Reconceptualization of the Mathematics Curriculum Based on Neuroscience of Narrative

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Abstract

This study aims to reconceptualize the mathematics curriculum through the lens of narrative neuroscience. Traditional mathematics education has primarily emphasized logical reasoning and procedural proficiency, often neglecting the affective and experiential dimensions of learning. Narrative neuroscience presents a novel framework that connects brain-based learning mechanisms with narrative structures that support understanding and retention. By adopting the literature review method, this study explores how narrative neuroscience-based approaches can enhance mathematical thinking and

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engagement. The paper analyzes the cognitive and emotional difficulties students confront in acquiring mathematical knowledge and discusses how narrative-driven instruction can activate intrinsic motivation, facilitate memory consolidation, and encourage flexible problem-solving. Practical implications for curriculum design, pedagogical strategies, and assessment methods are proposed, highlighting the potential of narrative neuroscience to humanize and enrich mathematics education.

Key words: Narrative, Neuroscience, Narrative Neuroscience, Mathematics Curriculum, Narrative Pedagogy

I. Introduction

Mathematics has long been regarded as a discipline that represents the pinnacle of logical reasoning, meticulous thinking, and numerical precision. However, traditional approaches to mathematics education have often emphasized excessive practice strategy and massive exam drilling, while overlooking the emotional, motivational, and narrative dimensions of learning. As a result, many learners feel that mathematics is detached from real life and fail to develop a meaningful understanding of mathematical concepts. Recent advancements in cognitive science and neuroscience have revealed that human learning is deeply connected to emotion, memory, and storytelling, suggesting that the brain naturally constructs knowledge through narrative structures.

Narrative neuroscience, as an emerging interdisciplinary field integrating neuroscience and narrative theory, provides novel insights into how narrative pedagogy influences the brain's learning mechanisms. Building on the foundational work of scholars such as Jerome Bruner (1990, 1996), who identified narrative as a fundamental mode of human thought, and incorporating contemporary findings from brain-based learning research, this study seeks to reimagine mathematics education as a narrative process that engages both cognition and emotion.

This research employed a literature review method to explore how the principles of narrative neuroscience can inform the development of a more human-centered mathematics curriculum. It investigates how narrative-based approaches can address students' difficulties in mathematical learning, promote intrinsic motivation, and support conceptual understanding through narrative and contextualized experiences. Ultimately, this study aims to provide theoretical and practical implications for mathematics curriculum design, elucidating concrete approaches that translate brain-based scientific findings into instructional practice.

II. Theoretical Background

1. Nature of Narrative Theory on Education

Fish live in water, yet they are the last to become aware of its existence, the moment a fish leaves the water marks the end of its life. Likewise, human beings live within narratives. Just as water constitutes the essential medium of existence for fish, narrative constitutes the existential medium for human life.

Bruner (1986) distinguished two fundamental modes of human cognitive function: paradigmatic thought and narrative thought. These two modes represent distinct but complementary ways through which individuals construct and understand the world.

Paradigmatic thought is grounded in the positivism tradition of the natural and empirical sciences. It emphasizes logic, rationality, and objectivity, seeking universal truths through theoretical, formal, and abstract reasoning. This mode of thought is characterized by its reliance on verification and logical coherence, remaining largely independent of specific contextual or situational factors. It operates through categorization, classification, and the formulation of general principles that can be empirically tested.

In contrast, narrative thought reflects a humanistic mode of cognition that focuses on meaning-making within social, cultural, and experiential contexts. Rather than discovering knowledge as something external and fixed, narrative thought constructs meaning through causal and intentional relationships among human actions and experiences. It inherently depends on context, attending to people's intentions, goals, and subjective experiences within specific social interactions. Through narrative, individuals interpret and organize events, connecting disparate and often chaotic experiences into coherent and meaningful wholes.

Bruner (1986) emphasized that these two modes of thought are complementary but irreducible to one another. While paradigmatic thought seeks to establish truth through formal reasoning, narrative thought aims to render human experience intelligible through story and interpretation. Narrative thus provides a cognitive framework that enables individuals to understand the meaning of reality and continuously reinterpret the significance of life events.

In this section, we examine narrative educational theory from several phenomenological perspectives, especially focusing on time, context, and intention. From a phenomenological standpoint, these aspects illuminate how human experience is constituted and understood through narrative.

Temporality is a crucial concept within narrative theory. As the saying goes, one can never step into the same river twice. Time is continuously flowing, and each moment carries unique meanings for different individuals. In educational contexts, the experience of time is profoundly subjective. For instance, a student who enjoys mathematics may feel that time passes quickly during math lessons, whereas a student who dislikes the subject may constantly check the clock, eagerly waiting for the class to end. A teacher's humor and engaging instructional style can also influence students' temporal experience, making lessons feel more enjoyable and fostering a positive attitude toward the subject. In some cases, students may even develop an affection for mathematics because they like their teacher. However, it is important for reflective learners to distinguish between the subject matter and the teacher's personal influence. They should not dislike a teacher simply because they struggle with the subject, nor should they reject a subject because of negative feelings toward the teacher. Such differentiation reflects a mature awareness of the temporal and emotional dimensions of learning experiences.

Context is a fundamental dimension of narrative understanding, emphasizing that meaning is always constructed within specific situations and contexts. As Lauritzen and Jaeger (1997) explain, narrative learning is inherently contextual because stories connect knowledge to life experience, allowing learners to make sense of knowledge content through the circumstances in which it is encountered. The meanings derived from a narrative or from any learning experience shift according to its context. For example, in elementary school, the equation "1 − 2 = " may be considered as an error because negative numbers have not yet been introduced; however, once students learn about integers in middle school, the same problem becomes meaningful and solvable. Likewise, the definition of a geometric concept varies depending on its spatial context. A circle in a plane differs fundamentally from a sphere in three-dimensional space. These examples illustrate that knowledge does not exist in isolation but is shaped by contextual frameworks that determine how it is interpreted and applied. In this sense, context in narrative education illuminates the dynamic interplay between knowledge, experience, and the situational environments in which meaning emerges (Lauritzen & Jaeger, 1997).

Intentionality in narrative theory highlights the direction of consciousness, the way human thought and action are always oriented toward meaning and purpose (Kang, 2023). Within educational contexts, intention signifies that learners do not simply accumulate fragmented pieces of knowledge. They actively organize and integrate these fragments to construct coherent understanding and to solve problems. This process reflects a narrative mode of cognition, in which learning unfolds as a purposeful act guided by personal intention and context. In mathematics education, for instance, students demonstrate intentionality when they apply previously learned concepts to new situations, strategically employing various forms of inference, such as induction, deduction, and abduction, to generate solutions. Through repeated practice, learners refine these reasoning skills and develop problem-solving fluency, embodying the narrative movement from experience to understanding. Thus, intentionality within the narrative framework emphasizes that learning extends beyond passive absorption of information and entails deliberate meaning construction directed toward coherent and purposeful engagement with knowledge.

2. Neuroscientific Mechanisms of Learning Mathematics

With the discovery of neurons in the early twentieth century, systematic and empirical research on the brain began in earnest. The development of computers, medical technology, and scientific instruments further accelerated the progress of scientific brain studies. Until the mid-twentieth century, research on the brain was conducted primarily from an anatomical perspective. However, since the 1960s, it has been revealed that brain functions are mediated by approximately forty types of neurotransmitters between neurons, leading to an active exploration of the brain's functional aspects. In the 1970s, the invention of computed tomography (CT), and later, in the 1980s, magnetic resonance imaging (MRI), enabled researchers to identify damaged brain regions in living patients, marking a significant turning point in neuroscience (Shin et al., 2021). During the 1980s and early 1990s, positron emission tomography (PET) and functional magnetic resonance imaging (fMRI) were widely used, extending brain research from patients with brain damage to healthy individuals. As a result, neuroscience achieved remarkable advances during this period.

Although neuroscience began to attract significant attention only in the 1990s, it has rapidly evolved into a field that generates substantial scientific discoveries through its integration with other disciplines, thereby opening up a wide range of possibilities. Since the 2010s, the cognitive science paradigm has gained increasing prominence, which conceptualizes the mind as an integrated system of the brain, body, and environment. As neuroscience has converged with other academic fields, it has given rise to efforts aimed at addressing real life issues and has inspired extensive research exploring the relationship between the brain and the mind. Neuroscience provides the advantage of enabling direct observation of neural activity within the brain, thereby offering new insights into human mental functions as well as the dynamic flow and interconnections among various cognitive processes.

Recent advances in neuroscience have provided profound insights into how the human brain processes, stores, and retrieves mathematical information. According to Sousa (2015), learning mathematics is not merely a process of rote memorization or procedural repetition but a complex cognitive activity involving multiple interconnected neural systems. Different areas of the brain are responsible for distinct aspects of mathematical thinking: the parietal lobes are primarily involved in number sense and spatial reasoning, the prefrontal cortex supports problem solving and executive functions, and the hippocampus contributes to the consolidation of mathematical knowledge into long-term memory (Sousa, 2015).

Sousa (2015) emphasizes that effective mathematical learning relies on the brain’s capacity to make connections between new information and existing neural networks. When learners actively construct meaning, particularly by linking abstract mathematical symbols to real world contexts or visual representations, stronger and more durable neural pathways are formed. This process is supported by the principle of neuroplasticity, which enables the brain to reorganize itself through repeated practice and meaningful engagement. Consequently, instructional strategies that incorporate multisensory input, including visual aids, concrete manipulations, and verbal reasoning, can substantially strengthen the encoding and retrieval of mathematical concepts.

Moreover, emotional engagement and motivation play a pivotal role in mathematical learning. Sousa (2015) argues that the amygdala (a brain region involved in emotional processing) can either facilitate or hinder learning depending on the learner’s emotional state. Positive emotional experiences and a supportive learning environment activate the brain’s reward system, releasing dopamine and thereby enhancing attention and memory retention. In contrast, anxiety or fear associated with mathematics can inhibit neural communication between the amygdala and the prefrontal cortex, reducing working memory capacity and impairing problem-solving ability.

In light of these findings, neuroscience suggests that mathematics instruction should be designed to align with the brain’s natural learning processes. Effective teaching should balance conceptual understanding with procedural fluency, provide frequent opportunities for retrieval practice, and encourage metacognitive reflection. By integrating neuroscientific principles into mathematics education, teachers can better support students’ cognitive development and foster deeper, more resilient mathematical reasoning.

3. Narrative Encounters Neuroscience in Mathematics Education

Each academic discipline possesses its own unique characteristics and distinct modes of representation. Mathematics, in particular, resembles a marathon of thought, in which the mind is continuously strengthened through repeated runs of reasoning. Human cognition is constructed through various representational forms, among which language and numbers serve as fundamental systems for symbolizing and communicating meaning.

In the field of mathematics education, both explanation and interpretation play indispensable yet distinct roles in the construction of knowledge. Within competency-based and understanding-oriented approaches grounded in the Science of Learning (SoL), explanation and interpretation are also frequently foregrounded when emphasizing the six facets of authentic understanding in backward curriculum design. Explanation seeks to clarify mathematical phenomena through logical reasoning, formal proof, and the articulation of cause and effect relationships. Interpretation, on the other hand, involves understanding mathematical ideas within their broader perspectives, discourses, and contexts. That is, how meaning is constructed, communicated, and experienced by learners. Neither mode can be reduced to the other. Explanation alone cannot fully reveal the interpretive dimensions of mathematical thinking, while interpretation cannot entirely account for the rigor of formal explanation. As Bruner (1996) suggests, the process of understanding requires both the analytic precision of explanation and the narrative coherence of interpretation. In this sense, the two modes function as mutually illuminating but irreducible processes in mathematical inquiry. Therefore, mathematical reasoning is simultaneously explained through structure and interpreted through meaning.

Recent developments in narrative neuroscience have demonstrated how storytelling engages the brain's cognitive and emotional systems to facilitate deeper learning. Narrative structures activate multiple neural networks responsible for language, memory, emotion, and sensory processing, thereby enhancing the integration of knowledge and experience. Applied to mathematics education, narrative renders abstract concepts more comprehensible and personally relevant to learners. Neuroscientific studies suggest that when students encounter mathematical problems embedded in narrative contexts, their brains show increased activity in areas associated with empathy, visualization, and problem-solving (Mar, 2011). This alignment between narrative engagement and neural activation underscores the potential of narrative-based instruction to strengthen the brain's associative networks involved in mathematical reasoning. Consequently, integrating narrative approaches into mathematics instruction not only supports cognitive processing but also fosters motivation, memory retention, and the construction of personally meaningful mathematical understanding.

III. Research Method

Literature review is rather appropriate when the research purpose is to reconceptualize existing theories, integrate insights across disciplines, or propose new analytical perspectives grounded in established scholarship. According to Hong (2002), literature-based research does not merely summarize prior studies but functions as an analytical process through which researchers critically engage with existing knowledge to clarify theoretical relationships, construct theoretical frameworks, and establish a coherent foundation for new inquiry.

Method of literature review was conducted in three stages: literature selection, analytical procedure, and systematic integration into the present study. Literature selection focused primarily on key terms such as narrative, neuroscience of narrative, brain-based learning, mathematics education, and narrative pedagogy. To ensure theoretical relevance and academic rigor, foundational works by Bruner, Gardner, Vygotsky, and Sousa were intentionally included due to their sustained influence on narrative cognition, learning theory, and neuroscience-informed education. During the literature analysis stage, iterative reading and comparative examination were utilized to extract recurring themes, including the nature of narrative cognition, the neural mechanisms underlying mathematical learning and memory, and the affective dimensions of knowledge acquisition. This theory-driven literature analysis allowed the study to synthesize insights across multiple disciplines such as neuroscience, curriculum theory, and mathematics education. Eventually, the findings from the literature analysis were systematically integrated into the structure and argument of the present study. Theoretical insights from narrative theory and neuroscience were used to reinterpret mathematics learning as a narrative and cognitive process, and to derive implications for curriculum design, instructional practice, and assessment. In this way, the analyzed findings were embedded throughout the paper to support the reconceptualization of the mathematics curriculum based on neuroscience of narrative. Through this process, the literature review functioned not only as a foundation for theoretical discussion but also as an interpretive channel that informed the overall argument and educational implications of the study.

IV. An Approach to Mathematics Curriculum Development through Narrative Neuroscience

1. Analysis of the Difficulties in Acquiring Mathematical Knowledge

Acquiring mathematical knowledge presents tremendous challenges for learners due to the inherently abstract and hierarchical nature of the discipline. Prior research indicates that students' difficulties stem not only from the complexity of mathematical concepts but also from the interaction of cognitive, instructional, and affective factors. Accordingly, this section analyzes the major sources of difficulty that impede effective mathematical learning.

From a cognitive perspective, mathematics requires learners to manipulate abstract symbols, coordinate multiple representations, and engage in higher order reasoning. Many students struggle to integrate conceptual understanding with procedural fluency, resulting in fragmented knowledge structures. Moreover, because mathematics frequently functions as a filtering mechanism for entrance examinations, competitive ranking systems allow only one first place, implicitly positioning the success of that student as the failure of all others. Consequently, students experience heightened anxiety, which consumes cognitive resources essential for reasoning, problem solving, and working memory intensive tasks.

Difficulties also arise from instructional practices and learning environments. When teaching focuses primarily on procedural routines, learners may fail to grasp the underlying concepts, which limits their ability to transfer knowledge to unfamiliar contexts. Textbooks and classroom discourse often present mathematics in a linear and decontextualized manner, obscuring the relational and sense-making aspects of the discipline. Additionally, insufficient opportunities for mathematical discussion, modeling, and feedback hinder the development of deep understanding.

Individual beliefs about personality also shape learning behavior. While blood type and astrological signs lack empirical validity, students often use them to interpret their tendencies and identity, influencing self-perception and academic confidence. More structured frameworks, such as the Myers–Briggs Type Indicator (MBTI) (Myers et al., 1998), provide insight into cognitive preferences relevant to mathematics learning. For example, intuitive (N) students often gravitate toward abstract patterns, whereas sensing (S) students rely on concrete examples; thinking (T) types typically excel in analytical reasoning but may be more susceptible to self-criticism, while feeling (F) types may be more sensitive to relational dynamics or teacher feedback. Although MBTI is not a measure of ability, such personality preferences affect how students cope with mathematical challenges and which learning environments they perceive as supportive.

Finally, differences in fluid intelligence (Gf) and crystallized intelligence (Gc) contribute substantially to variation in mathematical learning. Fluid intelligence supports analogy, deductive inference, spatial visualization, and novel problem solving (Cattell, 1963). Students with lower Gf may struggle with multi-step reasoning, conceptual transformations, analogical mapping, or non-routine tasks that require flexible thinking. Crystallized intelligence, which reflects accumulated knowledge and mathematical vocabulary, influences the ability to connect new concepts with prior understanding and to draw on established schemes during problem solving. When disparities in Gf and Gc intersect with environmental pressures and personality traits, the difficulties become more pronounced, amplifying individual differences in mathematical performance.

Taken together, these cognitive demands, instructional factors, personality-related self-perceptions, and intelligence differences create layered and intersecting barriers to the acquisition of mathematical knowledge. Understanding how these influences interact is essential for designing more effective and supportive learning environments that value individual diversity, mitigate unnecessary pressure, and promote sustained engagement in mathematics.

2. The Connection Between Mathematics Education and Narrative Neuroscience

Recent developments in narrative neuroscience lay a theoretically robust foundation for reinterpreting mathematics education as a meaning-making, context-embedded cognitive activity rather than a purely procedural one. Integrating insights from narrative neuroscience with Gardner’s (1983) Multiple Intelligences (MI) theory provides a multidimensional framework for understanding how learners construct mathematical meaning. Narrative neuroscience demonstrates that stories engage neural systems responsible for emotion, attention, intention, and memory consolidation, suggesting that learning is enhanced when new information is embedded within meaningful contexts. MI theory complements this view by emphasizing that learners process information through diverse cognitive pathways, such as linguistic, logical-mathematical, spatial, interpersonal, and intrapersonal intelligence, rather than through a single, uniform mode of intelligence (Gardner, 1983).

When narrative structures are incorporated into mathematics instruction, they support an entry point for multiple intelligences to operate simultaneously. For instance, context-rich problem narratives can activate linguistic and interpersonal intelligences, while visual storylines and modeling scenarios can engage spatial intelligence. This synthesis aligns with MI theory's central claim that understanding is strengthened when learners mobilize multiple cognitive resources rather than relying solely on logical-mathematical processing.

It is essential to recognize that every story is the product of a speaker who brings specific intentions, perspectives, and interpretive stances to the act of narration. Stories reflect the narrator's choices about what to emphasize, how to frame a problem, and which meanings to make salient. This insight is highly relevant to mathematics education, where narrative forms, such as problem scenarios, modeling contexts, or metaphorical explanations, mediate how learners construct mathematical meaning. When teachers introduce mathematical ideas through narratives shaped by particular viewpoints, they implicitly guide students' attention, highlight certain conceptual relationships, and promote specific forms of reasoning.

Mathematics education emphasizes thinking, and thinking itself can be understood as an inner dialogue (Bruner, 1996). This internal conversation allows learners to interrogate assumptions, compare alternative representations, and negotiate meanings as they work through mathematical ideas. From a pedagogical standpoint, fostering this inner dialogue requires learning environments that encourage students to articulate their reasoning, confront cognitive conflict, and connect new concepts with prior understanding. Ultimately, cultivating rich inner dialogue supports deeper conceptual understanding, promotes metacognitive awareness, and enables learners to approach mathematics as a meaning-making process rather than a set of procedures to be memorized.

Consequently, combining narrative neuroscience with mathematics education facilitates a shift from procedural competence to holistic mathematical literacy, where learners construct meaning through diverse intelligences and narrative-structured engagement with mathematical concepts. This interdisciplinary integration underscores the pedagogical value of designing mathematical learning environments that are cognitively pluralistic, contextually meaningful, and neurologically aligned with how the brain constructs understanding.

3. Exploring the Possibility of Adopting Narrative Neuroscience in Mathematics Curriculum Development

Narrative neuroscience offers a promising framework for rethinking how mathematical knowledge is introduced, structured, and experienced in curriculum design. Building on Bruner’s (1960, 1990) cognitive revolution, which reframed learning as an active process of meaning construction rather than mere information transmission, this perspective is rooted in the understanding that the human brain processes information through intentional, meaning-oriented, and contextually embedded narrative structures. Such an approach resonates with contemporary findings in cognitive science showing that narrative organization strengthens associative memory, enabling learners to connect new mathematical ideas with existing cognitive schemes. Consequently, abstract concepts can be more effectively grasped when situated within coherent narrative frames that mirror the brain's natural strategies for organizing experience.

Narrative framing further supports conceptual understanding by linking new mathematical concepts to familiar contexts, thereby reducing cognitive load and increasing opportunities for transfer. It also models forms of reasoning in ways that make problem solving appear as a structured yet creative inquiry rather than a set of isolated procedural steps. Moreover, narrative-based pedagogy can enhance intrinsic motivation by providing emotional coherence and personal relevance, factors that neuroscientific research associates with improved long-term retention and more flexible forms of mental processing. These benefits extend even to domains such as mental arithmetic, where narrative structures can scaffold the organization of numerical relationships, and facilitate the rapid retrieval of operations through associative memory pathways.

Despite the challenges associated with integrating narrative neuroscience into mathematics curriculum design, this perspective remains a viable and potentially transformative approach for reimagining how mathematical learning is organized. By aligning curriculum development with the brain's natural mechanisms for information processing and meaning-making, narrative neuroscience offers a compelling horizon for humanizing mathematics education and enhancing students' conceptual engagement.

V. Implications of Narrative Neuroscience for Mathematics Curriculum Design

1. Instructional Content Selection in Mathematics Education

From the perspective of narrative neuroscience, the selection of instructional content in mathematics education should prioritize concepts that facilitate meaning-making, relational connections, and the formation of associative memory. While maintaining mathematical rigor is essential, content choices must also ensure cognitive accessibility by allowing abstract ideas to be situated within coherent narrative structures. Aligning content selection with the brain's natural mechanisms for intention-driven processing and meaning construction, mathematics curricula can enhance long-term memory consolidation and cultivate more meaningful learning experiences.

Mathematics is a foundational discipline within the sciences, and learners' developmental trajectories determine their cognitive readiness and the level of complexity in mathematical concepts they can meaningfully acquire. Drawing on Piaget's (1952) theory of cognitive development, children make progress from the preoperational stage to the concrete operational stage and eventually to the formal operational stage, each of which affords increasingly sophisticated forms of reasoning. These developmental shifts influence not only how mathematical ideas can be introduced but also the degree of abstraction, symbolic manipulation, and logical inference that learners are capable of mastering at different ages.

In mathematics education, emphasizing the structure of knowledge is essential, as mathematical learning develops through recognizing patterns, establishing relationships, and applying rules rather than memorizing isolated procedures. Discovering mathematical structures is itself an act of inquiry, requiring learners to engage both intuitive and analytical modes of thinking. Through the processes of acquisition, transformation, and evaluation, students are able to construct their own mathematical meanings. This approach encourages learners to investigate patterns, formulate conjectures, test hypotheses, and generalize results, allowing them to experience the joy of discovery that accompanies solving a problem or identifying a structural insight. In this way, students actively explore numerical relationships and geometric structures, thereby opening the gateway to mathematical cognition.

Whereas transmission-based instruction emphasizes the unidirectional delivery of information from teacher to student, heuristic approaches focus on cultivating learners' cognitive structures, problem-solving abilities, and conceptual understanding through active engagement. Such approaches align with constructivism learning theory, which views knowledge not as something imposed from the outside but as something constructed through meaningful interaction, reasoning, and reflection.

Narrative constitutes the most natural and primordial means by which we organize our experiences and knowledge (Kang, 2022). Bruner proposes the notion of narrative heuristics in the understanding of science. Narrative heuristics consist in transforming events into narrative form and emphasize that these transformations must conform to the expectations and norms that guide how such events are to be perceived. Restoring "dead science" to the activity of "science-making" requires precisely this shift in consciousness. The process of science-making is fundamentally narrative. What Bruner seeks to underscore is not a lifeless science confined to books or printed text, but the vibrant, living practice of science-making itself (Bruner, 1996).

In mathematics education, cultivating students' capacity for knowledge transfer is essential. Probability instruction offers particularly effective contexts for developing such transferable thinking. Everyday scenarios, such as interpreting traffic signal lights (red, yellow, green) or evaluating products as either qualified or defective, further illustrate how probabilistic reasoning extends beyond formal mathematics into real-world decision-making. By engaging students in these varied contexts, instruction enables them to transfer core probabilistic concepts, including randomness, independence, conditionality, and expected outcomes, across different representational forms and problem structures.

Neuroscientific research suggests that the cognitive flexibility required to break mental set, generate divergent thinking, and engage in brainstorming is supported by neuromodulatory systems, particularly those involving dopamine and serotonin. Dopamine is associated with reward prediction, novelty-seeking, and exploratory behavior. Thus, tasks that encourage students to search for alternative strategies or unexpected solutions in mathematics can activate dopamine pathways that reinforce curiosity and experimentation. Moments of insight, the sudden emergence of problem-solving inspiration, have also been linked to dopamine-mediated shifts in attention and cognitive reorganization. Serotonin, by contrast, contributes to emotional regulation and cognitive stability, enabling students to persist through mathematical uncertainty and to overcome frustration when confronting challenging problems. By designing learning experiences that promote exploration, reinterpretation, and positive affect, mathematics instruction can leverage these neuromodulatory influences to enhance creativity, insight generation, and flexible problem solving.

The human brain possesses an inherent tendency toward cognitive economy, automatically evaluating the cognitive effort required when confronted with abstract, complex, or highly uncertain tasks. When substantial cognitive resources are anticipated, the brain's energy minimization mechanism triggers an avoidance response, which learners subjectively experience as fear of difficulty, procrastination, or reluctance to begin. Moreover, according to predictive processing theory, the brain is constantly working to minimize prediction error. Mathematics learning, however, is often accompanied by high levels of uncertainty and frequent conceptual leaps, which require the brain to continuously update its internal models.

It is precisely these moments that constitute the most critical points of breakthrough in mathematics learning, because learners must bridge conceptual gaps and reconstruct their knowledge structures. Each direct encounter with difficulty prompts the prefrontal cortex to integrate information more effectively, strengthens abstract reasoning, and consolidates conceptual networks in long-term memory. In other words, overcoming avoidance and deliberately entering a “high-effort cognitive zone” does not strain the brain; rather, it represents a necessary pathway for the development of mathematical competency. Therefore, in mathematics learning, the willingness to confront cognitive challenges and counteract the brain’s natural avoidance tendencies is central to achieving deep understanding and meaningful intellectual growth.

In the context of mathematics learning, error awareness is also frequently emphasized. The strength of this awareness determines whether a student can “wake up” at the very moment an error occurs, that is, whether the learner can immediately recognize a mistake right after making it. Deep within the brain, a small region known as the anterior cingulate cortex (ACC) functions as the brain’s “error radar,” monitoring discrepancies between one’s actions and intended goals even at the precise moment when one believes the response is correct. Error awareness represents a form of “slow, invisible change”. Each moment of reflective self-monitoring signals the growth of this capacity, as the neural pathways that support it gradually become more stable and efficient through repeated activation.

Moreover, instructional content related to narrative thinking should be selected so that it complements and enriches logical–mathematical knowledge. This perspective resonates with insights from the Feynman learning method, which emphasizes the value of explaining what one has learned to others in clear and simple words. When students attempt to articulate mathematical ideas within a coherent narrative, they inevitably uncover gaps in their understanding and revisit the material for refinement until they can accomplish a fluent and accurate explanation. Through this iterative process, complex ideas are transformed into accessible language, supporting the development of individualized and durable knowledge structures. This constitutes a form of generative learning, in which deeper cognitive processing enhances learning efficiency and long-term retention. Furthermore, the presence of peers can activate neural systems related to social feedback and audience awareness, motivating learners to improve the clarity, coherence, and acceptability of their explanations. Consequently, selecting mathematical content that lends itself to narrative reconstruction, whether through explanation, teaching, or peer interaction, can effectively stimulate learners’ motivation and lead to better knowledge comprehension and transfer abilities.

If learners cannot articulate a body of knowledge in their own words, it cannot be considered truly learned. Our brain requires generative processing in order to form lasting impressions. During the process of “explaining to others,” the brain reorganizes its knowledge structures, transforming vague concepts into clearer and more coherent forms. The transition from understanding to expression represents a qualitative leap in learning, making the learner’s thinking visible.

2. Practical Mathematics Classroom Applications of Narrative Pedagogy

As is widely recognized, knowledge is not transmitted but constructed through the learner’s own experience. Narrative serves as a primary way in which human beings organize learning experiences so that these experiences become intelligible, memorable, and personally meaningful (Kang, 2023). Narrative pedagogy can therefore be applied in mathematics classrooms to transform how students make sense of abstract ideas by grounding them in meaningful and coherently structured learning experiences.

Bruner argued that learning is an individual and active process of discovery, in which children gradually progress through three modes of representation: enactive, iconic, and symbolic (Smidt, 2011). In mathematics education, this developmental progression is highly valuable for designing instructional activities that help learners connect, reorganize, and generate understanding over time.

> Bruner's representational stages - enactive, iconic and symbolic - may be useful to you if only in the sense that you pay attention to what children are using when they represent their thoughts and ideas. You may notice that the child is relying primarily on movements and sensory exploration, on using pictures and images or on using symbolic systems. You may want to introduce alternative forms of representation if you feel that a child is stuck at one phase. For example, if the child does not want to use symbols you might want to ensure that the child has more concrete experience, building confidence. Or if the child is being pressured to do formal things (such as sums), you may want to invite the child to represent things enactively or iconically.
>
> (Smidt, 2011: 25)

In the enactive representation, learners engage with mathematical ideas through concrete actions. Such activity-based experiences allow students to internalize mathematical relationships as patterns of action. As learners move into the iconic mode, they begin to use images, diagrams, and visual models to represent mathematical structures. Number lines, geometric figures, graphs, and other visual representations help students perceive relationships such as magnitude, proportion, spatial configuration, and functional variation. These iconic representations serve as transitional tools that bridge concrete actions and abstract reasoning. The symbolic mode involves the use of language, symbols, and formal notation, such as numerals, algebraic expressions, equations, or mathematical statements to represent and manipulate abstract concepts. For young learners, linguistic forms such as narratives, ordered sequences of events, and causal explanations function as symbolic representations that parallel mathematical structures. Understanding the sequence of a story, recognizing causal relations, or reconstructing a narrative plot supports the development of logical thinking and verbal expression. These skills directly contribute to interpreting mathematical symbols, articulating reasoning, and constructing mathematical arguments.

Moreover, when learners reconstruct or create narratives, they simultaneously develop imagination and problem-solving abilities. In problem-solving contexts, the narrative process encourages them to mentally simulate mathematical situations, anticipate outcomes, and reason through alternative approaches. In this way, narrative-based mathematical instruction aligns naturally with Bruner's representational stages, enabling students to progress from action to visualization to abstraction while constructing a deeper mathematical understanding.

Narrative pedagogy encourages students to generate verbal or written explanations that articulate how and why a mathematical idea works. This practice aligns with research showing that narrative expression strengthens neural pathways related to comprehension and long-term memory. When students explain mathematical knowledge to others through narratives, they externalize their thinking in ways that make implicit reasoning explicit, thereby deepening their own understanding.

The collaborative nature of narrative work also resonates with Vygotsky's notion of the Zone of Proximal Development (ZPD), which maintains that learners will reach higher levels of development through social interaction and others' guided participation (Vygotsky, 1978). In peer-to-peer narration, students alternate between the roles of novice and expert. By narrating problem-solving processes, offering justifications, and responding to one another's explanations, learners provide the scaffolding that enables their peers to operate within the ZPD.

Collaborative narration further supports classroom discourse practices that emphasize reasoning, justification, and perspective-taking, these skills are essential to mathematical literacy. Through jointly constructed narratives, students co-create meaning, negotiate interpretations, and refine their knowledge understanding, allowing them to progress beyond what they could achieve independently.

However, learning in different subject areas follows different developmental patterns, and not all learners benefit from the same scaffolding model. Just as we cannot expect every frog to remain at the bottom of a well, we cannot assume that all students require identical forms or degrees of instructional support. Gifted children or students with exceptional abilities may achieve advanced levels of understanding without extensive external assistance. Thus, some scholars argue that the Zone of Proximal Development (ZPD) is particularly well suited to field-dependent learners, who tend to make rapid progress when provided with structured guidance and collaborative learning opportunities.

As previously discussed, thinking itself is an internal dialogue of the learner, and it is precisely during this internal dialogue process that narrative-related neural mechanisms are most actively engaged. For field-independent and highly capable students, it is not the case that they lack narrative processes; rather, their narrative activity tends to occur internally, autonomously, and with minimal reliance on external scaffolding. Their ability to construct meaning, generate explanations, and mentally simulate mathematical situations often takes the form of self-directed narrative reasoning. In this sense, narrative cognition remains fundamental to their learning, even though their developmental progression appears to be driven primarily by individual insight rather than guided social interaction.

The principle that practice makes perfect underscores the importance of providing learners with adequately increased and appropriately calibrated practice to consolidate their knowledge. From a behaviorism perspective, this is consistent with Thorndike's laws of exercise and readiness, which emphasize that repeated practice strengthens associations, while adequate preparation enables effective learning. In mathematics instruction, consolidation-oriented practice, typically implemented at approximately 150% of the baseline requirement, is frequently used to reinforce procedural fluency and promote long-term retention.

Refreshing learning experiences can remodel neural circuitry in our brain. Research on brain-based learning underscores the importance of instructional design that aligns with the brain's natural mechanisms for receiving, processing, and storing information. Importantly, the brain more readily retains information that is connected to learners' prior knowledge, background experiences, or personal interests. As learners repeatedly apply new skills or review recently acquired knowledge, the corresponding neural pathways gradually become strengthened, enabling them to effectively counteract forgetting and overcome the pedagogical “plateau effect” often observed in the learning process.

In the context of mathematics learning, the principles of hippocampal-dependent memory consolidation are equally applicable. Reviewing key formulas, theorems, or even geometric representations, such as ellipses and hyperbolas, briefly within one to two hours before sleep can facilitate more effective consolidation. During sleep, the brain organizes, categorizes, and remembers newly acquired information, and the hippocampus plays a crucial role in this process. Once asleep, the hippocampus automatically reprocesses the material reviewed before bedtime, engaging in repeated activation that strengthens memory traces. The following day, recalling the content reviewed the night before provides an additional opportunity for the hippocampus to reconsolidate the information, effectively creating a 24-hour cycle of automatic reinforcement that enhances learning efficiency.

Moreover, emotional state plays a significant role in learning. Stress can impair memory formation and retrieval, whereas positive emotional experiences increase students' willingness to engage with lessons and classroom activities. Therefore, effective mathematics instruction should not only provide sufficient practice but also foster emotionally supportive learning environments that promote sustained motivation and cognitive performance.

When narrative-based strategies are applied, it is highly important to recognize that language-comprehension reading in literacy instruction and task-oriented reading in mathematics activate different neural pathways. Literacy reading primarily involves processing sentences, whereas mathematical reading requires perceiving and interpreting structural relationships. During story reading, understanding plot development and characters' emotions predominantly recruits regions associated with language comprehension, particularly the temporal lobe. By contrast, reading mathematical tasks additionally engages the prefrontal executive system, which is responsible for extracting conditions, identifying targets, and rapidly establishing operational relationships in order to integrate numerical and structural information. Consequently, reading a mathematics problem without identifying its underlying structure does not constitute authentic comprehension. In mathematics classrooms, students who are able to restate the "task objective" of a mathematics problem in their own words demonstrate conspicuously higher success rates in problem-solving than those who cannot.

Learning is never merely the passive acceptance of others' conclusions.

Instead, it emerges through the interactional process linking learners with learning content. This process is the active construction of one's own knowledge system. Knowledge must undergo a process of input, reflection, construction, and output to be transformed into genuine competence. In this sense, learning can be understood as the privatization of public knowledge.

3. Considerations for Educational Assessment Methods

Building on insights from narrative neuroscience, educational assessment in mathematics should shift from a narrow emphasis on correct answers toward a more comprehensive evaluation of the cognitive processes through which students construct mathematical meaning. Because narrative thought involves self-explanation, mental simulation, and the articulation of relational structures, assessment methods should be designed to capture the learner's internal dialogue processes rather than merely their final solutions.

Mathematics is a discipline that vividly reflects the logic of a spiral curriculum, as its knowledge structure is inherently hierarchical and recursive. Foundational concepts are not only reactivated in later stages of learning but also reinterpreted, reorganized, and applied across diverse contexts. This iterative process aligns closely with the central principle of the spiral curriculum. Each return to these ideas offers students opportunities to build new connections upon prior understanding and to develop more advanced forms of mathematical narration, thereby enabling them to transition gradually from intuitive reasoning to more abstract and structural modes of thought.

In this regard, assessments must include longitudinal components that trace the progressive elaboration of students’ mathematical narratives. When learners re-encounter fundamental concepts at higher levels of abstraction, they produce increasingly coherent explanations that reflect the maturation of their internal narrative structures. Because narrative understanding deepens through the repeated reconstruction of internal meaning structures, assessment methods should be designed to capture these successive refinements rather than to measure performance at a single time point.

Solomon (2012) argues that assessment should function as a bridge between curriculum standards and actual classroom practice, enabling teachers to monitor not only whether students meet predefined outcomes but also how their understanding evolves across instructional episodes. Pedagogical methods such as reflective prompts and dialogic feedback provide ongoing opportunities for students to refine the internal narratives through which they interpret mathematical ideas. These strategies allow educators to examine how learners organize problem information, generate explanatory narratives, and revise their thinking processes as they engage in reasoning. In addition, narrative-based assessment tasks that require students to explain how different representations relate or to articulate the conceptual structure underlying a given problem can be used to activate narrative reasoning mechanisms. Such explanation-driven items promote deeper comprehension and enable instructors to evaluate the coherence, accuracy, and flexibility of students' mathematical narratives.

Another important implication for assessment design involves the complementary practices of isomorphic tasks across different lessons and heterogeneous approaches to the same task. When students engage with isomorphic tasks from different lessons, they are encouraged to identify common underlying structures and articulate cross-contextual explanations, thereby revealing how their internal narratives support transfer and structural abstraction. Conversely, heterogeneous approaches to the same task allow students to compare and evaluate multiple narrative pathways toward a shared mathematical goal, making visible the variations in reasoning strategies, representational choices, and conceptual emphases. Integrating these assessment practices into mathematics classrooms foregrounds the unfolding narratives through which students organize mathematical ideas, exposes the evolution of their conceptual structures, and provides richer evidence of their developing mathematical cognition.

Insights from narrative neuroscience indicate that mathematical understanding relies not merely on the accumulation of information but on the learner's ability to transform that information through internally constructed narratives. Consequently, process-oriented assessment becomes more critical than purely outcome-based evaluation, as it captures how learners construct understanding through individualized narrative processes that mediate interpretation, reasoning, and meaning-making. From this perspective, assessment should attend to how students interpret problem contexts, articulate intermediate reasoning steps, and revise their explanations in response to cognitive conflict or new insights. Such an approach allows educators to evaluate the quality of students' meaning-making processes, tracing how conceptual structures are formed, reorganized, and consolidated over time, thereby providing a more valid representation of mathematical thinking than final answers alone can offer.

What is education? Ultimately, what remains in students' minds after they graduate constitutes the genuine substance of education. Although we have long striven to teach students as much content as possible, their authentic understanding has been far from satisfactory. Education should not be equated with the accumulation or memorization of fragmented facts; rather, it is the acquisition of intellectual insight and the internalization of productive modes of thought. This perspective also calls for profound reflection in the mathematics classroom. Therefore, "less is more" should be taken into account when implementing every well-designed curriculum, every effective lesson plan, and every advisable pedagogy practice (Bruner, 1996).

4. Prospects for Implementation and Teachers' Role

According to Tyler (1949), curriculum development begins with the establishment of objectives, and instruction is the process through which those objectives are realized. In this view, instruction constitutes the "implementation stage" of the curriculum. Planning is first undertaken systematically at the curriculum level, after which teachers translate it into practice.

Contemporary educational theory, however, emphasizes that curriculum and instruction exist in a cyclical relationship characterized by mutual feedback. The curriculum provides direction for instruction, while instructional practice, in turn, serves to verify the validity of the curriculum; the results of this process then feed back into curriculum improvement. Thus, although planning formally begins at the curriculum level, its genuine completion occurs within instruction. From a practical and implementation-oriented perspective, planning begins anew in the instructional process. By guiding instruction and being continually reconstructed through instructional practice, curriculum and instruction together form a cyclical and mutually complementary relationship (Oliva, 2009).

As School-based Curriculum Development (SBCD) is emphasized in contemporary education, teachers are seen as key agents who actively participate in curriculum planning at the school level. The curriculum does not merely exist as a written document; it is fully realized only when it is enacted in classroom instruction. Teachers are not simply executors of the national curriculum but reflective practitioners who reconstruct it by considering learners' characteristics and contextual needs. Through lesson design, the organization of learning activities, and assessment planning, teachers both implement and simultaneously reinterpret the curriculum.

Teaching is often regarded as the art of regret. Teachers make every endeavor to design their lessons carefully in advance so that they can present ideal instructional content. However, the implemented lesson can never completely align with the original plan. Just as weather forecasts attempt to predict future conditions with accuracy but ultimately remain probabilistic estimates, classroom instruction inevitably involves uncertainty. When unexpected situations arise, teachers must flexibly utilize pedagogical tact to maintain the integrity of classroom learning. Particularly, incorporating the latest insights from narrative neuroscience into mathematics curricula further amplifies this complexity. As more diverse cognitive pathways are explored and more student voices are brought into the learning process, teachers should prepare to cope with a broader set of challenges that emerge in real-time classroom interactions.

Teachers' Pedagogical Content Knowledge (PCK) enables them to anticipate common student misconceptions, select appropriate representations of mathematical concepts, and design learning tasks that correspond to students' cognitive development. When combined with narrative neuroscience, PCK informs the creation of instructional sequences that leverage contextual, narrative-based tasks to facilitate deeper understanding. In this way, teachers can implement lessons that not only present mathematical content accurately but also effectively engage students' narrative cognition, fostering meaningful knowledge construction and retention.

Future implementation of narrative neuroscience-informed mathematics curriculum design requires a renewed understanding of the teacher's role. As Theory of Mind (ToM) suggests, in actual classroom instruction, teachers must be able to "read" students' thinking, anticipate their difficulties, and construct explanations that are intelligible within students' cognitive and emotional frames. Likewise, students need to understand and internalize teachers' explanations, forms of reasoning, and narrative representations of mathematical concepts. Thus, effective mathematics instruction relies on reciprocal mental modeling between teachers and learners.

Students' potential resembles a gas, its volume expands in proportion to the space of trust, expectations, and possibilities that a teacher creates. Accordingly, the future of narrative-based mathematics curriculum design depends on teachers' ability to integrate insights from neuroscience while simultaneously sustaining high and supportive expectations for learners. When teachers skillfully orchestrate narrative, cognitive, and affective forms of mediation, they cultivate learning environments in which mathematical ideas become meaningful and accessible. Over time, the classroom becomes a flexible container that supports learners' holistic growth, allowing their potential to fill the space made available to them.

Recently, discussions on generative artificial intelligence (AI) have highlighted its potential to expand the possibilities for creating mathematics learning environments that are both intellectually rigorous and narratively meaningful. In particular, generative AI has prominent implications for the cultivation of teachers' professional development. As narrative neuroscience emphasizes the importance of contextualization, coherence, and mental simulation in mathematical understanding, AI-assisted tools can support teachers in designing instructional materials that align with these cognitive processes. Generative AI cannot replace teachers' professional judgment, however, it enables teachers to examine alternative pedagogical approaches and refine narrative scaffolds.

VI. Conclusion

This study aims to reconceptualize the mathematics curriculum through the lens of narrative neuroscience, arguing that mathematical learning is not merely an exercise in logical reasoning but a meaning-making process shaped by cognition, emotion, and context. By integrating insights from narrative theory, neuroscience, cognitive psychology, and mathematics education, this research has illuminated how narrative structures align with the brain's natural mechanisms for constructing, organizing, and retaining knowledge. In this way, narrative neuroscience offers a robust theoretical foundation for rehumanizing mathematics education and bridging the long-established divide between abstract mathematical ideas and learners' life experiences.

The study demonstrated that many long-standing difficulties in mathematical learning stem from instructional approaches that fail to resonate with how the brain processes information. Neuroscientific findings indicate that meaningful learning occurs when new ideas are anchored in intentional, emotionally coherent, and contextually grounded structures. Narrative, as a fundamental human mode of cognition, provides precisely such a structure, enabling learners to connect mathematical concepts with prior knowledge, construct relational understanding, and continuously engage in the processes of assimilation and accommodation, thereby forming durable and coherent memory networks.

By examining the interaction of narrative with mathematical reasoning, multiple intelligences, and representational development, this study argued that narrative-based instruction can enrich conceptual understanding without compromising mathematical rigor. Narrative structures can scaffold transitions from enactive experience to iconic representation and eventually to symbolic abstraction, supporting learners across diverse cognitive profiles. Moreover, narrative engagement activates neural pathways related to attention, empathy, and imagination, thereby enhancing intrinsic motivation and promoting flexible problem solving.

This research also proposed several implications for curriculum design and assessment. Instructional content should be organized around structural relationships, meaningful contexts, and opportunities for interpretive reasoning. Assessment should move beyond correctness to capture the evolving narrative processes through which learners construct understanding over time. Because mathematical comprehension develops recursively, aligned with the logic of a spiral curriculum, narrative-based assessments can trace conceptual growth across successive stages and reveal how internal meaning structures are reorganized.

Finally, the study emphasized that the successful implementation of narrative neuroscience-informed mathematics curriculum depends heavily on teachers. Teachers must act as interpreters, designers, and mediators who can translate neuroscientific insights into classroom practice. Their pedagogical content knowledge enables them to craft narrative-rich instruction, read students' thinking, and construct explanations attuned to learners' cognitive and emotional needs. As educational contexts increasingly incorporate generative AI, teachers will gain new tools to design narrative-based learning environments, but their professional judgment remains critical.

In conclusion, by integrating narrative neuroscience into curriculum development, instructional design, and assessment practice, mathematics education can become a discipline that not only fosters analytical rigor but also cultivates divergent thinking, conceptual insight, and humanistic understanding.

Future research should continue exploring concrete pedagogical models, classroom applications, and teacher empowerment programs that further operationalize narrative neuroscience, allowing mathematics education to evolve toward greater coherence with how the human brain naturally learns.

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