Journal of Inclusive Methodology and Technology in Learning and Teaching
ISSN 2785-5104
Anno 6 n.1sup (2026)

Edizioni Universitarie Romane
editoria scientifica dal 1952

Rethinking mathematics education: learning environments as generative systems

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Abstract: Learning environments, understood as cognitive and relational educational spaces, are capable of orienting and co-determining the processes of knowledge construction. Within this perspective, starting from the design of a STEAM-based board game, an environmental configuration is analyzed in which material artifacts, interactive practices, and symbolic codes contribute to the co-construction of learning processes. The environment is interpreted as an epistemic infrastructure that integrates physical, social, and semiotic dimensions, thus acting as an active agent in the mediation and transformation of knowledge. The interaction between mathematics and artistic languages enables a multisensory translation of abstract concepts, activating participatory, collaborative, and situated dynamics. In this framework, the game is configured as a networked and distributed space, capable of reconfiguring teaching practices within an ecological perspective on learning, aimed at the development of transversal competences and the enhancement of cognitive diversity.

Keywords: STEAM education; board game; art; mathematics

1. Introduction

Mathematics, a fundamental discipline for the development of logical and critical thinking, continues to be perceived by many students as abstract, complex, and disconnected from everyday experience (Boero, 1999; Zan, 2007). This perception generates anxiety and frustration (Ashcraft & Krause, 2007), making its teaching particularly challenging: it is not merely a matter of transmitting formal knowledge, but of constructing meaning, fostering transversal competences, and cultivating positive attitudes toward the discipline. Mathematical competence is widely recognized as a key competence for lifelong learning. The Recommendation of the European Parliament and of the Council (2006) defines it as the ability to develop and apply mathematical thinking to solve problems in everyday contexts, emphasizing not only procedural skills but also the use of logical and spatial reasoning (EU Recommendation, 2006; 2018).

This perspective has been progressively reflected in Italian curriculum documents. The 1985 National Guidelines already highlighted that mathematics education contributes to the development of multiple dimensions of thinking, including intuition, imagination, hypothesis formulation, and verification (D.P.R. 12 February 1985, no. 104). They also recognized play as a powerful educational tool capable of fostering intellectual engagement and comparison of ideas. The 2007 and 2012 National Guidelines further reinforced the importance of direct experience, laboratory-based activities, and active learning processes, presenting mathematics as a domain of exploration, inquiry, and problem solving (MIUR, 2007; MIUR, 2012). This perspective is extended in the 2018 document National Guidelines and New Scenarios, which emphasizes the role of mathematics, particularly statistics, as a means of critically interpreting contemporary reality (MIUR, 2018). Across these developments, a clear cultural shift emerges from a discipline traditionally associated with calculation and memorization, mathematics is increasingly conceived as a dynamic experience centered on reasoning, problem solving, and data interpretation. Within this framework, play, hands-on activities, and laboratory practices become key tools for fostering creative and meaningful learning connected to everyday life. Despite this shift, the PISA 2022 report highlights persistent challenges in students' mathematical competences in Italy. While overall performance remains close to the OECD average, significant disparities emerge across regions, school types, and socio-economic backgrounds (INVALSI, 2023). Italy achieved an average score of 471 in mathematics, broadly in line with the OECD average (472), but lower than performance levels recorded a decade earlier. Higher results are observed in Northern regions, while Southern regions and the Islands lag behind by more than 60 points, corresponding to over one proficiency level. School type also plays a significant role: general upper secondary schools score above 490 on average, whereas vocational schools remain below 410, falling under the minimum proficiency threshold. Socio-economic background continues to be a strong predictor of performance, although a minority of disadvantaged students demonstrate resilience by achieving high levels of excellence. In this context, mathematical literacy, as assessed by PISA, does not coincide with the mere execution of algorithms, but with the ability to use concepts, representations, and procedures to interpret phenomena and solve complex problems—competences that are now central to active citizenship. However, the gap between formal mathematical language and everyday experience leads many students to perceive mathematics as abstract, anxiety-inducing, and disconnected from reality, fostering forms of math anxiety that negatively affect motivation and learning. These findings point to the need to rethink teaching practices by promoting approaches that make mathematics more meaningful, accessible, and relevant to students' lived experiences, while fostering logical, critical, and transversal competences essential for active citizenship. Rethinking the teaching of mathematics entails bringing it closer to students' lived experiences, transforming it from an abstract exercise into a meaningful language for understanding and interpreting reality. Within this perspective, play emerges as an effective pedagogical mediator: through shared rules, stimulating challenges, and cooperative activities, learners develop logical and strategic thinking, acquire respect for timing and turn-taking, and begin to perceive error not as a limitation but as an opportunity for growth. What may initially appear as mere entertainment thus becomes a genuine laboratory of thought, in which complex concepts are rendered more accessible and teachers, by observing group dynamics, are able to recalibrate their methodological choices in a targeted manner.

Alongside play, art represents a further privileged pathway to mathematical understanding: shapes, symmetries, and geometric structures demonstrate that rigor and imagination are not mutually exclusive, but rather complementary dimensions of the same cognitive process. The intersection between art and mathematics restores an aesthetic dimension to the discipline, fostering wonder and curiosity and opening educational spaces in which logical reasoning is intertwined with creativity. This perspective gives rise to a dynamic and inclusive model of teaching, capable of integrating laboratory practices, play, and artistic languages into a coherent pathway that transforms mathematics from a discipline often perceived as abstract and selective into a meaningful and culturally rich experience. Mathematics thus emerges as a discipline that connects rather than separates, includes rather than excludes, and functions not only as a scientific language but also as an aesthetic experience, capable of guiding learners toward a critical understanding of the world and the conscious construction of active citizenship. Within this theoretical and methodological framework, the board game Math&Art is introduced as a pedagogical tool designed to promote a stimulating and multisensory approach to mathematical learning. Intended for children in preschool and primary education, it proposes challenges and activities that transform abstract concepts such as number, shape, and symmetry into concrete and engaging experiences, while simultaneously fostering logical reasoning, creativity, and collaborative skills.

1.1 *Ecological perspectives on learning environments*

Although a systemic perspective emphasizing the relational and transactional nature of the individual–environment relationship is now well established in the human sciences, common understanding still tends to view the educational environment as a static structure, defined according to the needs of individual actors. Such a view overlooks the interdependence between the two poles, which should instead be conceived as elements of a single dynamic system. Within this perspective, grounded in the ecological approach to education, the individual–environment relationship is understood as a bidirectional process of mutual influence and co-construction. The individual, conceived as a dynamic entity, is not only open to environmental inputs but also actively contributes to their reinterpretation and transformation, in a continuous balance between adaptation and redefinition of the environment (Strollo & Buccini, 2025).

Consequently, the learning environment cannot be regarded as a mere backdrop to educational action, but rather as an active and generative context composed of relationships, resources, and constraints that orient knowledge construction processes (Santoianni, 2007;2017). It assumes a dual function: on the one hand, as a mediator in the development of cognitive, social, and emotional competences; on the other, as an object of exploration and appropriation by learners. In this sense, the educational environment can be understood as a relational and dynamic space capable of fostering reflective and decentered forms of thinking, in which knowledge emerges through the interaction among subjects, practices, and contexts (Frauenfelder, 1994; 2001).

Attention thus extends not only to teaching methodologies but also to the environments in which learning takes place. Educational spaces, in their physical, social, and symbolic dimensions, are not neutral containers but genuine cognitive and relational agents capable of shaping practices, interactions, and processes of knowledge construction.

Rethinking the teaching of mathematics therefore entails questioning the configuration of learning environments, understood as dynamic ecologies in which material, social, and cultural dimensions are intertwined.

2. The board game: Math&Art

The relationship between mathematics and board games is grounded in a structural convergence: both involve shared rules, processes of formalization, and an intrinsically strategic dimension (Traverso et al. 2024; Pirrone et al 2021). Board games, in fact, are not merely forms of entertainment, but structured contexts for thinking in which players are required to make decisions, formulate hypotheses, predict outcomes, and evaluate alternatives.

These operations correspond to the main cognitive functions stimulated by mathematics: logic, abstraction, problem-solving, and generalization skills (Ligabue & Farné, 2020).

From an educational perspective, they represent a genuine cognitive training ground for the development of mathematical thinking, as they promote the understanding of numerical, relational, and spatial concepts while fostering skills such as calculation, classification, measurement, and combinatorial reasoning (Silva, 2021).

In this sense, play not only supports disciplinary learning but also encourages the development of transversal competences such as cooperation, communication, and the management of shared rules (Cera, 2009; Chiappetta Cajola, 2012; Bobbio & Bondioli, 2019; Capra & Lovecchio, 2021). Within these dynamics, additional relevant cognitive abilities can be developed, including:

• Logical-deductive thinking, required to follow rules and predict the consequences of actions.

• The ability to abstract and represent, activated by the transition between concrete elements (tokens, cards, boards) and mental models.

• Calculation and estimation skills, implicit in many games that require counting, resource management, and probability.

• Strategic competence, related to anticipating others' moves and planning sequences of actions.

To these cognitive aspects are added motivational and social elements: board games, due to their interactive nature, stimulate both cooperation and competition within a regulated framework, creating an emotionally positive context for addressing challenges that, in other settings, might be perceived as difficult. This has a direct impact on mathematical learning: play transforms the effort associated with calculation or reasoning into a stimulating challenge, supported by curiosity and enjoyment.

From the perspective of mathematics education, board games can be framed within the three perspectives identified by D'Amore (2006; 2024). In Didactics A, they function as tools and artificial environments aimed at making content more accessible; in Didactics B, they become experimental situations that allow the observation and analysis of students' cognitive processes; and in Didactics C, they represent a conscious methodological choice by the teacher, who recognizes their educational value and exploits their epistemological and motivational potential.

The board game Math&Art was designed with the aim of making mathematical learning an active, creative, and engaging experience. It has been specifically developed for preschool and primary school, accompanying children from their first steps in logical thinking to the construction of more complex competences in handling numbers, shapes, and relationships.

The Math&Art board is organized into spaces marked by colors and symbols, each corresponding to a specific type of game card designed to stimulate different dimensions of reasoning and creativity. The "Observe & Count" cards propose activities involving visual attention, counting, and numerical comparison, with simple and intuitive tasks particularly suitable for younger children, often inspired by the sequences of Yayoi Kusama or the shapes of Wassily Kandinsky. The "Draw &

Create" cards encourage artistic expression and geometric creativity: players are invited to produce small compositions inspired by the rigorous grids of Piet Mondrian or the intricate patterns of M. C. Escher, experimenting directly with symmetry and proportion. Finally, the "Challenge & Solve" cards have a more logical and collaborative nature, presenting puzzles, sequences to complete, or problems to solve together with peers.

The gameplay is simple and intuitive: each player rolls the die, moves along the board, and draws the card corresponding to the space reached. By successfully completing the task, the player earns an illustrated tile used to build their own "mathematical-artistic exhibition." The winner is the player who completes the exhibition with at least one element inspired by each of the four reference artists—Escher, Kandinsky, Mondrian, and Kusama—along with three correctly solved quizzes and two creative challenges.

The game is calibrated for the two educational levels it targets. In preschool (ages 3–5), activities focus on classifying shapes and colors, ordering, recognizing spatial relationships (above/below, inside/outside), comparing quantities, and introducing early numerical sequences. In primary school (ages 6–10), challenges are enriched with numbers and operations, fractions and proportions, perimeters and areas, symmetries and rotations, as well as data collection and interpretation. In both contexts, the playful experience translates into a multisensory and cooperative form of learning that values different cognitive styles and facilitates the engagement of students who are less interested in mathematics.

The pedagogical value of the game lies precisely in its ability to transform abstract concepts, such as number, operation, proportion, or symmetry, into tangible and creative experiences. Art becomes the bridge that translates mathematical formality into images, patterns, and compositions, making knowledge more accessible, less anxiety-inducing, and more motivating.

Children are thus involved in an experience in which mathematics is not presented as a set of abstract rules, but as a creative, visual, and participatory process. The game invites participants to recognize structures, create connections, observe regularities, and formulate strategies, encouraging flexible and divergent thinking. Through the shared design of the game, which includes defining rules, constructing materials, and creating activities, art also becomes a tool for both personal and collective expression. In this way, students not only learn mathematical content but also develop transversal competences such as observing, reflecting, communicating, collaborating, and decision-making.

3. Conclusion

In an educational context that values play as an opportunity for discovery, the role of the teacher is profoundly reconfigured: no longer merely a transmitter of knowledge, but a facilitator of processes and a mediator of meaning. Within this perspective, the teacher acts as a discreet guide who fosters autonomy, participation, and critical thinking, transforming learning into an authentic space of interaction and knowledge construction (Silva and Maffia, 2022; Canevaro, 2007).

The game thus becomes a space for cooperation, negotiation, and the collective construction of knowledge, in which each action involves planning, hypothesis formulation, and the ability to adapt to change, fostering critical thinking and effective problem-solving strategies (Galliani, 2010).

Within this framework, Math&Art is positioned as an approach designed to make mathematics learning an active, creative, and engaging process, promoting the integration of logical-mathematical reasoning with aesthetic and artistic sensitivity. Designed for early childhood and primary education, the game supports the progressive development of logical thinking, fostering increasingly complex competences in working with numbers, shapes, and relationships. What may initially appear as mere entertainment reveals itself as a genuine laboratory of thought, in which complex concepts become more accessible and the teacher, by observing group dynamics, can purposefully reorient their instructional strategies. Alongside play, art represents a further effective pathway for accessing mathematical content: forms, symmetries, and geometric structures demonstrate how rigor and imagination are not opposed but rather constitute complementary dimensions of the same cognitive process.

The encounter between art and mathematics restores to discipline an aesthetic dimension capable of arousing wonder and curiosity, opening learning spaces in which the rigor of logical thinking intertwines with creativity. This gives rise to a dynamic and inclusive teaching model, capable of integrating laboratory activities, play, and artistic languages into a pathway that transforms mathematics from a discipline often perceived as abstract and selective into a meaningful and culturally rich experience. Mathematics thus emerges as a discipline that does not separate but connects, that does not exclude but includes, and that does not function solely as a scientific language, but also as an aesthetic experience, capable of guiding students toward a critical understanding of the world and the conscious development of active citizenship.

References

Ashcraft, M.H., & Krause, J.A. (2007). *Working memory, math performance, and math anxiety. Psychonomic Bulletin & Review*, *14*(2), 243–248. DOI https://doi.org/10.3758/BF03194059

Bobbio, A., & Bondioli, A. (2019). *Gioco e infanzia. Teorie e scenari educativi*.Carocci.

Boero, P. (1999). *Matematica e difficoltà di apprendimento*.La Nuova Italia

Capra, L., & Lovecchio, N. (2021). *Imparare giocando*. Pensa Multimedia.

Cera, R. (2009). *Pedagogia del gioco e dell'apprendimento. Riflessioni teoriche sulla dimensione educativa del gioco*. Franco Angeli.

Chiappetta Cajola, L. (2012). *Didattica del gioco e integrazione. Progettare con l'ICF*. Carocci

D'Amore, B. (2006). *La didattica della matematica*. Pitagora.

D'Amore, B. (2024). *Arte e matematica: dialoghi educativi*. Pitagora.

Frauenfelder, E. (1994). *Pedagogia e biologia, una possibile alleanza*. Napoli.

Frauenfelder, E. (2001). Una dinamica dialogica per la nascita delle Scienze bioeducative. *Studi Sulla Formazione/Open Journal of Education, 14*(1), 7-17. https://doi.org/10.13128/Studi_Formaz-10787

Hidi, S. & Renninger, K.A. (2006*). The four-phase model of interest development. Educational Psychologist, 41*(2), 111–127. https://doi.org/10.1207/s15326985ep4102_4

INVALSI, (2023). OCSE PISA 2022. *I risultati degli studenti italiani in matematica, lettura e scienze*. Rapporto nazionale. INVALSI.

Ligabue, A., & Farné, R. (2020). Didattica ludica. *Competenze in gioco*. Erickson.

Mayer, R.E. (2020). *Multimedia learning.* Cambridge University Press.

Parlamento Europeo & Consiglio dell'Unione Europea. (2006). *Raccomandazione del 18 dicembre 2006 relativa a competenze chiave per l'apprendimento permanente (2006/962/CE).* Gazzetta Ufficiale dell'Unione Europea, L394, 10–18.

Parlamento Europeo & Consiglio dell'Unione Europea. (2018). *Raccomandazione del 22 maggio 2018 relativa alle competenze chiave per l'apprendimento permanente (2018/C 189/01).* Gazzetta Ufficiale dell'Unione Europea, C189, 1–13.

Pirrone, C., Castellano, S., Amata, C. G., & Tienken, C. H. (2021). Il gioco con le costruzioni e lo sviluppo cognitivo: Una review narrativa. *Ricerche di Psicologia*, 44(1), 24. https://doi.org/10.3280/rip2021oa12859

Santoianni, F. (2007). Bioeducational perspectives on adaptive learning environments. In F. Santoianni, C. Sabatano. *Brain development in learning environments: Embodied and perceptual advancements* (pp. 83–96). Cambridge Scholars Publishing.

Santoianni, F. (2017). Lo spazio e la formazione del pensiero: la scuola come ambiente di apprendimento. *Research Trends in Humanities Education & Philosophy, 4*, 37-43. https://doi.org/10.6093/2284-0184/5020

Silva, L. (2021). Sviluppo della professionalità del docente sulla valutazione in matematica mediante l'uso del gioco da tavolo: un percorso di ricerca-formazione Teachers' professional development about mathematical assessment by using tabletop games: a Teacher Professional Development Research project. In Lucisano P. *RICERCA e DIDATTICA per promuovere intelligenza comprensione e partecipazione* (pp. 396-410). Pensa MultiMedia.

Silva, L., & Maffia, A. (2022). Promuovere l'autovalutazione coi giochi da tavolo: il modello del progetto Numeri e Pedine. *Annali online della Didattica e della Formazione Docente*, *14*(24), 47-64. https://doi.org/10.15160/adfd.v14i24.2583

Strollo, M. R., & Buccini, F. (2025). Il Potenziale Trasformativo del Service-Learning: Nuove Prospettive per l'Educazione e la Formazione nelle Università. *PEDAGOGIA E VITA*, *3*, 135-145.

Traverso, A., Armani, S., Morselli, F., & Robotti, E. (2024). EduMath: una sperimentazione didattica di gioco di ruolo immersivo (Edu-larp) per l'apprendimento della matematica. *Nuova Secondaria*, *42*(2).

Yasar, H., & Kiyici, M. (2021). A Descriptive Analysis of the Literature on Educational Games Published between 1965 and 2019. *International Journal of Technology in Education and Science*, *5*(2), 258-276.

Zan, R. (2007). *Difficoltà in matematica: aspetti teorici e didattici*. Springer.