. Frontiers in Education, 9, Article 1306189. https://doi.org/10.3389/feduc.2024.1306189
7. Caratachea, M. X., Debbagh Greene, M., & Jones, W. M. (2023). Maker-centered professional learning for inservice and preservice K-12 educators: A systematic literature review. TechTrends, 67(4), 648–663. https://doi.org/10.1007/s11528-023-00865-7
8. Chen, C.-H., & Yang, Y.-C. (2019). Revisiting the effects of project-based learning on students' academic achievement: A meta-analysis investigating moderators. Educational Research Review, 26, 71–81. https://doi.org/10.1016/j.edurev.2018.11.001
9. Ching, Y.-H., & Hsu, Y.-C. (2024). Educational robotics for developing computational thinking in young learners: A systematic review. TechTrends, 68(3), 423–434. https://doi.org/10.1007/s11528-023-00841-1
10. Coşkun, T. K., & Deniz, G. F. (2022). The contribution of 3D computer modeling education to twenty-first century skills: Self-assessment of secondary school students. International Journal of Technology and Design Education, 32(3), 1553–1581.

https://doi.org/10.1007/s10798-021-09660-y
11. Dragicevic, N., Vladova, G., & Ullrich, A. (2023). Design thinking capabilities in the digital world: A bibliometric analysis of emerging trends. Frontiers in Education, 7, Article 1012478. https://doi.org/10.3389/feduc.2022.1012478
12. Funk, M. G., Cascalho, J. M., Santos, A. I., & Mendes, A. B. (2021). Educational robotics and tangible devices for promoting computational thinking. Frontiers in Robotics and AI, 8, Article 713416. https://doi.org/10.3389/frobt.2021.713416
13. Gerosa, A., Koleszar, V., Tejera, G., Gómez-Sena, L., & Carboni, A. (2022). Educational robotics intervention to foster computational thinking in preschoolers: Effects of children's task engagement. Frontiers in Psychology, 13, Article 904761. https://doi.org/10.3389/fpsyg.2022.904761
14. Gilligan-Lee, K. A., Hawes, Z. C. K., Williams, A. Y., Farran, E. K., & Mix, K. S. (2023). Hands-on: Investigating the role of physical manipulatives in spatial training. Child Development, 94(5), 1205–1221. https://doi.org/10.1111/cdev.13963
15. Grönman, S., Lindfors, E., & Rönkkö, M.-L. (2024). Design thinking in early childhood education and care: A literature review and consideration from the perspective of young learners' craft, design, and technology education. International Journal of Technology and Design Education. https://doi.org/10.1007/s10798-024-09944-z
16. Halawa, S., Lin, T.-C., & Hsu, Y.-S. (2024). Exploring instructional design in K-12 STEM education: A systematic literature review. International Journal of STEM Education, 11, Article 43. https://doi.org/10.1186/s40594-024-00503-5
17. Hawes, Z. C. K., Gilligan-Lee, K. A., & Mix, K. S. (2022). Effects of spatial training on mathematics performance: A meta-analysis. Developmental Psychology, 58(1), 112–137. https://doi.org/10.1037/dev0001281
18. Hong, L. (2024). The impact of educational robots on students' computational thinking: A meta-analysis of K-12. Education and Information Technologies, 29(11), 13813–13838. https://doi.org/10.1007/s10639-023-12415-y
19. Hu, W., Huang, R., & Li, Y. (2024). Young children's experience in unplugged activities about computational thinking: From an embodied cognition perspective. Early Childhood Education Journal, 52(4), 769–782. https://doi.org/10.1007/s10643-023-01475-x
20. Iwata, M., Pitkänen, K., Laru, J., & Mäkitalo, K. (2020). Exploring potentials and challenges to develop twenty-first century skills and computational thinking in K-12 maker education. Frontiers in Education, 5, Article 87. https://doi.org/10.3389/feduc.2020.00087
21. Kafai, Y. B., & Proctor, C. (2022). A revaluation of computational thinking in K–12 education: Moving toward computational literacies. Educational Researcher, 51(2), 146–151. https://doi.org/10.3102/0013189X211057904
22. Kijima, R., Yang-Yoshihara, M., & Maekawa, M. S. (2021). Using design thinking to cultivate the next generation of female STEAM thinkers. International Journal of STEM Education, 8, Article 14. https://doi.org/10.1186/s40594-021-00271-6
23. Kocabas, S., Zhu, Y., & Bofferding, L. (2023). Spatial reasoning and debugging with Lego structures. En Proceedings of the 17th International Conference of the Learning Sciences – ICLS 2023. International Society of the Learning Sciences.
24. Lane, D., & Sorby, S. (2022). Bridging the gap: Blending spatial skills instruction into a technology teacher preparation programme. International Journal of Technology and Design Education, 32(4), 2195–2215. https://doi.org/10.1007/s10798-021-09691-5
25. Leonard, J., Djonko-Moore, C., Francis, K. R., Carey, A. S., Mitchell, M. B., & Goffney, I. D. (2023). Promoting computational thinking, computational participation, and spatial

reasoning with LEGO robotics. Canadian Journal of Science, Mathematics and Technology Education, 23(1), 120–144. https://doi.org/10.1007/s42330-023-00267-0
26. Lin, L., Shadiev, R., Hwang, W.-Y., & Shen, S. (2020). From knowledge and skills to digital works: An application of design thinking in the information technology course. Thinking Skills and Creativity, 36, Article 100646.
https://doi.org/10.1016/j.tsc.2020.100646
27. McDougal, E., Silverstein, P., Treleaven, O., Jerrom, L., Gilligan-Lee, K. A., Gilmore, C., & Farran, E. K. (2023). Associations and indirect effects between LEGO® construction and mathematics performance. Child Development, 94(5), 1381–1397. https://doi.org/10.1111/cdev.13933
28. Medina Herrera, L. M., Juárez Ordóñez, S., & Ruiz-Loza, S. (2024). Enhancing mathematical education with spatial visualization tools. Frontiers in Education, 9, Article 1229126. https://doi.org/10.3389/feduc.2024.1229126
29. Monterroza Ríos, Á. D., & Escobar Gómez, V. A. (2021). Technology Education in Colombia. An Epistemic Framework for Rethinking a Conceptual Problem. Un marco epistémico para repensar un problema conceptual. Trilogía Ciencia Tecnología Sociedad, 13(25), Article e1759. https://doi.org/10.22430/21457778.1759
30. Nazlidou, I., Efkolidis, N., Kakoulis, K., & Kyratsis, P. (2024). Innovative and interactive technologies in creative product design education: A review. Multimodal Technologies and Interaction, 8(12), Article 107. https://doi.org/10.3390/mti8120107
31. Ng, D. T. K., Tsui, M. F., & Yuen, M. (2022). Exploring the use of 3D printing in mathematics education: A scoping review. Asian Journal for Mathematics Education, 1(3). https://doi.org/10.1177/27527263221129357
32. OECD. (2019). Trends shaping education 2019. OECD Publishing. https://doi.org/10.1787/trends_edu-2019-en
33. Özbek, T., Greisel, M., Wekerle, C., Gegenfurtner, A., & Kollar, I. (2024). How do different goals affect students' internal collaboration script configurations? Results of an epistemic network analysis study. Frontiers in Psychology, 15, Article 1410152.
https://doi.org/10.3389/fpsyg.2024.1410152
34. Palmera Quintero, L. M., Solano Cabarcas, M. J., Gutiérrez de Piñeres Orozco, J., & Jálabe Saldaña, C. A. (2024). Implementation of STEAM Strategies to Strengthen Computational Thinking in Disruptive Educational Management. Actualidades Pedagógicas, 1(83), 1–20. https://doi.org/10.19052/ap.vol1.iss83.5202
35. Papert, S. (1980). Mindstorms: Children, computers, and powerful ideas. Basic Books.
36. Quiroz-Vallejo, D. A., Carmona-Mesa, J. A., Castrillón-Yepes, A., & Villa-Ochoa, J. A. (2021). Integration of Computational Thinking in Primary and Secondary Education in Latin America: A Systematic Literature Review. Revista de Educación a Distancia (RED), 21(68), Article 485321. https://doi.org/10.6018/red.485321
37. Šafhalter, A., Glodež, S., Šorgo, A., & Ploj Virtič, M. (2022). Development of spatial thinking abilities in engineering 3D modeling course aimed at lower secondary students. International Journal of Technology and Design Education, 32(1), 167–184. https://doi.org/10.1007/s10798-020-09597-8
38. Santhosh, M., Farooqi, H., Ammar, M., Siby, N., Bhadra, J., Al-Thani, N. J., Sellami, A., Fatima, N., & Ahmad, Z. (2023). A meta-analysis to gauge the effectiveness of STEM informal project-based learning: Investigating the potential moderator variables. Journal of Science Education and Technology, 32(5), 671–685. https://doi.org/10.1007/s10956-023-10063-y

39. Sweller, J., van Merriënboer, J. J. G., & Paas, F. (2019). Cognitive architecture and instructional design: 20 years later. Educational Psychology Review, 31(2), 261–292. https://doi.org/10.1007/s10648-019-09465-5
40. Talan, T. (2021). The effect of computer-supported collaborative learning on academic achievement: A meta-analysis study. International Journal of Education in Mathematics, Science and Technology, 9(3), 426–448.
41. Tan, J., Kinshuk, & Wu, L. (2024). The effectiveness of design thinking on K-12 school students' creativity in a maker curriculum. Educational Technology Research and Development, 72(2), 1091–1110. https://doi.org/10.1007/s11423-023-10332-y
42. Thyssen, C., & Meier, M. (2023). 3D printing as an element of teaching—Perceptions and perspectives of teachers at German schools. Frontiers in Education, 8, Article 1233337. https://doi.org/10.3389/feduc.2023.1233337
43. UNESCO. (2021). Reimagining our futures together: A new social contract for education. UNESCO. https://www.unesco.org/en/articles/reimagining-our-futures-together-new-social-contract-education
44. Valente, J. A., & Blikstein, P. (2019). Maker education: Where is the knowledge construction? Constructivist Foundations, 14(3), 252–262.
https://constructivist.info/14/3/252
45. Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.
46. Xiao, Y., & Watson, M. (2019). Guidance on conducting a systematic literature review. Journal of Planning Education and Research, 39(1), 93–112.
https://doi.org/10.1177/0739456X17723971
47. Xu, M., Williams, P. J., Gu, J., & Zhang, H. (2020). Hotspots and trends of technology education in the International Journal of Technology and Design Education: 2000–2018. International Journal of Technology and Design Education, 30(2), 207–224. https://doi.org/10.1007/s10798-019-09508-6
48. Zhu, C., Leung, C. O.-Y., Lagoudaki, E., Velho, M., Segura-Caballero, N., Jolles, D., Duffy, G., Maresch, G., Pagkratidou, M., & Klapwijk, R. (2023). Fostering spatial ability development in and for authentic STEM learning. Frontiers in Education, 8, Article 1138607. https://doi.org/10.3389/feduc.2023.1138607