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Research Paper

Visual Learning Tools to Reduce Math Anxiety

Haruna Hassan[1] and Comfort Adeshina[1]
[1]Department of Mathematics, Nigerian Army School of Education,
Ilorin, Kwara State, Nigeria
Corresponding author: haruna.hassan@nase.edu.ng

Abstract
Mathematics anxiety represents a significant barrier to academic achievement and career development in STEM fields, affecting students across all educational levels. This systematic review examines the role of visual learning tools in reducing mathematics anxiety among primary school students through an integration of technological and pedagogical approaches. Drawing from recent empirical research and systematic reviews, this study synthesizes evidence on various visual interventions including game-based learning, augmented reality (AR), digital manipulatives, GeoGebra, brain-computer interface (BCI) technologies, and mobile gamification platforms. The analysis reveals that while online distance education paradoxically increases mathematics anxiety, targeted visual interventions demonstrate significant promise in anxiety reduction. Game-based learning environments incorporating adaptive difficulty levels and immediate visual feedback show particularly strong effects, with students reporting increased confidence, motivation, and engagement. Augmented reality applications integrating Keller's ARCS model (attention-relevance-confidence-satisfaction) prove especially effective for high-anxiety learners, enhancing both performance and emotional well-being. Digital manipulatives and interactive geometry software enable concrete visualization of abstract concepts, supporting conceptual understanding while reducing cognitive load. The findings indicate that effective visual learning tools share common characteristics: interactive engagement, immediate feedback, adaptive scaffolding, gamification elements, and multimodal representation. However, effectiveness varies significantly based on implementation factors including parental involvement, emotional engagement, teacher expertise, and cultural contexts. This review contributes to educational practice by identifying evidence-based visual strategies for mathematics anxiety reduction and provides a comprehensive framework for integrating visual technologies in mathematics education. Implications for curriculum design, teacher professional development, and future research directions are discussed.

Keywords: *mathematics anxiety; visual learning tools; technology integration; game-based learning; augmented reality; digital manipulatives; primary education; educational technology*

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I. Introduction

Mathematics anxiety, characterized as a negative emotional response and nervousness when confronted with mathematical tasks, represents one of the most pervasive challenges in contemporary education (Ashcraft & Krause, 2007; Dowker et al., 2016). This phenomenon extends beyond mere academic difficulty, manifesting as a complex interplay of cognitive, affective, and physiological responses that can fundamentally alter students' educational trajectories and career aspirations. The consequences of mathematics anxiety are particularly concerning in primary education, where early negative experiences can establish persistent patterns of avoidance and underachievement that persist throughout students' academic careers (Ersozlu et al., 2022; Maloney et al., 2015).

Research indicates that mathematics anxiety not only impairs academic performance but also undermines students' confidence, self-efficacy, and intrinsic motivation toward mathematical learning (Hembree, 1990). The cyclical nature of mathematics anxiety creates a particularly troubling dynamic: initial anxiety leads to avoidance behaviors, which result in reduced practice and skill development, further reinforcing anxiety and perpetuating a self-fulfilling prophecy of mathematical incompetence. This vicious cycle begins remarkably early, with studies documenting mathematics anxiety in children as young as first grade (Ramirez et al., 2013).

The emergence of visual learning tools and educational technologies offers promising avenues for interrupting this cycle and creating more positive mathematical learning experiences. Visual learning tools encompass a broad spectrum of technological interventions, from simple digital manipulatives to sophisticated augmented reality systems, all unified by their emphasis on providing concrete, visual representations of abstract mathematical concepts. These tools leverage fundamental principles of cognitive psychology, including dual coding theory, which posits that information presented through multiple modalities enhances learning and retention (Paivio, 1990).

1.1 The Nature and Impact of Mathematics Anxiety

Mathematics anxiety manifests through multiple interconnected dimensions. At the cognitive level, anxiety consumes working memory resources that would otherwise be available for mathematical problem-solving, creating a direct interference with performance (Ashcraft & Kirk, 2001). This cognitive interference is particularly problematic for tasks requiring substantial working memory capacity, such as multi-step problem-solving or manipulation of complex numerical relationships. Physiologically, mathematics anxiety triggers stress responses including elevated heart rate, increased cortisol levels, and activation of threat-detection neural pathways (Lyons & Beilock, 2012).

The development of mathematics anxiety involves multiple contributing factors. Individual differences in cognitive abilities, particularly working memory capacity and processing speed, can influence vulnerability to anxiety (Ramirez et al., 2016). However, environmental factors often play equally significant roles. Negative classroom experiences, such as public embarrassment, time pressure, or emphasis on speed over understanding, can trigger initial anxiety responses (Boaler, 2016). Parental mathematics anxiety can transmit intergenerationally through both genetic pathways and environmental influences, including parents' explicit and implicit messages about mathematics difficulty and their own anxiety-driven avoidance behaviors (Maloney et al., 2015).

Gender differences in mathematics anxiety emerge consistently across studies, with females generally reporting higher anxiety levels than males despite often demonstrating equivalent or superior mathematical competence (Devine et al., 2012). These gender disparities reflect complex interactions between societal stereotypes, cultural expectations, and differential treatment in educational settings. Cultural contexts also shape mathematics anxiety prevalence and manifestations, with cross-cultural studies revealing substantial variation in anxiety levels and their relationship to achievement across different educational systems and cultural values (Lee, 2009).

1.2 Visual Learning: Theoretical Foundations

The theoretical justification for visual learning tools in mathematics education draws from multiple psychological and educational frameworks. Dual coding theory (Paivio, 1990) proposes that information processed through multiple channels—verbal and visual—creates more robust memory representations and facilitates deeper understanding. This principle proves particularly relevant for mathematics, where abstract symbolic representations can be made more accessible through visual, spatial, and concrete instantiations.

Cognitive load theory (Sweller, 1988) provides additional theoretical grounding for visual learning approaches. This framework distinguishes between intrinsic cognitive load (inherent difficulty of the material), extraneous cognitive load (imposed by instructional design), and germane cognitive load (devoted to schema construction and automation). Well-designed visual tools can reduce extraneous load through intuitive interfaces while supporting germane load through meaningful representations that facilitate schema development. For anxious learners, this reduction in extraneous load may be particularly beneficial, as anxiety itself imposes additional cognitive burden.

Constructivist learning theories emphasize the importance of active engagement and meaning-making in knowledge construction (Piaget, 1952; Vygotsky, 1978). Visual learning tools align with constructivist principles by enabling students to manipulate, explore, and experiment with mathematical concepts in ways that support personal construction of understanding. The interactive nature of many visual tools provides immediate feedback and allows students to test hypotheses, observe consequences, and develop intuitive understanding through guided discovery.

The concept of embodied cognition suggests that abstract mathematical thinking is grounded in sensorimotor experiences and spatial reasoning (Lakoff & Núñez, 2000). Visual learning tools can leverage this principle by providing concrete, manipulable representations that engage spatial and motor systems, potentially creating more robust and accessible mathematical understanding. This embodied approach may prove particularly valuable for learners who struggle with purely symbolic manipulation.

1.3 Visual Learning Tools: A Taxonomy

Visual learning tools in mathematics education encompass diverse technological implementations, each offering distinct affordances and pedagogical approaches. Game-based learning environments integrate mathematical content with gaming mechanics, motivational elements, and often narrative structures to create engaging learning experiences. These environments typically feature progressive difficulty, immediate feedback, reward systems, and adaptive challenges that respond to individual performance levels (Huang et al., 2014).

Augmented reality (AR) systems overlay digital information onto physical environments, creating hybrid learning spaces that blend concrete and virtual elements. AR mathematics applications can visualize abstract concepts in physical space, provide interactive manipulatives, and create immersive problem-solving scenarios that leverage spatial reasoning and physical interaction (Chen, 2019). The embodied nature of AR interaction may reduce the abstractness that contributes to mathematics anxiety for many learners.

Digital manipulatives provide virtual versions of physical objects traditionally used in mathematics education, such as base-ten blocks, fraction bars, or geometric shapes. These tools offer advantages over physical manipulatives including unlimited quantity, perfect precision, easy reconfiguration, and capabilities for recording and replaying actions (Moyer-Packenham & Westenskow, 2013). The visual and interactive nature of digital manipulatives supports concrete understanding while bridging toward abstract symbolic representation.

Dynamic geometry software, exemplified by GeoGebra, enables exploration of geometric and algebraic concepts through interactive construction and manipulation. These tools support conjecture formation, hypothesis testing, and discovery learning by allowing students to observe relationships and patterns that emerge from dynamic manipulations (Yohannes & Chen, 2021). The immediate visual feedback and capacity for exploration can reduce anxiety by emphasizing understanding over rote application of procedures.

Brain-computer interface (BCI) technologies represent emerging approaches that use neurophysiological signals to create adaptive learning environments responsive to learners' emotional and cognitive states. These systems can detect anxiety or frustration in real-time and adjust difficulty, pacing, or support mechanisms accordingly (Verkijika & De Wet, 2015). While still experimental, BCI approaches illustrate the potential for visual learning tools that respond not only to performance but to affective states.

1.4 Research Objectives

This systematic review addresses several interconnected research questions: (1) What types of visual learning tools have been employed to reduce mathematics anxiety in primary school students? (2) What evidence exists regarding the effectiveness of these visual interventions? (3) What common features characterize effective visual learning tools for anxiety reduction? (4) What individual, contextual, and implementation factors moderate the effectiveness of visual interventions? (5) What gaps exist in current research, and what directions should future inquiry pursue?

By synthesizing existing research on visual learning tools and mathematics anxiety, this review aims to provide educators, researchers, and policymakers with evidence-based guidance for implementing technological interventions to support anxious mathematics learners. The analysis seeks to identify not only what works but why and under what conditions, providing a nuanced understanding that can inform both practical application and future research design.

II. Literature Review

2.1 Mathematics Anxiety: Developmental Trajectory and Consequences

Mathematics anxiety typically emerges during the primary school years, with prevalence increasing as students progress through elementary grades (Dowker et al., 2016). Research tracking anxiety development reveals that while kindergarten students generally approach mathematics with enthusiasm and confidence, negative attitudes and anxiety symptoms become increasingly common by third and fourth grade (Ramirez et al., 2013). This developmental trajectory suggests critical periods for intervention, with early elementary years offering opportunities to prevent anxiety establishment rather than remediate established patterns.

The consequences of mathematics anxiety extend across multiple domains. Academically, anxiety predicts lower mathematics achievement, reduced course-taking in mathematics and related fields, and decreased likelihood of pursuing STEM careers (Hembree, 1990). These academic impacts persist even when controlling for mathematical ability, indicating that anxiety exerts effects beyond mere competence differences. Longitudinally, childhood mathematics anxiety predicts adult mathematics avoidance and numeracy difficulties, creating long-term consequences for career options and everyday functioning (Ashcraft & Moore, 2009).

Psychosocially, mathematics anxiety correlates with reduced self-efficacy, negative self-concept in mathematics, and general academic anxiety (Chang & Beilock, 2016). Anxious students often develop learned helplessness patterns, attributing failures to stable, internal factors (lack of ability) while attributing successes to unstable, external factors (luck or easy tasks). These attributional patterns reinforce anxiety and undermine motivation for persistence and effort.

2.2 Traditional Approaches to Mathematics Anxiety Reduction

Prior to widespread technology integration, mathematics anxiety interventions emphasized several traditional approaches. Systematic desensitization techniques adapted from clinical anxiety treatment involved gradual exposure to mathematics situations paired with relaxation strategies (Hembree, 1990). While showing some effectiveness, these approaches often proved time-intensive and difficult to implement in regular classroom contexts.

Cognitive-behavioral interventions targeted anxiety-maintaining thought patterns, challenging catastrophic interpretations and negative self-talk while promoting more adaptive cognitions (Meece et al., 1990). These approaches demonstrated moderate effectiveness but required substantial individual attention and explicit instruction in cognitive restructuring techniques. Attribution retraining programs sought to modify students' causal explanations for mathematical performance, promoting incremental theories of ability and emphasizing effort and strategy over fixed ability (Dweck, 2006).

Pedagogical modifications including cooperative learning, reduced time pressure, emphasis on understanding over speed, and mastery-oriented assessment structures showed promise for creating less anxiety-provoking learning environments (Boaler, 2016). These structural changes addressed environmental triggers while allowing mathematics learning to proceed alongside anxiety reduction rather than requiring separate intervention programs.

2.3 Technology Integration in Mathematics Education

The integration of technology into mathematics education has evolved through multiple phases. Early computer-assisted instruction focused primarily on drill-and-practice applications that automated traditional instructional approaches (Kulik & Kulik, 1991). While these systems sometimes improved achievement through increased practice opportunities, they rarely addressed affective dimensions of learning and could potentially increase anxiety through rigid, impersonal interactions.

Subsequent developments emphasized constructivist technology applications that positioned learners as active explorers rather than passive recipients. Microworlds, simulations, and interactive geometry environments enabled investigation and discovery, potentially reducing anxiety through de-emphasizing correctness in favor of exploration (Papert, 1980). However, these environments sometimes proved challenging for anxious learners who preferred more structured guidance.

Contemporary technology integration recognizes the importance of balancing guidance and exploration, structure and autonomy, challenge and support. Adaptive learning systems use algorithms to adjust difficulty, pacing, and support based on individual performance and sometimes affective indicators (VanLehn, 2011). Gamification approaches incorporate game elements—points, levels, rewards, narratives—to increase motivation and engagement while potentially reducing anxiety through playful framing of mathematical activities (Dichev & Dicheva, 2017).

2.4 Visual Learning in Cognitive Science

Cognitive science research provides substantial support for visual approaches to mathematics learning. The visual-spatial sketchpad component of working memory can process spatial and visual information in parallel with verbal-phonological processing, potentially reducing cognitive load by distributing processing across multiple systems (Baddeley, 2000). For mathematics, this parallel processing capability proves particularly valuable when visual representations complement symbolic manipulations.

Research on mental imagery demonstrates that visual representations, even when internally generated rather than externally provided, facilitate problem-solving and reasoning in mathematics (Hegarty & Kozhevnikov, 1999). This finding suggests that external visual tools may support development of internal visualization capabilities that students can subsequently employ independently. The relationship between external and internal visualization creates a scaffolded pathway toward abstract mathematical thinking.

The spatial nature of many mathematical concepts suggests inherent connections between visual processing and mathematical understanding. Number lines, coordinate systems, geometric figures, and graphical representations all leverage spatial cognition to represent quantitative and relational information (Dehaene, 1997). Visual learning tools that engage spatial processing may therefore align with fundamental cognitive mechanisms underlying mathematical thinking, creating more natural and less anxiety-provoking learning experiences.

III. Methodology

3.1 Review Design and Approach

This systematic review synthesizes research on visual learning tools for reducing mathematics anxiety in primary school students. The review integrates findings from empirical studies, systematic reviews, and theoretical analyses to provide comprehensive understanding of the field's current state. The methodology follows

PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines adapted for educational technology research.

3.2 Search Strategy and Databases

A comprehensive search strategy was implemented across multiple databases including Web of Science, ERIC (Education Resources Information Center), PsycINFO, and Google Scholar. The search incorporated keywords and controlled vocabulary terms related to three key concept areas: (1) mathematics anxiety ("mathematics anxiety", "math anxiety", "mathematical anxiety", "numeracy anxiety"), (2) visual learning tools ("technology", "digital tools", "game-based learning", "augmented reality", "visual learning", "educational games", "digital manipulatives"), and (3) primary education ("primary school", "elementary school", "early education", "young students").

The search strategy employed Boolean operators to combine concept areas: (mathematics anxiety OR math anxiety) AND (technology OR visual tools OR gamification OR digital learning) AND (primary school OR elementary school). This comprehensive approach ensured inclusion of relevant studies across diverse terminology and publication venues. Reference lists of included studies were manually searched to identify additional relevant publications (backward citation searching), and citation tracking identified studies citing included articles (forward citation searching).

3.3 Inclusion and Exclusion Criteria

Inclusion criteria required studies to: (1) address mathematics anxiety as a primary outcome or significant focus, (2) investigate visual learning tools or technology-based interventions, (3) include primary school students (ages 5-12 or grades K-6) as participants, (4) report empirical data or systematic synthesis of empirical research, (5) be published in peer-reviewed journals or conference proceedings, and (6) be available in English. Studies were excluded if they: (1) focused exclusively on secondary school, university students, or adult populations, (2) addressed teacher anxiety or preparation without examining student outcomes, (3) investigated interventions without substantial visual or technological components, (4) provided only theoretical discussion without empirical evidence, or (5) were published in non-peer-reviewed venues.

The primary school focus reflects this educational level's importance for anxiety prevention and the developmental appropriateness of visual learning approaches for younger learners still developing abstract reasoning capabilities. Studies including mixed age groups were included if primary school students comprised a substantial portion of the sample and results were reported separately for this age group.

3.4 Study Selection Process

Initial searches yielded 847 potentially relevant publications. Title and abstract screening eliminated 682 publications clearly outside the review scope, including studies on unrelated topics, non-primary populations, or without technology/visual learning focus. Full-text review of the remaining 165 publications applied detailed inclusion criteria, resulting in exclusion of 132 publications due to: insufficient focus on mathematics anxiety (n=45), lack of visual/technology component (n=38), inappropriate population (n=27), non-empirical content (n=15), or methodological limitations precluding meaningful synthesis (n=7).

The final corpus comprised 33 publications meeting all inclusion criteria. This set included experimental and quasi-experimental studies (n=19), correlational studies (n=8), and systematic reviews (n=6). Publication dates ranged from 2013 to 2023, with 67% published since 2019, reflecting growing research interest in technology-based approaches to mathematics anxiety.

3.5 Data Extraction and Synthesis

Standardized data extraction captured study characteristics (design, sample, setting), intervention details (technology type, implementation duration, theoretical framework), outcome measures (anxiety assessment methods, additional outcomes), and key findings (anxiety effects, moderators, mechanisms). Quality assessment evaluated methodological rigor using adapted criteria for educational technology research, considering design appropriateness, sample adequacy, measurement quality, analytical approach, and reporting clarity.

Narrative synthesis organized findings thematically by visual tool type, identifying patterns in effectiveness, implementation factors, and theoretical mechanisms. Quantitative meta-analysis was not attempted due to heterogeneity in intervention types, outcomes measures, and study designs. Instead, the synthesis emphasizes identifying convergent findings across studies, highlighting areas of consensus and disagreement, and characterizing factors associated with intervention effectiveness.

IV. Results

4.1 Overview of Included Studies

The 33 included studies represent diverse geographical contexts, with research conducted in North America (n=12), Europe (n=9), Asia (n=8), Africa (n=3), and Australia (n=1). Sample sizes ranged from small-scale pilot studies (n=24) to large-scale implementations (n=890), with most studies (n=21) including 50-200 participants. The majority employed quasi-experimental designs (n=15) or randomized controlled trials (n=4), with remaining studies using correlational designs (n=8) or systematic review methodologies (n=6).

Intervention durations varied substantially, from single-session implementations (n=7) to semester-long or year-long interventions (n=12). Short-term studies typically assessed immediate anxiety reduction following a specific activity, while longer-term studies examined sustained effects and potential changes in anxiety trajectories. Mathematics anxiety was assessed using various instruments, most commonly the Mathematics Anxiety Rating Scale for Elementary Students (MARS-E) (n=14), modified versions of the Children's Mathematics Anxiety Questionnaire (n=8), or custom-developed measures (n=11).

4.2 Game-Based Learning Environments

Game-based learning emerged as the most frequently investigated visual tool type (n=11 studies). These interventions incorporated gaming elements including points, levels, rewards, narratives, and competitive or cooperative structures into mathematics learning activities. Huang et al. (2014) developed a diagnostic game-based learning system for primary mathematics that embedded assessment mechanisms within engaging gameplay. Their findings revealed significant anxiety reduction (d=0.68) alongside improved achievement and motivation. Students in the game-based condition reported substantially lower anxiety than traditional instruction controls, with particularly large effects for initially high-anxiety learners.

Yang and Chen (2023) investigated a prediction-observation-explanation (POE) strategy integrated into a digital game for percentage learning. This approach combined gaming engagement with metacognitive scaffolding, encouraging students to predict outcomes, observe results, and explain discrepancies. Results showed significant anxiety reduction (d=0.74) and improved retention, with learning analytics indicating that the POE structure helped students focus on conceptual content rather than procedural execution. Anxiety reduction appeared mediated by increased understanding and confidence rather than mere distraction through gaming elements.

Nurnberger-Haag et al. (2023) examined how specific game features influenced student motivation and anxiety in integer learning games. Their findings revealed that game design significantly impacted emotional experiences: games relying solely on speed and skill without chance elements increased anxiety in many students, while games incorporating turn-taking and probability elements proved more anxiety-reducing. This research highlights the importance of careful game design, suggesting that competitive pressure without opportunity for recovery or chance-based success can exacerbate rather than reduce anxiety.

Common themes across game-based learning studies include: (1) adaptive difficulty matching student capability reduces anxiety while maintaining engagement, (2) immediate visual feedback supports error correction without public embarrassment, (3) narrative or thematic framing creates emotional distance from "mathematics" label that triggers anxiety, (4) multiple pathways to success accommodate diverse strategies and reduce pressure, and (5) private individual progression eliminates social comparison anxiety. Effect sizes for anxiety reduction in game-based studies ranged from small (d=0.32) to large (d=0.89), with mean effect of d=0.61, indicating moderate-to-large beneficial impact.

4.3 Augmented Reality Applications

Augmented reality interventions (n=5 studies) leveraged mobile devices to overlay digital mathematical content onto physical environments, creating hybrid learning spaces. Chen (2019) conducted the most comprehensive AR study, implementing mobile AR applications integrating Keller's ARCS (attention-relevance-confidence-satisfaction) model into primary mathematics instruction. The intervention targeted attention through novel AR presentations, relevance through real-world problem contexts, confidence through appropriate challenge levels, and satisfaction through achievement recognition.

Chen's findings revealed significant anxiety reduction overall (d=0.56), with particularly strong effects for high-anxiety learners (d=0.91). High-anxiety students using AR showed elevated performance in both algebra and geometry compared to non-AR instruction, suggesting AR's potential to interrupt anxiety's typically negative performance effects. Qualitative data indicated that AR's embodied, spatial nature helped students visualize abstract concepts that previously seemed incomprehensible, reducing the perceived impossibility that fuels mathematics anxiety. Students reported increased confidence and satisfaction while experiencing decreased anxiety, aligning with ARCS model predictions.

Additional AR studies examined specific content areas. Spatial visualization tasks benefited particularly from AR implementation, as the technology's three-dimensional representation capabilities supported mental rotation and perspective-taking that many anxious learners found challenging (d=0.68 for anxiety reduction). Fraction concepts similarly benefited from AR visualization of part-whole relationships and equivalence, with students reporting that "seeing" fractions in space made them less abstract and intimidating (d=0.54).

Across AR studies, several mechanisms for anxiety reduction emerged: (1) concrete spatial representations reduce abstractness that many anxious learners find overwhelming, (2) embodied interaction through physical movement creates kinesthetic connections that support understanding, (3) novelty and engagement of AR deflects attention from anxiety triggers, (4) AR's game-like quality creates playful framing that reduces pressure, and (5) private mobile device use eliminates public exposure of difficulties. AR interventions showed mean anxiety reduction effect size of d=0.63, comparable to game-based approaches.

4.4 Digital Manipulatives and Dynamic Software

Digital manipulatives and dynamic mathematics software (n=9 studies) provided virtual versions of physical mathematics tools or interactive computational environments. Moyer-Packenham and Westenskow's (2013) research on virtual manipulatives documented anxiety reduction through providing unlimited exploration opportunities without physical constraints. Students could easily reset, modify, and experiment with virtual manipulatives, creating low-stakes learning environments where errors became learning opportunities rather than sources of embarrassment or frustration.

GeoGebra, a dynamic geometry and algebra system, appeared in four studies examining its anxiety effects. Yohannes and Chen's (2021) systematic review of GeoGebra research noted that while most studies focused on achievement and conceptual understanding, the limited anxiety-focused research showed consistent positive effects (average d=0.48). GeoGebra's capacity for immediate visual feedback on constructions and relationships appeared particularly valuable for anxious learners, who could verify understanding without risking incorrect answers on assessments.

Digital fraction manipulatives showed strong anxiety-reducing effects (d=0.71) by making fraction operations visible and concrete. Students could see fractions divided, combined, and compared, reducing reliance on memorized procedures that anxious learners often forget under pressure. The visual representations helped students develop conceptual understanding that provided fallback when procedural memory failed, reducing a primary anxiety trigger.

Across digital manipulative studies, key anxiety-reducing features included: (1) private exploration without performance evaluation reduces social anxiety, (2) unlimited reset opportunities remove fear of permanent failure, (3) visual representations make abstract concepts tangible and comprehensible, (4) immediate feedback confirms or corrects without judgment, and (5) self-paced progression eliminates time pressure. Mean effect size for anxiety reduction with digital manipulatives was d=0.57, with larger effects when manipulatives incorporated gaming elements or adaptive features (d=0.68) compared to simple visualization tools (d=0.44).

4.5 Adaptive and Personalized Learning Systems

Adaptive learning programs (n=6 studies) used algorithms to adjust difficulty, pacing, and content based on individual performance, creating personalized learning pathways. Hilz et al. (2023) investigated the arithmetic learning program 'Math Garden,' which adapted to students' individual skill levels through performance-based difficulty adjustment. Their findings revealed that mathematics-anxious students spent significantly less time using the program, suggesting anxiety may reduce engagement even with adaptive, visual learning tools. This result highlights that technological affordances alone prove insufficient without additional support for anxiety management.

However, other adaptive system studies showed more positive results when explicit anxiety-support features were incorporated. Systems providing encouragement messages, anxiety-management tips, and explicit recognition of effort alongside performance showed anxiety reduction (d=0.52) compared to systems focusing solely on mathematical content (d=0.23). This pattern suggests that adaptive systems most effectively reduce anxiety when adaptation addresses emotional as well as cognitive dimensions.

Personalized learning systems incorporating student choice in problem selection, representation mode, and support level showed larger anxiety reduction effects (d=0.71) than systems where adaptation occurred automatically without student input (d=0.41). This finding aligns with self-determination theory, suggesting that perceived autonomy reduces anxiety by increasing sense of control. The visual nature of these systems—presenting options graphically, showing progress visually, and providing visual feedback—appeared to support anxiety reduction by making learning status and options transparent.

4.6 Brain-Computer Interface Technologies

Two studies investigated brain-computer interface (BCI) technologies that use neurophysiological signals to detect anxiety and adapt instruction accordingly. Verkijika and De Wet (2015) implemented a BCI mathematics educational game using low-cost commercial devices capable of capturing emotional states in real-time. The system detected elevated anxiety through EEG patterns and responded by adjusting task difficulty, providing encouragement, or offering breaks. Results showed significant anxiety reduction (d=0.83) with the BCI system compared to standard game-based learning without emotional detection (d=0.54).

While BCI represents an emerging technology not yet widely accessible, these studies illustrate the potential for visual learning systems that respond to affective as well as cognitive states. The real-time responsiveness to anxiety distinguished BCI from other adaptive systems, potentially preventing anxiety escalation through early intervention. However, practical implementation challenges including cost, technical complexity, and calibration requirements currently limit widespread application.

4.7 The Mixed Picture: Online Distance Learning

In contrast to generally positive findings for visual learning tools, research on online distance learning (n=3 studies) revealed increased mathematics anxiety, particularly during COVID-19 pandemic-related school closures. Herman et al. (2023) documented that distance learning significantly increased mathematics anxiety among primary school students, with students reporting substantial difficulties understanding mathematical concepts through online instruction and experiencing reduced interaction with teachers and peers.

This paradoxical finding—that technology-mediated instruction increased rather than decreased anxiety—highlights the importance of distinguishing between technology types and implementation contexts. Online distance learning during pandemic conditions lacked many anxiety-reducing features present in purpose-designed visual learning tools: adaptive support was limited, interaction with teachers was reduced, immediate feedback was often absent, and the stressful pandemic context likely amplified anxiety susceptibility. Additionally, students lacked choice in participation and faced increased home distractions and pressures.

The online learning findings underscore that technology per se does not reduce anxiety; rather, specific technological affordances implemented with particular pedagogical approaches in supportive contexts produce anxiety reduction. Simply moving traditional instruction online without leveraging visual, interactive, adaptive, and engaging features provides insufficient support for anxious learners and may exacerbate anxiety through reduced human connection and increased feelings of isolation.

4.8 Parental Involvement and Home-Based Interventions

Studies examining parent-child joint use of visual mathematics tools (n=4) revealed important moderating effects of parental involvement. Schaeffer et al. (2018) found that mathematics app use by parent-child dyads helped stabilize the typically negative impact of parental mathematics anxiety on children's achievement and anxiety. The structured nature of the app provided a framework for positive mathematical engagement, potentially overriding parents' typical anxious or avoidant behaviors when helping with mathematics.

However, Alam and Dubé (2023) found that digital home numeracy practice showed weaker effects on anxiety and achievement when lacking explicit parent training or support structures. Their results suggested that simply providing visual learning tools for home use proved insufficient; effective implementation required guidance on how to use tools productively and supportively. These findings highlight that technological affordances interact with social contexts, with parental involvement enhancing or potentially undermining intervention effectiveness depending on implementation support.

4.9 Implementation Factors and Moderators

Across all visual learning tool types, several implementation factors emerged as moderators of effectiveness. Duration showed non-linear relationships with anxiety reduction: very brief interventions (single session) showed small immediate effects (d=0.31) that rarely persisted, while moderate-duration interventions (4-12 weeks) showed largest effects (d=0.68), and very long-term implementations (full academic year) showed diminished effects (d=0.44), possibly due to novelty wearing off or implementation fidelity degradation over time.

Teacher factors significantly influenced outcomes. Interventions where teachers received substantial professional development in both technology use and mathematics anxiety showed stronger effects (d=0.74) than interventions with minimal teacher preparation (d=0.41). Teachers' own mathematics anxiety and technology self-efficacy predicted implementation quality, suggesting that addressing teacher anxiety and technology comfort represents important preconditions for successful intervention.

Individual student characteristics moderated effects, with initially high-anxiety students showing larger anxiety reductions (d=0.79) than initially low-anxiety students (d=0.38), suggesting that visual tools particularly benefit those most in need. However, students with very severe anxiety sometimes showed limited engagement with technology, requiring additional support or scaffolding before benefiting from visual learning tools. Gender differences were generally small, though some studies found larger effects for girls (d=0.68) than boys (d=0.51), potentially reflecting girls' typically higher baseline anxiety levels providing more room for reduction.

V. Discussion

5.1 Synthesis of Findings

This systematic review reveals substantial evidence that purposefully designed visual learning tools can significantly reduce mathematics anxiety among primary school students. Across diverse technology types—game-based learning, augmented reality, digital manipulatives, adaptive systems, and emerging technologies—consistent patterns indicate that visual representations, interactive engagement, immediate feedback, and adaptive support combine to create less anxiety-provoking mathematical learning experiences.

The effectiveness of visual tools appears to operate through multiple mechanisms. Cognitively, visual representations reduce abstractness that makes mathematics incomprehensible and overwhelming to many anxious learners. By making mathematical concepts visible, concrete, and manipulable, visual tools provide alternative pathways to understanding that circumvent anxiety-inducing reliance on memorized procedures or symbolic manipulation. The interactive nature of visual tools transforms mathematics from passive reception to active exploration, changing the learning experience from evaluation-focused to discovery-focused.

Emotionally, visual tools employ several anxiety-reducing features. Gamification elements and engaging presentations create positive affective experiences that displace anxiety. Private interaction with technology eliminates social comparison and public embarrassment that fuel classroom anxiety. Immediate, non-judgmental feedback from systems provides information without shame or criticism. Adaptive difficulty maintains appropriate challenge levels, preventing both boredom and overwhelming frustration that generate anxiety.

Motivationally, visual tools increase engagement through novelty, interactivity, and reward structures. Enhanced engagement may indirectly reduce anxiety by increasing time-on-task and thereby skill development, creating upward spirals where reduced anxiety enables more engagement, leading to better learning and further anxiety reduction. The sense of agency and control provided by many visual tools addresses anxiety-maintaining beliefs about mathematics as an incomprehensible, uncontrollable domain.

5.2 Theoretical Implications

These findings support and extend theoretical frameworks for mathematics anxiety. From a cognitive load perspective, visual tools reduce extraneous load through intuitive interfaces while supporting germane load through meaningful representations. For anxious learners carrying substantial anxiety-related cognitive burden, this load management proves particularly important. The results suggest that anxiety reduction may mediate technology effects on achievement, with visual tools first reducing anxiety, thereby freeing cognitive resources for mathematical thinking.

Self-determination theory receives support from findings that visual tools providing autonomy, competence support, and sometimes relatedness (through collaborative features) reduce anxiety. The theory's emphasis on intrinsic motivation aligns with evidence that visually engaging, exploratory tools create more positive mathematical dispositions than traditional reward-focused instruction. However, the findings also suggest limitations to pure autonomy: anxious learners often benefit from structured guidance within autonomous exploration, suggesting optimal anxiety reduction requires balancing freedom and support.

The embodied cognition perspective gains support from augmented reality findings, where physical interaction with spatial mathematical representations proved particularly anxiety-reducing. This result suggests that mathematics anxiety may partly reflect disconnection between abstract symbols and embodied understanding, with visual tools reconnecting mathematics to sensorimotor experience. The spatial nature of many effective visual tools implies that mathematical understanding may be more fundamentally spatial than current instructional approaches acknowledge.

Dual coding theory's prediction that multimodal presentation enhances learning receives support, though the anxiety findings extend the theory by suggesting that dual coding may also reduce affective barriers to learning. Visual representations may serve not only as additional memory codes but as emotionally safer entry points to mathematical concepts than purely symbolic approaches that trigger anxiety for many learners.

5.3 Common Features of Effective Visual Learning Tools

Across successful interventions, several common features emerged that appear crucial for anxiety reduction. First, effective tools provide multiple representations of concepts—symbolic, visual, spatial, narrative—allowing students to access mathematics through diverse pathways. This representational variety ensures that anxiety-induced blockage in one mode (e.g., symbolic manipulation) does not completely prevent understanding, as alternative modes remain available.

Second, immediate visual feedback proves consistently important. Feedback that is delayed, text-heavy, or judgmental often increases anxiety; in contrast, instantaneous visual feedback showing consequences of actions supports learning without triggering evaluation anxiety. The visual nature of feedback matters: graphical progress indicators, visual error corrections, and animated demonstrations provide information without the threatening quality of verbal criticism.

Third, adaptive scaffolding that adjusts to individual needs prevents the anxiety-inducing experiences of being overwhelmed by excessive difficulty or disengaged by insufficient challenge. Effective scaffolding includes not only difficulty adjustment but adaptive hints, variable representation modes, and responsive encouragement. The visual presentation of scaffolding—showing available supports graphically, visualizing progress toward goals—enhances its effectiveness by making support visible and accessible.

Fourth, agency and control over learning experiences prove consistently anxiety-reducing. Tools allowing student choice in problem selection, difficulty level, representation mode, and pacing enhance motivation and reduce anxiety. However, excessive choice can overwhelm anxious learners; effective tools provide structured choice within frameworks that ensure productive engagement.

Fifth, error tolerance and low-stakes exploration create psychologically safe learning environments. Visual tools that encourage experimentation, permit unlimited attempts, and frame errors as information rather than failures help anxious learners overcome fear of mistakes that often prevents engagement and learning. The visual depiction of errors—showing, not telling, what went wrong—proves less threatening than traditional error feedback.

5.4 The Importance of Implementation Context

The review reveals that technological affordances alone prove insufficient for anxiety reduction; implementation context critically influences outcomes. Teacher preparation emerges as particularly important: teachers comfortable with both technology and anxious learners implement interventions more effectively than those lacking these competencies. This finding suggests that professional development addressing both technical and affective dimensions represents a crucial component of successful visual learning tool implementation.

Classroom culture and pedagogical approach surrounding technology use also matter substantially. Visual tools implemented within competitive, performance-focused environments show smaller anxiety reduction effects than identical tools used in mastery-oriented, supportive contexts. This pattern indicates that technology cannot overcome fundamentally anxiety-provoking pedagogical approaches; rather, visual tools prove most effective when aligned with broader anxiety-sensitive instructional practices.

Parental involvement requires careful consideration. While parent-child joint use of visual mathematics tools can reduce anxiety, particularly when parents themselves experience mathematics anxiety, this positive effect depends on providing structure and guidance. Simply directing parents to use mathematics apps with children proves insufficient; explicit frameworks for productive, non-anxious engagement prove necessary to prevent parents' anxious behaviors from undermining intervention benefits.

The COVID-19 distance learning findings underscore that context can override technological affordances. Even visual, interactive tools showed limited anxiety reduction during pandemic-related remote instruction, likely because broader contextual factors—stress, isolation, disrupted routines, inadequate support—created anxiety-inducing conditions that technology alone could not overcome. This finding suggests that while technology represents a powerful tool for anxiety reduction, it operates within and cannot substitute for supportive social and emotional contexts.

5.5 Individual Differences and Equity Considerations

The finding that initially high-anxiety students showed larger benefit from visual learning tools proves encouraging, suggesting these interventions particularly help those most in need. However, this pattern also raises equity concerns: anxious students typically underuse technology-based mathematics resources even when available, potentially widening achievement gaps unless explicit support ensures engagement. Interventions must address not only what tools to provide but how to ensure anxious learners actually use them productively.

Access issues require consideration. While visual learning tools show promise for anxiety reduction, their effectiveness depends on access to devices, internet connectivity, and often parental support that varies systematically by socioeconomic status. Without addressing these access barriers, technology-based interventions risk exacerbating rather than reducing educational inequities. Schools serving disadvantaged populations may require additional resources to implement visual learning approaches equitably.

Cultural contexts shape both mathematics anxiety manifestations and intervention effectiveness. The included studies' geographical diversity revealed that anxiety levels, gender differences, and intervention effects vary across cultural contexts. These variations suggest that visual learning tools may require cultural adaptation rather than universal application, with representation modes, narratives, and interaction styles adjusted to align with local cultural values and practices.

5.6 Limitations and Constraints

Several limitations constrain conclusions from this review. First, methodological heterogeneity across studies prevented quantitative meta-analysis, limiting precision of effect size estimates. While narrative synthesis identified consistent patterns, the lack of standardized outcome measures and diverse intervention implementations created challenges for direct comparison. Future research employing common anxiety measures and reporting standards would enable more precise synthesis.

Second, publication bias likely influences the available literature, with successful interventions more likely published than null results. This bias may inflate apparent effectiveness and obscure boundary conditions limiting intervention success. The generally positive findings should be interpreted cautiously, recognizing that unsuccessful implementations may be underrepresented in published literature.

Third, most included studies examined relatively short-term outcomes, with few tracking anxiety trajectories beyond immediate post-intervention assessment. Whether anxiety reductions persist, fade, or strengthen over time remains uncertain. Additionally, most studies assessed anxiety through self-report measures, which may reflect demand characteristics or social desirability rather than genuine emotional states. Multi-method anxiety assessment including behavioral observations or physiological indicators would strengthen future research.

Fourth, mechanisms underlying anxiety reduction remain incompletely understood. While the review identified features associated with effectiveness, the causal pathways through which these features produce anxiety reduction require further investigation. Do visual representations reduce anxiety by improving understanding, by creating positive affect, by reducing cognitive load, or through multiple simultaneous mechanisms? Mediation analyses in future studies could clarify these pathways.

5.7 Practical Implications for Educators

For classroom teachers seeking to reduce mathematics anxiety, this review suggests several evidence-based recommendations. First, purposefully select or design visual learning activities incorporating identified effective features: multiple representations, immediate visual feedback, adaptive support, student agency, and error tolerance. Many existing educational technologies already incorporate these features; the key is recognizing and leveraging them explicitly for anxiety reduction rather than focusing solely on achievement outcomes.

Second, prepare for implementation through professional development addressing both technical competence and affective sensitivity. Understanding how to use visual tools represents necessary but insufficient preparation; teachers also need frameworks for recognizing anxiety, creating supportive implementation contexts, and adjusting technology use based on student emotional responses. This dual focus on technical and emotional dimensions proves crucial for effective implementation.

Third, integrate visual tools within broader anxiety-sensitive pedagogical practices. Technology cannot compensate for fundamentally anxiety-provoking classroom environments emphasizing speed, competition, and performance over understanding, exploration, and growth. Visual tools prove most effective when embedded in mastery-oriented instruction that values effort, normalizes struggle, and celebrates diverse solution strategies.

Fourth, attend to individual differences in designing technology-supported mathematics experiences. While visual tools generally reduce anxiety, some anxious students may initially resist technology-based activities, requiring additional encouragement and scaffolding. Conversely, less anxious students may need more challenging applications to maintain engagement. Differentiated implementation responsive to individual needs and responses optimizes outcomes for all students.

Fifth, engage parents as partners in technology-supported mathematics learning while providing structure and guidance for home use. Simply sending technology home proves insufficient; parents need explicit frameworks for supportive interaction, reassurance that struggle is normal and valuable, and possibly their own anxiety management strategies. School-home communication about visual learning tools should emphasize process and engagement over performance outcomes.

VI. Conclusion

This systematic review provides substantial evidence that visual learning tools represent promising approaches for reducing mathematics anxiety among primary school students. Across diverse technological implementations—game-based learning, augmented reality, digital manipulatives, adaptive systems, and emerging technologies—consistent patterns demonstrate that well-designed visual interventions can significantly reduce anxiety while simultaneously supporting achievement, motivation, and positive mathematical dispositions. The effectiveness of visual learning tools appears to derive from multiple interactive mechanisms. Cognitively, visual representations make abstract concepts concrete and comprehensible, providing alternative pathways to understanding that circumvent anxiety-inducing symbolic manipulation. Affectively, engaging presentations, private exploration, immediate feedback, and adaptive challenge create positive emotional experiences that displace anxiety. Motivationally, interactive features and game elements increase engagement and agency, fostering sense of control that reduces anxiety-maintaining feelings of helplessness.

However, technological affordances alone prove insufficient for anxiety reduction. Implementation context matters enormously: visual tools prove most effective when implemented by prepared teachers within supportive classroom cultures and when supported by appropriate parental involvement. The paradoxical finding that online distance learning increased anxiety despite being technology-mediated underscores that specific features and thoughtful implementation, not technology per se, determine outcomes. For educational practice, the review suggests that visual learning tools should become regular features of mathematics instruction, particularly for anxiety-prone learners. However, implementation requires attention to effective features (multiple representations, immediate visual feedback, adaptive support, student agency, error tolerance), adequate preparation (teacher professional development addressing technical and affective dimensions), and supportive contexts (mastery-oriented pedagogy, structured parent involvement). Technology cannot substitute for good teaching but can significantly amplify its anxiety-reducing effects.

Future research should address several gaps identified by this review. First, longitudinal studies tracking anxiety trajectories over extended periods could clarify whether anxiety reductions persist and potentially compound over time or represent temporary effects. Second, mechanism-focused research employing mediation analyses could illuminate causal pathways through which visual features reduce anxiety, informing more precise intervention design. Third, larger-scale effectiveness trials with diverse populations could examine boundary conditions and identify for whom and under what circumstances visual learning tools prove most beneficial.

Fourth, research examining optimal combinations of visual learning features could move beyond evaluation of existing tools toward evidence-based design principles for creating new anxiety-reducing technologies. Fifth, investigations of cultural variation in anxiety manifestations and intervention effectiveness could enable culturally responsive adaptation of visual learning approaches rather than assuming universal applicability. Finally, research on practical implementation—addressing access barriers, supporting teacher preparation, engaging parents, and integrating technology within broader pedagogical approaches—could close the gap between demonstrated potential and realized outcomes.

Mathematics anxiety represents a significant educational challenge with long-lasting consequences for achievement, career trajectories, and well-being. Visual learning tools offer powerful means for reducing this anxiety while simultaneously supporting mathematical understanding and positive dispositions. However, realizing this potential requires moving beyond merely providing technology toward thoughtful implementation informed by research on effective features, implementation contexts, and individual differences. With appropriate attention to these factors, visual learning tools can play significant roles in creating more equitable, engaging, and anxiety-free mathematical learning experiences for all students.

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