Thinking beyond numbers: Rewiring Mathematics Education through Neuroscience, emotion, and agency

Pensando além dos números: Reconfigurando a Educação Matemática por meio da Neurociência, emoção e agenciamento

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Abstract. This article introduces an innovative, interdisciplinary pedagogical framework for Mathematics Education, integrating insights from cognitive Neuroscience, Psychopedagogy, and Problem-Solving research. Grounded in empirical evidence from a comprehensive case study with elementary students, the approach advocates for a paradigm shift that recognizes cognitive diversity, fosters emotional safety, and promotes conceptual autonomy. Leveraging neural plasticity and executive function development, it challenges deterministic notions of mathematical ability, positioning Mathematics as a deeply human, accessible, and meaningful intellectual pursuit. Employing archeogenealogical analysis, this study critically examines how prevailing pedagogical discourses shape, constrain, and open pathways to reimagining mathematical learning. The findings highlight the necessity of holistic practices that engage cognitive, emotional, and neurodevelopmental dimensions, emphasizing respect for individual neurodiversity and fostering an inclusive, agency-driven mathematical experience.
Keywords: Neuroeducation; Executive Function Development; Neurodiversity in Mathematics; Pedagogical Innovation; Emotional Engagement; Cognitive Agency.

Resumo. Este artigo apresenta um framework pedagógico inovador e interdisciplinar para a Educação Matemática, integrando aportes da Neurociência Cognitiva, da Psicopedagogia e da pesquisa em Resolução de Problemas. Fundamentado em evidências empíricas provenientes de um estudo de caso abrangente com estudantes do ensino fundamental, o enfoque propõe uma mudança paradigmática que reconhece a diversidade cognitiva, promove a segurança emocional e favorece a autonomia conceitual. Valendo-se da plasticidade neural e do desenvolvimento das funções

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executivas, a proposta desafia conceções deterministas sobre a habilidade matemática, posicionando a Matemática como uma atividade intelectual profundamente humana, acessível e significativa. Por meio de uma análise arqueogenealógica, o estudo examina criticamente como os discursos pedagógicos vigentes moldam, restringem e, ao mesmo tempo, abrem caminhos para a ressignificação do aprendizado matemático. Os resultados evidenciam a necessidade de práticas holísticas que articulem dimensões cognitivas, emocionais e neurodesenvolvimentais, ressaltando o respeito à neurodiversidade individual e a promoção de uma experiência matemática inclusiva e orientada pelo agenciamento do aprendiz.
Palavras-chave: Neuroeducação; Desenvolvimento das Funções Executivas; Neurodiversidade em Matemática; Inovação Pedagógica; Engajamento Emocional; Agenciamento Cognitivo.

Rethinking perceptions in the Mathematics classroom

Mathematics transcends mere calculation-it is a language, a philosophy, a lens through which we navigate complexity. Paradoxically, however, it has long been taught as a static set of rules and procedures, disconnected from its human and cognitive foundations. For many students-and even adults-Mathematics remains a source of insecurity, fear, and silent failure, echoing early educational wounds that are rarely addressed with sensitivity.

The motivation underlying this study arises from a long-standing tension between teaching practices and the neurodiverse profiles of students. In mathematics education, emotional regulation, executive functioning, and the construction of self-efficacy are still treated as peripheral to cognition, when in fact they form part of the same learning process. Recognizing these dimensions as inseparable from mathematical reasoning is not only a pedagogical necessity but also an ethical one, as it affirms the right of every learner to experience mathematics as a meaningful and inclusive space for cognitive and affective development.

These affective barriers reflect a deeper systemic misalignment: a disconnect between conventional pedagogies and the neurocognitive realities of human learning. Beyond the execution of mathematical procedures, a complex interplay occurs among the brain's information processing, emotional responses, and socio-cultural narratives shaping perception. To foster genuine educational transformation, pedagogical approaches must holistically engage these intertwined dimensions.

This article advocates a paradigm shift: from content-centered curricula to learner-centered frameworks that recognize neural wiring, emotional landscapes, and cognitive diversity. We argue that questioning what we teach is insufficient; we must interrogate how, why, and for whom Mathematics is taught. To this end, we integrate three interconnected domains: Neuroscience, illuminating the brain's plasticity and the influence of attention, emotion, and executive function; Educational Psychology, emphasizing individual histories, affective states, and internal narratives; and Problem Solving, framing inquiry as a pedagogical philosophy that prioritizes curiosity, reasoning, and construction over rote memorization.

These disciplines converge to establish an evidence-based, human-centered pedagogical model that recognizes learners as active, complex agents. This framework moves beyond reductionist views of the student as neural circuitry, instead embracing the affective, social, and neurodevelopmental intricacies that underpin meaningful mathematical engagement. Central to this approach is the shift from error correction to fostering conceptual insight. Learning environments should cultivate divergent thinking, reframe errors as heuristic opportunities, and empower students to trust their cognitive capacities-diverse as they are. In this context, the pursuit of a singular "correct answer" yields to an exploratory, personalized mathematical journey.

Empirically, this study employs a mixed-methods design: qualitative analyses via archeogenealogy reveal how pedagogical discourses shape, constrain, or liberate mathematical understanding; quantitative assessments measure the impact of integrated strategies on student learning. This triangulation ensures a comprehensive understanding of how holistic, neuro-psycho-pedagogical interventions can catalyze deep, inclusive engagement with Mathematics.

Despite significant progress in neuroeducation and socio-constructivist research, few studies have sought to articulate, in a single theoretical frame, the cognitive, affective, and socio-discursive dimensions of learning mathematics. This study addresses that gap by proposing and examining a Triadic Integrated Framework that interweaves neuroscience, psychopedagogy, and problem solving. Through an archeogenealogical lens, this framework makes it possible to unveil how cognitive patterns, emotional regulation, and pedagogical discourse intersect to shape mathematical thinking and the learner's sense of agency.

Theoretical foundations: A triadic dialogue in Mathematics Education

Transforming Mathematics Education requires moving beyond compartmentalized knowledge toward an embodied, dynamic practice-one that recognizes theory not as abstraction but as a living, ethical engagement capable of reshaping perception and pedagogy (Freire, 1996; Leal Junior & Onuchic, 2020). Central to this transformation is the integration of three interconnected domains: Neuroscience, Educational Psychology, and Problem Solving. Each offers a unique language and set of tools, but it is in their dialogue-rather than in isolation-that the most fertile ground for reimagining mathematical learning emerges.

The theoretical foundation of this study recognizes the indispensable contribution of classical authors such as Piaget, Vygotsky, and Pólya, whose works constitute the epistemological base of mathematical cognition and problem-solving pedagogy. However, it also integrates more contemporary perspectives emerging from neuroscience and psychopedagogy, which have expanded our understanding of cognitive flexibility, emotional regulation, and executive functions in mathematical learning (Diamond, 2013; Grabner et al., 2016; Grabner et al., 2017; Leikin, 2020; Sušac & Braeutigam, 2014).

This articulation between classical and current perspectives allows the discussion to move beyond the merely procedural, emphasizing how neurodiversity and affective modulation influence the learner's agency and performance in problem-solving contexts.

Contemporary Neuroscience has revolutionized our understanding of learning, emphasizing neuroplasticity-the brain's capacity to reorganize structurally and functionally in response to experience (Doidge, 2007; Draganski et al., 2004). Critical to mathematical cognition are executive functions: working memory, inhibitory control, and cognitive flexibility (Diamond, 2013). These are not innate traits but develop through targeted pedagogical strategies that foster emotional and cognitive regulation. As Immordino-Yang and Damasio (2007) assert, deep thinking is neurobiologically contingent on emotional engagement; thus, affective factors are integral to effective learning environments.

Educational Psychology complements this neurobiological perspective by situating learning within the learner's socio-cultural context. Guided by Vygotsky's (1978) theory of mediated, social constructivism, this domain emphasizes the importance of dialogue, interaction, and the Zone of Proximal Development (ZPD). Effective learning occurs when instruction aligns with the learner's current capabilities and is mediated through meaningful social and cultural interactions. Addressing persistent Mathematics anxiety-often the result of pedagogical environments prioritizing speed over understanding (Boaler, 2015)-requires acknowledging the emotional and identity-related dimensions of learning. From a psychopedagogical standpoint, errors are reframed as opportunities for metacognitive and affective growth, fostering resilience and a positive mathematical identity.

Problem Solving, as both heuristic and philosophical approach, anchors this triad. Pólya's (1945) classic framework-understanding, planning, executing, and reflecting-remains foundational. Beyond technique, problem-solving embodies constructivist principles: it cultivates flexible knowledge, metacognitive control, and self-efficacy (Leal Junior, 2018; Schoenfeld, 1992). Engaging students with authentic, complex problems develop not only mathematical reasoning but also resilience, identity, and agency-attributes vital in navigating an uncertain world. As Dweck (2006) emphasizes, fostering a growth mindset enhances engagement with challenges, transforming failures into opportunities for development.

The cognitive–affective profiles were established through a triadic psychopedagogical assessment process, designed to capture both cognitive functioning and emotional dispositions toward mathematics. This process involved three complementary stages:

(a) an initial *executive functions screening*, focusing on working memory, inhibitory control, and cognitive flexibility;

(b) *narrative interviews*, in which each student reflected on their previous experiences, self-image, and emotional responses to mathematical tasks; and

(c) *direct observation of their initial problem-solving strategies*, emphasizing how they approached uncertainty, reasoning, and error correction.

The integration of these data allowed the identification of specific cognitive–affective profiles-such as anxiety-prone but abstract reasoners, or concrete thinkers with low self-efficacy-which guided the interpretive depth of the analysis.

Table 1. Intersecting Dimensions of Neuroscience, Educational Psychology, and Problem Solving

Dimension	Neuroscience	Educational Psychology	Problem Solving
Focus	Brain-based learning	Subjectivity & learning history	Mathematical reasoning & agency
Core Contribution	Executive functions, emotion	Emotional safety, identity	Inquiry, resilience
Methodology	Task design, scaffolding	Narrative listening, mediation	Open-ended problems, heuristics
Risks if Neglected	Cognitive overload, disengagement	Anxiety, disidentification	Shallow learning, mechanization

By synthesizing insights from neurobiology, socio-cultural understanding, and heuristic methodologies, this triadic model advocates for an education that is both scientifically grounded and experientially validated. It positions learners as active agents constructing knowledge within a relational, emotionally supportive environment-transforming Mathematics from a mere curriculum into a living practice of inquiry, resilience, and agency.

Potential interconnections between Cognitive Neuroscience, Psychopedagogy, and Problem Solving in Mathematics Education

The convergence of cognitive Neuroscience, Psychopedagogy, and Problem-Solving offers transformative insights into optimizing mathematical learning. By elucidating neural mechanisms underpinning mathematical reasoning, educators can craft strategies aligned with students' neurocognitive functions, promoting deeper understanding and durable skills. Metacognition, as highlighted by Schoenfeld (1985), plays a pivotal role, enabling learners to reflect on and regulate their cognitive processes, thereby enhancing Problem-Solving efficacy. Complementarily, heuristics serve as cognitive tools that foster strategic thinking and inquiry-based learning (Liljedahl et al., 2016a). Integrating these perspectives underscores the importance of pedagogical approaches grounded in an understanding of brain architecture, ultimately facilitating more effective mathematics instruction, which reinforces Sušac and Braeutigam's (2014) idea: "Mathematical proficiency will require the coordinated action of many brain regions as exemplified by an influential model of algebraic equation solving." (p. 2).

Neuroscientific research further clarifies how specific brain regions activate during mathematical tasks, informing instructional design attuned to underlying neural networks (Grabner et al., 2016; Grabner et al., 2017). Neuroimaging studies reveal distinct neural patterns engaged during mathematical reasoning, opening avenues for targeted interventions that leverage these insights (Leikin, 2017). As Sweller (1988, p. 266) observed, "Instructional design should be based on [the] cognitive architecture that supports learning," highlighting that effective instructional approaches must derive from an understanding of how the human mind processes, stores, and retrieves information. This perspective underscores the importance of aligning pedagogical strategies with the principles of cognitive functioning rather than relying solely on intuition or tradition. Nevertheless, researchers have emphasized that translating neuroscientific and cognitive insights into classroom practice remains a complex and gradual endeavor, requiring robust empirical validation before such applications can be broadly implemented.

Recent research exemplifies progress in this interdisciplinary domain. Studies by Grabner et al. (2016), Grabner et al. (2017), Leikin (2017), and Liljedahl et al. (2016b) examine the neural underpinnings of mathematical reasoning, the role of executive functions in problem-solving, and the development of cognitively informed pedagogical interventions. While these advances highlight promising directions, they also underscore the need for further empirical work to translate laboratory findings into effective classroom practices, ensuring that scientific insights yield tangible improvements in Mathematics Education. In this regard, Menon (2010) investigates how developmental cognitive neuroscience can inform arithmetic learning, emphasizing the importance of understanding the cerebral mechanisms that support mathematical acquisition.

Several international studies have contributed to consolidating the intersection between Neuroscience, Psychopedagogy, and Problem Solving in the field of Mathematics Education. Liljedahl et al. (2016b) proposed frameworks that foster creativity and learner success in complex mathematical tasks, highlighting the importance of environments that encourage exploration and divergent thinking. Schoenfeld (1987, 1992), in turn, established the foundations of cognitive science applied to Mathematics instruction, offering valuable insights into problem-solving strategies and metacognition. The research conducted by Grabner et al. (2017) advanced the understanding of the neurocognitive mechanisms underlying mathematical learning, revealing distinct neural patterns associated with numerical reasoning and problem-solving, which offer valuable insights for pedagogical design.

Leikin (2018) reinforces this perspective by arguing that the integration of Neuroscience enhances the validity of research in Mathematics Education, emphasizing the need for interdisciplinary collaboration. English and Gainsburg (2015) underscore the importance of preparing students for real-world problem-solving, stressing the relevance of mathematical reasoning in everyday contexts. Complementarily, De Smedt and Verschaffel (2010) address the contributions of neuroscientific approaches to understanding mathematical cognition, while Bernardo (1997) offers a cognitive psychology perspective on mathematical learning and instructional design. Finally, Aldous (2007) explores the interplay between creativity, problem-solving, and Neuroscience, proposing a theoretical framework that integrates cognitive and affective factors in the teaching and learning of Mathematics.

The synthesis of these works demonstrates a robust interconnection among Neuroscience, Psychopedagogy, and Problem-Solving in Mathematics Education. Schoenfeld's foundational insights (1985, 1987, 1992) delineate cognitive processes integral to learning, while Leikin (2018) and Grabner et al. (2017) deepen our understanding of neurocognitive mechanisms. Complementing this, Bernardo (1997) emphasizes instructional strategies rooted in cognitive and affective models, with Aldous (2007) highlighting the role of creativity.

Together, these disciplines foster a comprehensive understanding of mathematical learning, supporting the development of innovative, evidence-based pedagogies. This multidisciplinary approach advances Mathematics Education toward greater inclusivity, creativity, and scientific rigor, grounded in insights from cognitive and neuroscientific research.

Interdisciplinary intersections: Brain, emotion, and strategy

Educational practices are embedded within a dynamic interplay of cognitive, emotional, and strategic processes. Traditionally, these dimensions are treated as separate domains-cognition through content, emotion through discipline, and strategy through technique-yet in reality, learning is an integrated experience involving feeling, decision-making, memory, and imagination simultaneously.

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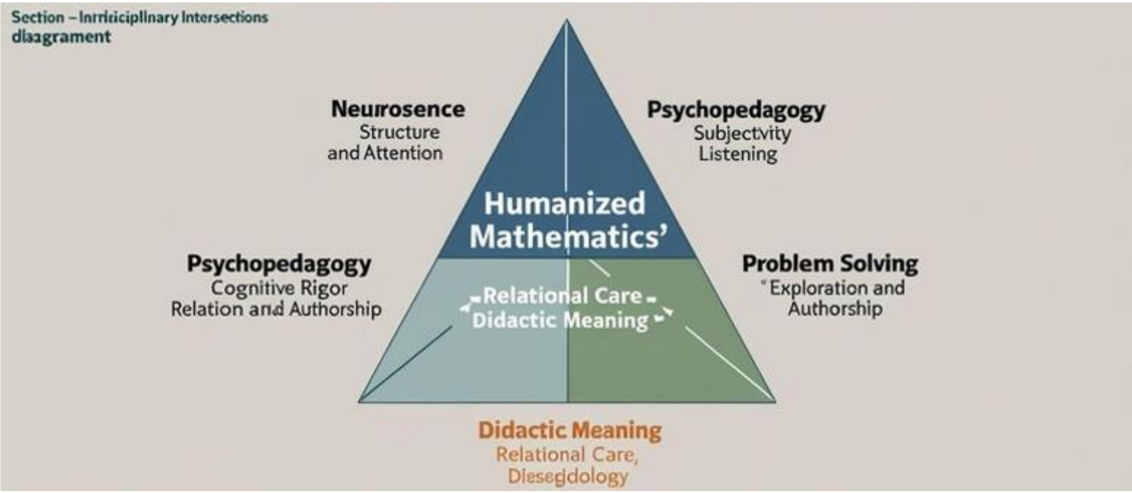

Figure 1. Pedagogical Integration Model linking Neuroscience, Psychopedagogy, and Problem-Solving as complementary frameworks for Mathematics Education

Drawing from Diamond (2013) and Sousa (2011), optimal learning occurs when instruction aligns with brain function: through chunked information, active engagement, pattern recognition, and feedback-rich contexts. For example, teaching the concept of "balance" in first-degree polynomial equations can be made concrete via manipulatives or visual metaphors, aligning with dual coding theory (Paivio, 1986), which posits that combining verbal and visual representations enhances retention.

Furthermore, stress and emotional overload impair executive functions and working memory-crucial for multi-step reasoning (Immordino-Yang, 2016; Sweller, 1988). Incorporating mindfulness exercises or reflective pauses reduces affective filters (Krashen, 1982), fostering deeper cognitive engagement. As Tokuhama-Espinosa (2014) emphasizes, brain-based teaching respects the biological limits and potentials of learners, emphasizing design aligned with neural reality rather than oversimplified "neuro-myths."

While Neuroscience reveals how the brain learns, Educational Psychology emphasizes who is learning and under what emotional and contextual conditions. Learning is mediated by relationships, self-image, and prior emotional experiences. Vygotsky (1978) articulated that higher psychological processes are socially and culturally mediated. Accordingly, effective pedagogies incorporate dialogic assessment, narrative construction, and metacognitive reflection-practices that recognize individual differences and foster humanization, not mere accommodation (Paim, 2005; Weiss, 2012).

Problem Solving, as conceptualized by Polya (1945) and further elaborated by Schoenfeld (1985, 1992) and Leal Junior (2020), transcends mere technique to become a paradigm shift. It invites learners into Mathematics through inquiry, exploration, and reflection-aligning with constructivist theories (Bruner, 1960; Piaget, 1950) and critical pedagogy (Freire, 1996). Rather than passively receiving answers, students are challenged to interpret situations, embrace productive struggle (Warshauer, 2015), and develop resilience and "Effective teaching of mathematics consistently provides students, individually and collectively, with opportunities and supports to engage in productive struggle as they grapple with mathematical ideas and relationships." (NCTM, 2014, p. 48).

When integrated with psychopedagogical strategies and neuroscientifically informed design, Problem Solving evolves into a holistic cognitive practice. It actively engages multiple dimensions-cognitive, affective, and metacognitive-fostering mathematical identity and learner autonomy. Teaching equations thus becomes more than symbolic transmission; it involves providing a language to conceptualize balance, transformation, and exploration-an empowering cognitive grammar that reframes students' approach to mathematical problems and their own intellectual capacities.

Methodology: An archeogenealogical inquiry as a catalyst for pedagogical transformation

The methodological orientation of this study draws upon the philosophical and pedagogical foundations established by Foucault (1979), Larrosa (1994), and Leal Junior and Onuchic (2020). Investigating educational practices, in this sense, transcends the act of description: it requires a critical and historically situated inquiry into the reasons such practices exist, the conditions that made them possible, and the meanings they acquire within specific social and institutional contexts. Guided by these premises, the study adopts a critical-interpretive and archeogenealogical framework, inspired by Michel Foucault's notions of archaeology and genealogy, to uncover the power relations and discursive formations that sustain contemporary Mathematics Education.

This perspective makes it possible to examine the invisible architectures of thought that govern pedagogical norms, curricular choices, and classroom practices, revealing how educational discourse naturalizes certain forms of reasoning and marginalizes others. Rather than seeking universal laws, this approach attends to the contingencies and epistemic ruptures that have historically configured what is recognized as "valid" mathematical knowledge.

The archeogenealogical framework allows us to analyze how specific ideas — such as notions of learning difficulty, assessment, or the "ideal" student — have emerged, stabilized, and been normalized within educational contexts. This involves examining curriculum documents, pedagogical language, and scholarly literature to identify the "rules of formation" that determine what is considered legitimate knowledge and practice. For instance, the persistent emphasis on procedural speed and correctness in Mathematics reflects deeper epistemic commitments rooted in modern disciplinary regimes that prioritize control, efficiency, and standardization. These are not arbitrary but historically contingent, shaped by legacies of modernity and disciplinary institutions that continue to influence contemporary classrooms.

Simultaneously, the genealogical dimension critically interrogates how certain practices and labels — such as "learning disabled," "disinterested," or "gifted" — serve to categorize and regulate learners, embedding normalized identities and marginalizing others. Drawing on Foucault's notions of disciplinary power and subjectivation, we explore how such labels function within a broader system of normalization, surveillance, and regulation of student subjectivities. This analysis reveals the historical struggles, ruptures, and negotiations that have contributed to the current landscape, highlighting whose interests are served by these categorizations and whose voices are silenced or marginalized.

Our methodological design unfolds across three interconnected levels, articulating qualitative and quantitative dimensions within a mixed-methods case study framework.

- First, a theoretical synthesis integrates insights from Neuroscience, Educational Psychology, and Problem-Solving research into a cohesive pedagogical vision, enriched by the critical understanding gained through archeogenealogical analysis.
- Second, discourse mapping and qualitative coding are employed to systematically identify continuities, ruptures, and epistemological tensions within educational texts, teacher discourse, and classroom practices.
- Third, this qualitative mapping informs a set of pedagogical micro-interventions with a small group of sixth-grade students. These sessions generate both qualitative observations (interpretive field notes, dialogic exchanges) and quantitative indicators (performance measures, response times, and task accuracy), used not as statistical generalizations but as contextual evidence to enrich the interpretive analysis.

The study was conducted in the interior of São Paulo, Brazil, within a private educational consulting program focused on developing cognitive and affective skills in mathematics. The participants were six sixth-grade students (aged 11–12) from a middle-income socioeconomic background. The sampling was intentional and based on convenience, as the study aimed to explore, in depth, the individual trajectories and neurocognitive diversity of learners rather than to produce generalizable statistical data. This design characterizes the research as an in-depth mixed-methods case study, where the richness of qualitative interpretation is complemented- not overshadowed- by descriptive quantitative data that contextualize the pedagogical process.

Throughout this process, we maintain a firm ethical stance, recognizing that research is inherently value-laden. As educator-researchers, our goal is to produce knowledge that is emancipatory — knowledge capable of challenging exclusionary practices, broadening cognitive and emotional horizons, and reimagining Mathematics as a generative and liberatory discipline. This approach does not aim to "solve" the challenges of Mathematics Education through prescriptive formulas but rather invites us to perceive the invisible structures that shape learning, question normative assumptions, and identify cracks through which innovative pedagogies can emerge. In essence, to research in this manner is to teach differently — and in doing so, to enact a form of radical pedagogical inquiry: an act of reimagining the very possibilities of Mathematics Education.

Case study: In-depth exploration of first-degree polynomial equations learning

Bridging theoretical frameworks and practical application remains a core challenge in contemporary Mathematics Education-particularly when aiming to humanize learning in a discipline often marked by abstraction and hierarchical rigor. This case study, conducted by an educational consultancy rooted in São Paulo's interior in Brazil and serving students nationwide, investigates a pedagogical intervention focused on sixth-grade students' mastery of first-degree polynomial equations.

Although the participant group was small (n = 6), this qualitative investigation offered a deeply textured examination of the singular ways in which cognitive and affective processes evolve throughout mathematical learning. The purpose here is not statistical generalization but an interpretive unveiling of how integrative strategies-anchored in Neuroscience, Educational Psychology, and Problem-Solving-can reconfigure students' mathematical identities, reshape emotional engagement, and enhance cognitive flexibility. Quantitative data operate as complementary evidence, not as validation by numbers, but as dialogical traces that illuminate the pedagogical transformations observed, aligning with contemporary principles of mixed-methods inquiry in Education.

The analytical process was grounded in a *triangulated interpretive design* that articulated three epistemically interdependent layers.

(1) A genealogical–discursive analysis, inspired by Foucault (1979), mapped the pedagogical regimes and epistemic regularities implicit in students' mathematical discourse and classroom interactions, revealing how language and power circulate in the constitution of learning subjectivities.

(2) A quantitative dimension employed a paired t-test and Cohen's d to estimate the magnitude of cognitive evolution between pre- and post-intervention tasks, offering an empirical contour to the interpretive field.

(3) Finally, a qualitative–narrative analysis traced the affective resonances of learning-changes in self-perception, agency, and emotional investment-through students' verbalizations, reflective journals, and behavioral patterns.

The reflective journals and interview transcripts were subjected to thematic content analysis, employing inductive coding and categorization of discursive and affective changes. Two researchers conducted independent coding; discrepancies were discussed and resolved by consensus, ensuring inter-rater reliability and interpretive rigor.

This triangulation, rather than merely combining methods, enacted an epistemological dialogue among cognitive evidence, discursive structures, and affective transformations. By aligning neurocognitive indicators with socio-discursive and emotional dimensions, the analysis unfolded a multilevel understanding of how thinking, feeling, and becoming intertwine in the mathematical act. The result is a robust interpretive framework in which learning ceases to be reduced to performance metrics and emerges as a process of subjectivation-a movement through which learners reorganize not only their cognitive architectures but also their emotional and epistemic relations with Mathematics itself.

Intervention design and framework

Spanning four weeks and comprising eight sessions, the intervention employed a triadic pedagogical model integrating:

- Neuroscience-Informed Principles: Content scaffolding, cognitive load management, enhancement of working memory, and affective regulation through evidence-based emotional strategies.
- Psychopedagogical Mediation: Empathetic listening and narrative reconstruction to support identity development and adapt to diverse cognitive-emotional profiles.
- Problem-Solving Methodology: Engagement with authentic, real-life problems designed to promote learner agency, creative reasoning, and robust mathematical understanding.

Each session began with a brief affective "check-in" to foster emotional safety, followed by activities that balanced cognitive demands with affective support. Resources included visual aids, manipulatives, and structured prompts, complemented by metacognitive journals to encourage self-reflection on learning processes and conceptual growth.

Participants and profiles

The cognitive and affective profiles of each participant were identified through a psychopedagogical screening protocol designed to map executive functions and emotional self-regulation in mathematical contexts. The process involved three complementary procedures: (a) behavioral observation during problem-solving tasks to assess cognitive flexibility and inhibitory control; (b) narrative interviews in which students described their previous experiences with mathematics and self-perceived difficulties; and (c) affective mapping through reflective journaling and dialogic exchanges. The synthesis of these instruments enabled the definition of individualized profiles, linking cognitive tendencies to affective patterns relevant to mathematical learning.

The six participants exhibited diverse cognitive and affective profiles, exemplifying the heterogeneity typical of classroom settings:

Isabela:	Anxious, abstract, verbally expressive
Caio:	Quick thinker, attention challenges
Lívia:	Visual learner, precise, methodical
Rafael:	Disengaged, low self-efficacy
Tainá:	Expressive, energetic, sequencing difficulties
Pedro:	Reflective, introverted, learns via games and non-verbal logic.

This diversity was viewed as an asset, providing a nuanced understanding of how tailored pedagogical strategies impact different learner archetypes. Pseudonyms were employed to ensure participant confidentiality in accordance with archeogenealogical principles.

The following synthesis outlines the main findings derived from the integrated analysis of students' cognitive performance and adaptive learning behaviors during the microinterventions. It highlights individual progress, emerging strategies, and neurocognitive responses observed throughout the pedagogical process.

Table 2. Cognitive gains and personalized learning strategies identified during the pedagogical microinterventions

Student	Pre-test (%)	Post-test (%)	Gain (%)	Strategies
Isabela	40	78	+38	Visual aids, anxiety management
Caio	55	81	+26	Metacognitive prompts
Lívia	38	70	+32	Visual flowcharts
Rafael	30	68	+38	Emotional validation
Tainá	50	79	+29	Sequencing tools
Pedro	42	75	+33	Game-based reasoning

The mean gain of 32.6 percentage points (SD=4.2) indicates consistent improvement. These results derive from the synergistic effect of Neuroscience-optimizing cognitive load and attention-Educational Psychology-fostering relational and emotional safety-and Problem Solving-contextualizing abstract concepts in meaningful situations.

Qualitative data reveal behavioral and discursive shifts aligned with the integrated strategies, emphasizing the transformative potential of this approach. Figure 2 depicts the Pedagogical Integration Model, illustrating how cognitive, relational, and didactic elements converge to humanize Mathematics Education.

Statistical interpretation and implications

To determine the statistical significance of the observed improvements, a paired-sample t-test was conducted. The analysis yielded $t(5) \approx 10.94$, $p < 0.001$, indicating a less than 0.1% probability that these gains occurred by chance. This robust result affirms the effectiveness of the integrated pedagogical model in enhancing conceptual understanding of first-degree polynomial equations. The effect size, measured by Cohen's d ≈ 2.84, reflects a very large educational impact-substantially exceeding typical effects reported in Mathematics remediation interventions (Cohen, 1988).

Beyond statistical significance, qualitative evidence underscores the model's transformative influence. Students demonstrated shifts beyond test performance: increased perceived competence, greater willingness to engage with challenging tasks, and enhanced strategic flexibility. Notably, Rafael, previously disengaged, independently completed a symbolic manipulation task with positive affect, while Isabela transitioned from self-deprecating statements-"I'm bad at Math"-to affirmations of agency: "I found a way that works for me." These discursive shifts indicate deep psychological and affective growth, reflecting increased self-efficacy and motivation.

These outcomes suggest that gains resulted from a pedagogical approach rooted in empathetic care, scientific principles, and a profound respect for individual cognitive and emotional differences. This holistic strategy is visually encapsulated by the Pedagogical Integration Model (Triadic Approach), depicted in Figure 2, which illustrates the synergy of cognitive rigor, relational care, and didactic relevance in fostering a truly humanized Mathematics Education.

Pedagogical interpretation: When the learner is seen

In conventional educational settings, students are often reductively labeled as 'anxious', 'slow', 'disengaged', or 'unfocused', which risks overlooking their unique cognitive and emotional potentials. This intervention, however, reconceptualized each profile as a pedagogical invitation-an opportunity to tailor strategies aligned with empirically validated principles of brain function, while respecting emotional dimensions and framing mathematical cognition within a Problem-Solving context.

By integrating insights from Neuroscience, Educational Psychology, and Problem Solving, students transitioned from mere algorithmic performers to authentic participants in mathematical thinking. This approach substantiates a central thesis: when Neuroscience informs pedagogical structure, Psychology mediates relational and emotional dynamics, and Problem Solving restores meaning, Mathematics evolves from a restrictive filter into an expansive realm of possibility.

Although limited in scope, this case exemplifies a broader paradigm shift: fostering a pedagogical culture attentive to individual narratives, emphasizing humane teaching, and embracing a holistic view of learning-transforming Mathematics from a gatekeeper of ability into a fertile ground for growth.

Table 3. Summary of students' performance and strategy alignment

Student	Pre-test (%)	Post-test (%)	Gain (%)	Profile	Strategies Applied
Isabela	40	78	+38	Verbal-Anxious	Visual modeling, anxiety reframing
Caio	55	81	+26	Fast-thinking, Rigid	Metacognitive prompts, error tolerance
Lívia	38	70	+32	Visual-Reflective	Visual mapping, scaffolding, peer mediation
Rafael	30	68	+38	Emotionally Withdrawn	Confidence scripts, narrative repair
Tainá	50	79	+29	Expressive-Disorganized	Sequencing aids, oral rehearsal, collaboration
Pedro	42	75	+33	Introverted-Strategic	Game-based reasoning, reflective space, non-verbal supports

Findings and discussion

Quantitative Evidence and Effect Size

The quantitative results revealed statistically significant improvements in students' performance on post-intervention problem-solving tasks. A paired samples t-test showed a meaningful increase in scores ($p < .01$), accompanied by a very large effect size (Cohen's $d = 2.84$; Cohen, 1988). Although cautious interpretation is required due to the small sample size ($n = 6$), the magnitude of the change indicates that the intervention meaningfully enhanced students' conceptual engagement with first-degree polynomial equations.

Taken together, these findings point to gains that exceed procedural recall. Improvements were associated with the refinement of working memory coordination, attentional control, and strategic decision-making, which are executive processes known to support mathematical reasoning (Diamond, 2013; Sweller, 1988). In this context, performance change signals an initial reorganization of cognitive strategies rather than isolated task-specific learning.

Interpreting the impact of pedagogical interventions solely through performance metrics, however, can be reductive. Evidence from students' verbalizations, self-reports, and behavioral patterns suggests broader shifts in how they position themselves in relation to mathematics. Students demonstrated greater willingness to engage in challenging tasks, increased persistence, and emerging confidence in explaining their reasoning. These qualitative traces reveal changes in autonomy and emotional orientation toward learning, resonating with research that highlights the interplay between cognition, identity, and affect in mathematics education (Boaler, 2015; Immordino-Yang & Damasio, 2007).

These outcomes emerged in a learning environment deliberately structured to integrate cognitive load management, emotional safety, and heuristic exploration. This pedagogical ecology aligns with evidence-based principles in the fields of cognitive neuroscience, educational psychology, and problem-solving research (Pinheiro et al., 2022; Sousa, 2011;

Tokuhama-Espinosa, 2014). While this case study does not permit generalization, it offers analytical insight into how a neurocognitively informed, relationally attentive approach can contribute to measurable and meaningful development in students' mathematical thinking.

Quantitative Evidence of Cognitive Expansion

The quantitative findings were complemented by observable qualitative shifts in how students engaged with mathematical reasoning, emotional regulation, and self-perception across the intervention. These changes, although emerging from individual trajectories, converged into a coherent pattern suggesting the expansion of students' cognitive, affective, and epistemic agency. Before presenting the numerical outcomes, it is essential to highlight these transformations, which serve as lived indicators of how neurocognitively informed practices can reshape students' dispositions toward mathematics.

Table 4 synthesizes these indicators, illustrating specific behaviors that reflect increased emotional safety, autonomy in problem-solving, the reconstruction of mathematical identity, and a willingness to engage in exploratory, risk-taking behaviors central to deep mathematical learning.

Table 4. Summary of observed qualitative changes through the intervention

Indicator	Description	Evidence
Emotional Safety	Reduced anxiety and self-doubt	Isabela designing her own problems
Cognitive Autonomy	Development of strategic reasoning	Students articulating thought processes
Identity Reconstruction	Reframing self-image in Math	Rafael explaining solutions confidently
Engagement and Risk-Taking	Increased curiosity and participation	Voluntary collaboration and exploration

Statistical analysis via paired t-test demonstrated a significant increase in students' understanding of first-degree polynomial equations ($t(5) \approx 10.94$, $p < 0.001$), with an average gain of 32.6 percentage points and low variability ($SD = 4.2$). The effect size (Cohen's $d \approx 2.84$) underscores the pedagogical efficacy of neurocognitively aligned strategies. This result converges with evidence from Sousa (2011), Pinheiro et al. (2022), and Tokuhama-Espinosa (2014), reinforcing the view that effective mathematical learning is strengthened when instruction aligns with cognitive and affective processes inherent to brain-compatible pedagogy.

Beyond scores, the intervention catalyzed a profound re-signification of students' emotional engagement with Mathematics. From initial anxiety and learned helplessnessexemplified by Rafael's reluctance to participate-to emergent agency, exemplified by his peer explanations, the shift was palpable. Isabela's transition from paralyzing fear to active problem-posing exemplifies this transformation. Such changes align with Boaler (2015) and Leal Junior et al. (2022), who argue that valuing reasoning, effort, and creativity fosters positive mathematical identities and deeper understanding.

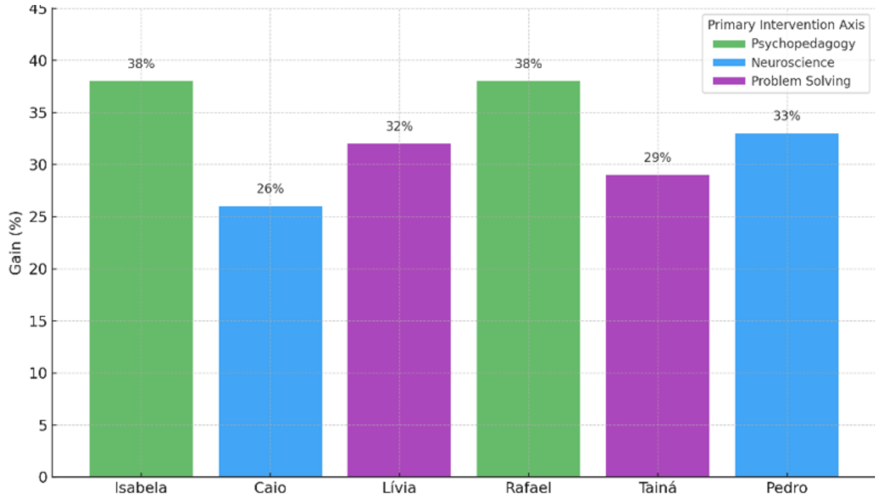

Figure 2. Students' cognitive and emotional development within the integrated framework of Neuroscience, Educational Psychology, and Problem-Solving

Figure 2 visually encapsulates these transformations, with color-coded indicators-green for Educational Psychology, blue for Neuroscience, and purple for Problem Solving-highlighting the intersectionality of mind, emotion, and strategy in humanized mathematical learning. Each student's progress reflects a tailored response to their cognitive and emotional profile, emphasizing that differentiation is a pedagogical right, not a privilege.

Insights from students like Isabela and Rafael-whose marked growth was primarily mediated through psychopedagogical strategies-affirm that addressing emotional barriers unlocks cognitive potential. Anxiety, trauma, and disidentification are reframed as meaningful aspects of the learning process, fostering a pedagogical ethics grounded in affective recognition.

Qualitative Transformations and Learner Agency

Beyond the quantitative results, the qualitative evidence indicates meaningful shifts in the affective and epistemic dimensions of students' engagement with mathematics. Students progressively reinterpreted their relationship with mathematical activity, moving from narratives of insecurity toward increased willingness to participate, explain reasoning, and accept uncertainty as part of learning.

Individual accounts illustrate these trajectories. Rafael, initially reluctant to take risks, began to approach errors as opportunities to reorganize his thinking rather than as personal failures. Isabela described a transition from anxiety regarding procedural steps to curiosity about underlying concepts, an evolution consistent with perspectives highlighting the interdependence between affective states and cognitive flexibility in mathematical reasoning (Immordino-Yang & Damasio, 2007).

Importantly, the problem-solving design functioned as a direct catalyst for learner agency. By providing open-ended problems, opportunities for heuristic exploration, and an emphasis on strategic reflection (Liljedahl et al., 2016a; Schoenfeld, 1992), the intervention enabled students such as Lívia and Tainá to exercise autonomous selection of procedures and justification of their choices. This structuring of activity promoted cognitive flexibility and made visible the transition from reproductive behavior to self-regulated metacognitive practices, an essential condition for epistemically relevant agency.

Likewise, the learning paths of Lívia and Tainá suggest that conceptual gains were supported by the Problem-Solving structure of the activities. As tasks were contextualized and open to exploration, these students demonstrated greater autonomy in selecting strategies and justifying solutions, aligning with Wilkerson's (2022) view that problem-solving environments enhance creativity, relevance, and identity in mathematics learning.

The varied progress among participants challenges the assumption of a homogeneous "typical learner." Instead, it reinforces the need for pedagogical approaches that respond to neurocognitive diversity and emotional variability as integral components of instructional design (Leite, 2020). Observational data showed increasing adoption of metacognitive behaviors, such as verbalizing thought processes and persisting through ambiguous stages of problem resolution. This development reflects the emergence of what Schoenfeld (1992) refers to as mathematical autonomy, which tends to remain invisible in standardized assessments but is essential to sustained reasoning beyond the classroom.

Changes in students' discursive positioning also suggest a gradual reconstruction of mathematical identity. Statements such as "I can't do this" increasingly gave way to expressions like "I found another way," indicating movement toward a more agentive stance. This aligns with sociocultural views that frame learning as a process of internalization and identity negotiation mediated through language and interaction (Pinheiro et al., 2022; Vygotsky, 1978).

Within the integrated pedagogical model implemented here, the classroom functioned not only as a space for content acquisition but also as a relational context where learners could renegotiate participation and belonging. Practices such as attending to students' interpretations, legitimizing their questions, and allowing time for exploration contributed to a form of symbolic repair, supporting the development of confidence and a sense of competence in the mathematical domain. While these interpretations require cautious generalization, the evidence highlights the potential of interdisciplinary, learner-attentive approaches for fostering deeper engagement and positive identity formation in mathematics.

Ethical and Pedagogical Implications of the Triadic Framework

The integrated framework adopted in this study brings together cognitive, affective, and discursive dimensions, operating both as an interpretive model and a reflective pedagogical stance. Informed by a genealogical perspective (Foucault, 1979), learning mathematics is understood not as adherence to predetermined norms but as a process through which students renegotiate their participation and positioning within the discipline. This perspective highlights how educational practices may reinforce mechanisms of standardization or open possibilities for challenging them, particularly when mathematics has historically functioned as a selective and exclusionary field.

The improvements observed in students' engagement and conceptual understanding appear to stem from the deliberate convergence of insights from Neuroscience, Educational Psychology, and Problem Solving. Instructional design aligned with cognitive functioning supported sustained attention and executive processes crucial for mathematical reasoning. Psychopedagogical mediation contributed relational and emotional grounding, legitimizing students' previous experiences and reducing anxiety around challenge. Meanwhile, problem-solving activities created opportunities for interpretive flexibility, strategic reasoning, and meaningful ownership over procedures and concepts.

In educational contexts frequently guided by standardized pacing and uniform expectations, these findings reinforce the value of approaches that acknowledge cognitive and affective diversity as integral to mathematical learning. When time is granted for conceptual exploration, when students' uncertainties are treated as starting points rather than obstacles, and when personal trajectories are considered in instructional decisions, mathematics becomes less a mechanism of exclusion and more a domain for intellectual inquiry and subjective expression.

The implications of this perspective are both ethical and epistemological. The model aligns with contemporary scholarship advocating for equitable and neuro-inclusive pedagogies (Leite, 2020), wherein mathematical learning is understood as the development of a participatory identity, not solely the production of procedural correctness. While this case study involves a small sample and therefore limits generalization, the evidence suggests that intentionally integrating cognitive, affective, and discursive supports may sustain not only conceptual growth but also students' willingness to remain engaged with mathematics through curiosity and confidence.

Future research may extend this approach to larger and more diverse populations, examining how such principles can inform teacher education and curriculum design committed to inclusive, responsive, and developmentally attuned mathematical learning environments.

From a genealogical standpoint, the triadic framework proposed here resists the normalizing logics that historically configured Mathematics as a disciplinary filter-an apparatus that classifies, excludes, and hierarchizes learners. By unveiling these regimes of control (Foucault, 1979), the neurodidactic perspective does not merely reinterpret cognition; it destabilizes the epistemic hierarchies that separate reason from emotion, mind from body, and knowledge from experience. In doing so, it reclaims Mathematics as an ethical and affective field of becoming, where learners negotiate their identities through processes of freedom, creativity, and relational awareness.

Conclusion: Toward a Humanized Mathematics

Traditional views of Mathematics Education often reduce it to a technical exercise-focused on rule transmission, procedural fluency, and correct answers. However, the insights from this case study, underpinned by an interdisciplinary framework integrating Neuroscience, Psychopedagogy, and Problem-Solving, demand a fundamental reimagining of the discipline. This new paradigm advocates for a pedagogy that transcends cognitive rigor, embracing an emotionally intelligent, ethically grounded, and truly human-centered approach. Such a model recognizes the learner as an active participant within a complex relational network-one where neural processes, affective states, and identity dynamically interact to foster meaningful understanding.

We posit that profound mathematical learning emerges not solely from isolated cognitive events but as an outcome of this intricate relational web. Effective pedagogical design must leverage neuroscientific insights into attention, memory, and executive functions; psychopedagogical strategies that prioritize learner voice, emotional safety, and active engagement; and Problem-Solving approaches that contextualize Mathematics as a tool for authentic inquiry and meaning-making.

The intervention's outcomes extend beyond statistically significant gains in standardized assessments; more importantly, they catalyzed a re-signification of the learning process itself. Previously disengaged students began to explore actively, rote learners transitioned to critical thinkers, and withdrawn individuals became participatory. These shifts exemplify the transformative potential of an integrated, humanized pedagogical approach. When structured intentionally, learning environments foster psychological safety, intellectual challenge, creative exploration, and empathetic support-elements that empower students to move beyond mere content acquisition toward cultivating agency, self-efficacy, and holistic development. The aim is not to accelerate progress for a few but to elevate the mathematical self-concept of all learners, recognizing and validating their unique cognitive and emotional pathways. This approach actively invites diverse voices, fostering genuine participation and authentic mathematical discourse.

In conclusion, this work advocates for a profound reimagination of Mathematics Education-grounded in empirical science, driven by interdisciplinary dialogue, and guided by the ethical conviction that every learner possesses the innate capacity-and the right-to understand, inquire, and belong within the rich landscape of mathematical thought. If education is, as Freire (1970) suggests, an act of love and liberation, then Mathematics must also embody and nurture this relational, developmental capacity, transforming not only minds but human lives.

To think mathematically, in this decolonial neurodidactic sense, is to reinhabit the act of knowing as a space of freedom and ethical becoming. From an archeogenealogical standpoint, this study does not merely advocate for didactic adjustments; it calls for the dismantling of disciplinary regimes that have historically positioned Mathematics as a mechanism of selection and normalization. Drawing on a Foucauldian perspective, we argue for an educational practice that recognizes processes of subjectivation and enables knowledge and affect to contribute ethically to the formation of meaningful mathematical learning.

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