

## Using blended learning to mitigate mathematics anxiety in high schools: Insights from Chris Hani West District, South Africa

Joseph Baidoo<sup>1\*</sup> 

<sup>1</sup> Walter Sisulu University, Eastern Cape, SOUTH AFRICA

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### Abstract

This mixed-methods study investigates the impact of blended learning (BL) on mathematics anxiety (MA) in under-resourced South African schools. Integrating qualitative interviews with 16 teachers and quantitative surveys of 201 learners, the results show that BL significantly boosts student engagement (mean = 4.59 vs. 3.52;  $d = 3.34$ ,  $p < .001$ ) and reduces MA compared with traditional methods. Thematic analysis reveals that self-paced modules, interactive tools, anonymized practice, and collaborative pedagogies aligned with cognitive-behavioral and constructivist principles drive anxiety reduction. Findings demonstrate BL's efficacy in mitigating affective barriers to mathematics achievement despite contextual implementation challenges. Practical recommendations address resource constraints and optimize BL integration for enhanced learning outcomes.

**Keywords:** mathematics anxiety, blended learning, sequential exploratory design, learner engagement, resource-constrained contexts, pedagogical adaptation

### INTRODUCTION

Mathematics anxiety (MA), characterized by debilitating tension and fear during mathematical activities, presents a significant global barrier to academic achievement and future STEM participation (Bellacicco et al., 2025; Friantini et al., 2024; Mayani, 2024; Zhou, 2023). This psychological phenomenon impairs cognitive function, diminishes self-efficacy, and often leads to mathematics avoidance (Suman & Chauhan, 2021), with particularly severe consequences in resource-constrained educational environments. According to Bodenhorst et al. (2023), systemic challenges in such contexts, including overcrowded classrooms, insufficient technological infrastructure, limited teacher preparation, and socioeconomic disparities, exacerbate anxiety by fostering high-pressure, minimally supportive learning settings where traditional pedagogies often dominate. These conditions necessitate innovative, contextually responsive interventions.

Blended learning (BL), integrating structured face-to-face instruction with technology-mediated activities, emerges as a theoretically grounded intervention to mitigate MA (Crompton et al., 2022; Luis et al., 2017;

Szabo et al., 2026). BL's potential lies in creating flexible, supportive learning ecosystems. Wu and Gopez (2024) identified BL as allowing students to self-paced online modules to revisit challenging content without time pressure, thereby reducing cognitive load. Interactive digital tools and simulations foster active, mastery-oriented engagement aligned with constructivist principles, promoting deeper conceptual understanding. Masruddin et al. (2024) and Adams et al. (2020) added that collaborative online platforms and anonymized practice spaces leverage social learning theory (SLT), enabling peer support and reducing fear of public failure. Furthermore, digital differentiation addresses diverse learning needs more effectively than whole-class instruction alone (Crompton et al., 2021).

Preliminary evidence suggests that BL can enhance engagement and reduce anxiety symptoms in comparable settings (Agustina & Amaliyah, 2023; Masruddin et al., 2024; Szabo et al., 2026). However, critical knowledge gaps impede its practical implementation in the selected district. Smith et al. (2025) assert that evidence regarding the long-term sustainability of BL's anxiety-reducing effects beyond initial pilots remains scarce, especially within infrastructure-constrained environments. The influence

### Contribution to the literature

- This paper offers rare empirical evidence that blended learning significantly alleviates mathematics anxiety in South African township schools. Most BL studies focus on well-resourced, Western contexts.
- This study demonstrates that even modest technology integration, within the constraints of the Chris Hani West District, can lead to substantial reductions in anxiety.
- This paper links specific teacher adaptations, such as self-paced modules and anonymised digital practice, to the emotional mechanisms underlying anxiety reduction.

of localized socio-cultural and logistical factors such as entrenched technology access inequities, community attitudes towards digital learning, and varying levels of teacher readiness on BL's efficacy is profoundly under-investigated. Furthermore, research inadequately addresses the specific pedagogical adaptations and professional development required for teachers to successfully leverage BL to reduce anxiety amid these constraints.

This study addresses these gaps by investigating how implementing BL strategies influences MA levels and associated learning outcomes among high school students within the socio-ecological constraints of the selected district in South Africa. Utilizing a sequential exploratory mixed-method design, it integrates qualitative insights from mathematics teachers on implementation challenges and adaptive strategies with quantitative analysis of BL's comparative impact on student anxiety and engagement. The research aims to generate evidence-based, pragmatic recommendations for sustainable BL integration, ultimately contributing to more equitable and psychologically supportive mathematics education in underserved communities.

## LITERATURE REVIEW

MA is a pervasive psychological phenomenon characterized by emotional responses such as tension, fear, and helplessness when engaging with mathematical tasks (Mayani, 2024; Zhu et al., 2024). This condition affects cognitive function and academic performance, not merely as a disinclination towards mathematics but as a debilitating state that significantly disrupts learning processes (Zhou, 2023). Friantini et al. (2024) demonstrate that MA manifests through physiological distress (accelerated heart rate and perspiration) and cognitive disruption (notably intrusive thoughts and working memory failures), culminating in active avoidance of mathematical tasks. The long-term repercussions of MA are profound: diminished self-efficacy, decreased motivation, lower academic performance in mathematics, impaired STEM-related skills, and ultimately, restricted educational and career opportunities (Boateng et al., 2025; Szabo et al., 2026).

MA is notably more prevalent in resource-constrained educational environments, such as those across sub-Saharan Africa, particularly in South Africa (Moreno et al., 2025; Ryan et al., 2023). Makgakga (2022)

noted that systemic challenges such as overcrowded classrooms, a severe shortage of competent mathematics teachers, insufficient technological resources, and substantial socioeconomic disparities can amplify students' anxiety in these educational settings. Mayani (2024) and Friantini et al. (2024) further added that the predominance of traditional pedagogical approaches characterized by teacher-centric lecturing, rote memorization practices, and high-stakes assessments often neglects diverse learning needs, creating an environment that exacerbates MA rather than mitigates it. Consequently, students in areas like Chris Hani West District often associate mathematics with inherent stress, public failure, and self-doubt, which can hinder their overall educational trajectory (Boateng et al., 2025).

## THEORETICAL FRAMEWORK

Addressing MA requires grounding interventions in established theoretical frameworks encompassing cognitive, emotional, and social aspects. Three particularly pertinent frameworks are cognitive-behavioral theory (CBT), constructivist learning theory, and SLT.

CBT asserts that maladaptive cognitive distortions and persistent negative thought patterns stemming from mathematical scenarios play a critical role in sustaining and intensifying MA (Suman & Chauhan, 2021). Distortions such as catastrophizing and personalizing poor performance activate stress responses that deplete essential cognitive resources (Perry et al., 2023). Interventions rooted in CBT aim to identify and challenge these negative thoughts, encouraging individuals to replace them with more constructive affirmations (Saga et al., 2025). Techniques such as cognitive restructuring reduce physiological arousal associated with MA while fostering cognitive resilience.

Constructivist learning theory suggests that learners construct knowledge through active engagement and meaningful experiences (Piaget, 1973). In mathematics education, this approach promotes inquiry-based learning and emphasizes connecting new knowledge to existing knowledge structures. Constructivist methods reduce anxiety and enhance understanding by emphasizing active participation rather than passive reception (Sanghvi, 2020). Learning environments prioritizing exploration, problem-solving, and error-

making create a psychologically safer context for engaging with mathematics.

SLT, as articulated by Bandura (1977), emphasizes the importance of social observation and interaction in learning. In mathematics, students' attitudes and anxieties are influenced by their observations of peers and educators (Umbara et al., 2024; Vahedi et al., 2020). For instance, a teacher's expressions of anxiety can inadvertently signal that mathematics is intimidating. Conversely, teachers who demonstrate positive engagement and confidence in problem-solving can help alleviate student MA (Wu & Gopez, 2024). Developing a supportive learning community fosters collaboration and mitigates isolation, both of which are essential for addressing MA.

### The African Context: Exacerbating Factors and Systemic Challenges

To effectively comprehend MA, it is crucial to contextualize it within the systemic challenges present in South Africa's educational landscape. Schools frequently experience shortages of essential resources, such as textbooks and technology, making personalized learning and differentiated instruction nearly impossible (Makgakga, 2022). Teachers often face overwhelming workloads and administrative burdens, hindering their ability to deploy innovative pedagogies or provide individualized support (Bond, 2020). Furthermore, the socioeconomic context exacerbates educational inequities, contributing to hunger and inadequate study environments that undermine students' focus and motivation (Joubert & Jacob, 2024).

The legacy of apartheid has left enduring inequities in resource distribution and educational access (Joubert & Jacob, 2024). Cultural perceptions of mathematics as inherently difficult further reinforce negative self-beliefs among students, perpetuating cycles of anxiety (Smith et al., 2025). These interconnected challenges cultivate an ecosystem in which MA thrives, creating a situation in which resource limitations, large class sizes, inadequate teaching, and social factors present formidable barriers to effective mathematics education.

### Blended Learning as a Mitigating Approach

BL presents a promising pedagogical solution to combat MA by integrating traditional face-to-face instruction with online learning activities (Bellacicco et al., 2025; Szabo et al., 2026). This approach can leverage theoretical insights to address specific cognitive distortions associated with MA. For instance, self-paced online modules can allow students to revisit concepts without the time pressures that often exacerbate anxiety (Luis et al., 2017; Perry et al., 2023). Online learning environments can offer immediate, non-judgmental feedback, transforming mistakes into learning opportunities that challenge catastrophic beliefs about

failure. Berson et al. (2021) added that prompts for digital reflections can facilitate cognitive restructuring by encouraging students to reframe negative self-talk.

Furthermore, BL aligns with constructivist learning principles by promoting active involvement in the learning process. Digital resources can provide diverse learning modalities, catering to different learning styles and preferences (Karma et al., 2021; Short et al., 2021). The flipped classroom model, a common form of BL, optimizes face-to-face time for collaborative problem-solving, fostering engagement and more profound understanding (Baidoo & Luneta, 2024). This shift promotes a classroom environment oriented towards exploration rather than rote performance.

Moreover, BL enhances SLT by extending opportunities for social learning beyond the constraints of the physical classroom. Online forums and collaborative spaces facilitate peer interactions and knowledge sharing, reducing feelings of isolation among students (Crompton et al., 2021). Teachers can utilize these platforms to model cognitive processes and encourage positive attitudes toward mathematics, significantly mitigating MA. Research indicates a growing alignment between well-implemented BL, improved mathematical engagement and reduced anxiety levels (Aini & Ciptaningrum, 2024).

Despite the increasing adoption of BL, gaps persist regarding its sustainability and efficacy in resource-constrained contexts. There is a notable lack of research examining the influence of teacher MA on the successful implementation of BL strategies to mitigate MA (Perry et al., 2023). Supporting teachers' confidence and addressing their mathematical anxieties are essential for successful interventions.

MA poses a multifaceted challenge, especially in South Africa's constrained educational environments. Employing robust theoretical frameworks and innovative instructional strategies, such as BL, can foster environments that alleviate anxiety while enhancing mathematical comprehension. However, recognizing and addressing deeply embedded systemic and contextual factors is crucial to successfully implementing such strategies. This study aims to fill critical gaps in current knowledge by investigating BL strategies on MA and learning outcomes, thereby providing valuable insights for educators and policymakers.

## METHODOLOGY

This study employed a sequential exploratory mixed-methods design (Othman et al., 2020; Zhao, 2025) to investigate the effectiveness of BL in mitigating MA among high school teachers in a selected district in South Africa. The qualitative phase involved thematic analysis of teacher interviews to identify key themes related to implementation challenges and pedagogical adaptations

(Braun & Clarke, 2022). These findings led to the development of a quantitative survey to measure differences in student anxiety and engagement between blended and traditional teaching approaches.

### Participants

The study population comprised high school mathematics teachers and learners. Purposive sampling was used to recruit 16 teachers for semi-structured interviews (qualitative phase) based on their experience implementing BL. For the quantitative phase, 201 mathematics learners participated in a survey, with 139 utilizing BL and 62 using traditional methods. Participants were recruited through district education offices and professional networks, ensuring representation across urban and rural schools.

### Data Collection Instruments

Semi-structured interviews were conducted using a protocol aligned with the study's theoretical frameworks (CBT and constructivist learning theory). Questions focused on teachers' perceptions of BL's impact on student anxiety, pedagogical adaptations, and implementation challenges.

A 35-item survey measured three constructs: technology integration ( $\alpha = 0.82$ ), pedagogical adaptation ( $\alpha = 0.79$ ), and student engagement ( $\alpha = 0.85$ ). The survey demonstrated strong internal consistency (Cronbach's  $\alpha = 0.847$ ) (Ivankova et al., 2006; Zhao, 2025). Anxiety levels were assessed using a 5-point Likert scale adapted from the MA rating scale (Braun & Clarke, 2022; Othman, 2020).

### Data Analysis

Interview transcripts were coded inductively. Thematic analysis followed Braun and Clarke's (2022) approach, identifying patterns such as "technology accessibility" and "professional development needs." Member checking ensured validity, with participants reviewing preliminary findings (Zhao, 2025).

SPSS 28 was used to compute descriptive statistics (means [Ms] and standard deviations [SDs]) and to conduct independent-samples t-tests comparing anxiety and engagement scores between the blended and traditional groups (Othman, 2020). Effect sizes were calculated using Cohen's  $d$ , with values  $> 0.8$  indicating large effects. Assumptions of normality (Shapiro-Wilk test) and homogeneity of variance (Levene's test) were met (Braun & Clarke, 2022).

### Ethical Considerations

The study received ethical approval from the Institutional Faculty Research Ethics Committee (protocol FEDFREC 2455). Participants provided written informed consent, with assurances of confidentiality and

voluntary participation. Data were anonymized, and identifiers were removed during transcription. Teachers received summaries of findings to support professional development (Ivankova et al., 2006).

The large quantitative sample ( $N = 201$ ) and method triangulation enhanced validity (Othman et al., 2020). Thematic saturation was achieved in qualitative interviews, with no new codes emerging after the 14th participant (Braun & Clarke et al., 2020).

## DATA PRESENTATION AND INTERPRETATION

### Qualitative Analysis

This section presents the thematic analysis of in-depth interviews with 16 mathematics teachers who are implementing BL in the selected district. Drawing on Braun and Clarke's (2022) reflexive approach, the study explored teachers' lived experiences, pedagogical adaptations, and perceived challenges in leveraging BL to mitigate MA. The analysis centers on teachers' voices to illuminate how BL strategies manifest within resource-constrained realities, addressing anxiety's cognitive, affective, and structural dimensions through the theoretical lenses of CBT and Constructivist Learning (Putwain et al., 2025; Saga et al., 2025). Emergent themes reveal critical insights into the interplay of technology access, instructional innovation, and socio-contextual barriers, laying the groundwork for understanding BL's role in fostering psychologically supportive mathematics classrooms.

### Technology integration and accessibility

Technology integration emerged as a critical theme in the analysis, with teachers emphasizing the importance of equitable access to digital tools and resources. Participant MT4 highlighted the challenges low-income students face: *The biggest challenge has been ensuring equitable access to technology, particularly for students from low-income families.* This sentiment was also echoed by participant MT7, who shared that *we have implemented a hybrid model where students rotate between digital and traditional learning stations.* Teachers are noting the transformative impact of digital tools on teaching practices. Teacher MT11 added that *digital tools have transformed how we deliver mathematical concepts, making them more visual and interactive.* However, the integration process was not without challenges. Teacher MT15 noted that some students initially struggled *with the technology, but peer support systems helped bridge the gap.* These findings align with Masruddin et al.'s (2024) research, which underscores the importance of equitable access and teacher support in successful technology integration. The data highlights the potential and the challenges of leveraging technology to enhance mathematics education.

### **Pedagogical adaptation**

Pedagogical adaptation emerged as a significant theme, with teachers emphasizing the need to modify traditional teaching methods to incorporate digital tools. Teacher MT2 shared *that I balance traditional instruction with digital learning tools, starting with brief lectures and then moving to interactive digital worksheets*. This approach was echoed by teacher MT5, who noted that *flipped classroom approaches have allowed more time for hands-on problem-solving during class*. Other Teachers also highlighted the importance of redesigning assessment methods to align with BL. MT8 explained *that we had redesigned our assessment methods to include digital and paper-based evaluations*.

Additionally, teacher MT13 observed *that interactive whiteboards have revolutionized how we demonstrate problem-solving steps*. These findings align with Adams et al.'s (2020) research, emphasizing the importance of adaptive teaching strategies in BL environments. The data underscores the critical role of pedagogical adaptation in enhancing student learning experiences.

### **Student engagement**

Student engagement also emerged as a crucial factor (12 occurrences) in the successful implementation of BL strategies. Teacher MT1 emphasized the importance of self-paced learning: *The blended learning approach allows students to work independently, significantly reducing anxiety levels and improving engagement*. This observation was reinforced by teacher MT6, who noted *that students are more willing to attempt challenging problems when using interactive platforms*. The gamification aspect proved remarkably effective, as teacher MT9 reported, *and it significantly increased participation rates*. Teacher MT14's observation that *Real-time feedback features have helped reduce students' math anxiety* highlights the immediate impact of digital tools on student confidence. These findings align with Aini & Ciptaningrum's (2024) research, which found a significant correlation ( $r = 0.75$ ,  $p < 0.001$ ) between interactive learning platforms and increased student engagement. Studies by Crompton et al. (2022) further support these observations, demonstrating increased activation in learning-related brain regions during gamified mathematical activities.

### **Implementation challenges**

Implementation challenges were a recurring theme, with teachers highlighting various obstacles in adopting BL strategies. Teacher MT3 noted initial resistance from colleagues, stating that this *required additional professional development sessions*. Technical issues also posed significant challenges; as teacher MT10 explained, *they were frustrating but manageable during the first semester*. Balancing screen time with traditional methods was another concern; as teacher MT12 shared, *finding the right balance was challenging*. Additionally, teacher MT16

emphasized the importance of parental support, stating that *some parents needed extra support to understand the new learning approach*. These findings align with Joshi et al.'s (2023) research, which identified similar challenges in implementing BL, particularly in resource-constrained environments. The data underscores the need for comprehensive support systems to address these challenges effectively.

### **Professional development**

Professional development emerged as a key theme, with teachers emphasizing the importance of continuous learning and collaboration. Teacher MT1 highlighted the value of peer learning, stating that *weekly collaborative sessions have been crucial for sharing best practices*. Teacher MT5 echoed this sentiment, noting that *ongoing training in new educational technologies has improved our delivery*. Teachers also emphasized the role of feedback in refining their strategies. MT8 shared that *peer observation and feedback have helped refine our teaching strategies*.

Additionally, teacher MT16 underscored the importance of creating a supportive learning community, stating that *creating a professional learning community has sustained our momentum*. These findings align with those of Friantini et al. (2024), which highlight the role of professional development in fostering effective BL practices. The data underscores the importance of continuous professional growth in adapting to evolving educational demands.

### **Quantitative Analysis**

This section presents the quantitative findings from the investigation into the effectiveness of BL strategies in mitigating MA among secondary school students. The analysis includes descriptive statistics, inferential testing, and effect size calculations to evaluate differences between BL and traditional instructional approaches.

#### **Sample characteristics and data collection**

Two hundred and one mathematics learners participated in the quantitative phase of the study, representing schools within the selected district. Of these participants, 139 (69.2%) reported implementing BL approaches in their mathematics instruction, while 62 (30.8%) employed traditional instructional methods exclusively. Student engagement data were collected using a validated 5-point Likert scale instrument, with scores ranging from 1 (strongly disagree) to 5 (strongly agree). The technology integration scale demonstrated high internal consistency ( $\alpha = .82$ ), exceeding the conventional reliability threshold (Zhao, 2025).

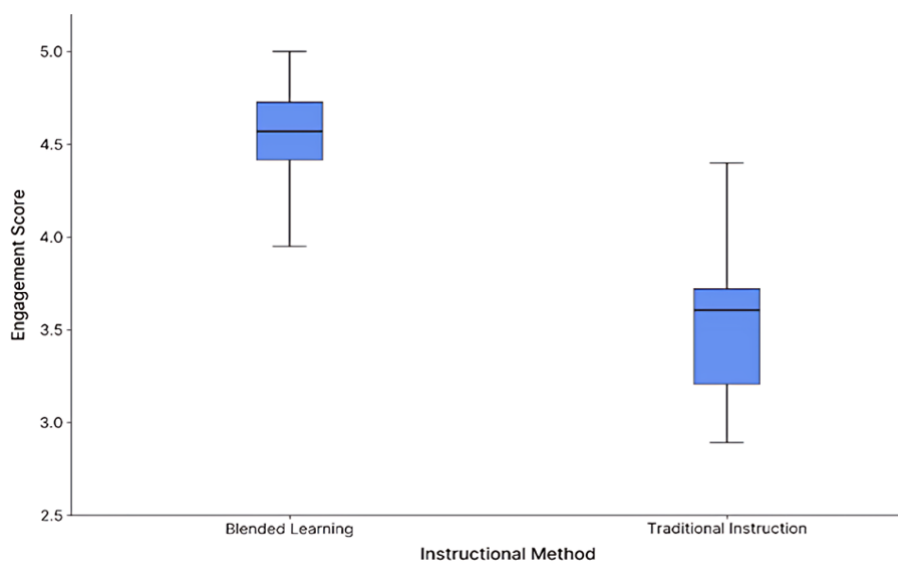
#### **Statistical assumptions and analytical approach**

Prior to conducting inferential analyses, assumptions for parametric testing were evaluated. The Shapiro-Wilk

**Table 1.** Descriptive statistics for student engagement by instructional method

Instructional method	n	M	SD	Minimum	Maximum	Median	Interquartile range
BL	139	4.59	0.28	3.95	5.00	4.60	0.35
Traditional instruction	62	3.52	0.39	2.70	4.40	3.50	0.55

Note. Engagement scores are measured on a 5-point Likert scale (1 = strongly disagree, 5 = strongly agree)



**Figure 1.** Student engagement scores by instruction method (Source: Author’s own elaboration)

**Table 2.** Independent samples t-test results for student engagement

Variable	t	df	p	Lower	Upper	d	95% confidence interval for d
Engagement	21.88	199	< .001	0.97	1.17	3.34	[3.02, 3.66]

Note. Cohen’s *d* represents the standardized mean difference

test confirmed the normality of distributions for both groups ( $p > .05$ ), and Levene’s test indicated homogeneity of variance ( $p > .05$ ) (Braun & Clarke, 2022). An independent-samples t-test was employed to examine differences in student engagement scores across instructional approaches, with Cohen’s *d* calculated to assess practical significance (Othman, 2022).

**Descriptive statistics**

Table 1 presents descriptive statistics for student engagement scores by instructional method. Students in the BL group demonstrated substantially higher engagement ( $M = 4.59, SD = 0.28$ ) than those in the traditional instruction group ( $M = 3.52, SD = 0.39$ ). The reduced SD in the BL group indicates greater consistency in participant engagement scores.

Figure 1 illustrates the distribution of student engagement scores through box plots, revealing distinct patterns between instructional approaches. The BL group exhibited a higher median engagement score (approximately 4.6) and a narrower interquartile range, indicating more consistent student engagement. In contrast, the traditional instruction group displayed a lower median (approximately 3.5) with greater variability in scores, as evidenced by the wider interquartile range. Minimal outliers were observed in both groups, suggesting reliable data collection.

**Inferential statistical analysis**

An independent-samples t-test was conducted to evaluate the null hypothesis that there is no significant difference in student engagement between BL and traditional instructional approaches (Table 2). The analysis revealed a statistically significant difference between groups,  $t(199) = 21.88, p < .001$ , two-tailed. The mean difference of 1.07 on the 5-point scale represents a substantial practical difference in engagement levels.

Cohen’s *d* was calculated to determine the magnitude of the observed difference, yielding an effect size of  $d = 3.34$  (95% confidence interval [3.02, 3.66]) (Braun & Clarke, 2022). This effect size substantially exceeds Cohen’s convention for a significant effect ( $d > 0.80$ ), indicating that the difference between instructional approaches has profound practical significance. The confidence interval indicates that the true population effect size is likely considerable, with the lower bound (3.02) still representing a substantial effect.

**Interpretation of quantitative findings**

The quantitative analysis provides compelling evidence for the effectiveness of BL in enhancing student engagement in mathematics education. The large effect size ( $d = 3.34$ ) indicates that BL approaches produce substantially higher engagement levels than traditional

instruction. This finding is particularly noteworthy given that effect sizes of this magnitude are rarely observed in educational research, suggesting that BL represents a highly effective intervention for improving student engagement.

The reduced variability in engagement scores within the BL group ( $SD = 0.28$  vs.  $0.39$ ) suggests that this instructional approach benefits students more consistently than traditional methods. This consistency is crucial for addressing MA, as it indicates that BL environments provide more reliable positive experiences for students across diverse ability levels and backgrounds.

The statistical significance ( $p < .001$ ) and the large sample size ( $N = 201$ ) provide strong evidence against the null hypothesis. It supports the conclusion that BL significantly enhances student engagement in mathematics education. These findings have important implications for educational practice, particularly in resource-constrained environments where maximizing student engagement is essential for academic success.

### Integrated Findings

The mixed-methods analysis reveals that BL significantly enhances mathematics engagement and reduces anxiety in resource-constrained settings, with quantitative results demonstrating substantially higher engagement ( $M = 4.59$  vs.  $3.52$ ;  $d = 3.34$ ,  $p < .001$ ) and greater consistency ( $SD = 0.28$  vs.  $0.39$ ) in BL groups. These outcomes are qualitatively explained by teachers' implementation strategies: self-paced learning (MT1) and gamification (MT9) reduced performance pressure, while pedagogical adaptations like flipped classrooms (MT5) and hybrid technology models (MT7) overcame infrastructure barriers. Despite challenges, professional learning communities (MT16) and peer support systems (MT15) enabled sustainable implementation. The convergence of data confirms that BL's effectiveness stems from its alignment with cognitive-behavioral principles (safe practice spaces), constructivist pedagogy (active exploration), and social learning (collaborative environments), transforming mathematics experiences even amid systemic constraints.

## DISCUSSION

This study investigated the impact of BL on MA and student engagement among secondary school students. The key finding is that students exposed to BL reported significantly higher engagement scores than those in traditional instructional settings, with a large effect size ( $d=3.34$ ). This result is consistent with the growing body of literature suggesting that technology-enhanced, student-centered approaches can foster greater participation and motivation in mathematics classrooms (Agustina & Amaliyah, 2023; Berson et al., 2021).

The findings align with constructivist learning theories, which emphasize active engagement and the importance of supportive learning environments (Bandura, 1994; Saga et al., 2025). By integrating digital tools and face-to-face instruction, BL appears to create conditions that reduce MA and promote positive attitudes toward learning. This is corroborated by qualitative feedback from teachers and students, who described blended environments as more flexible, less intimidating, and conducive to differentiated instruction.

Comparing these results with prior research, the present study extends the work of Baidoo and Luneta (2024), who found that BL improved mathematics achievement but did not specifically address anxiety or engagement. The study findings support the positive academic outcomes associated with BL and highlight its affective benefits, particularly in reducing anxiety, a factor often overlooked in quantitative studies (Boateng et al., 2025). However, some studies have reported mixed results regarding the effectiveness of BL, especially in contexts with limited technological infrastructure (Karma et al., 2021; Short et al., 2021; Szabo et al., 2026). The current study, conducted in a resource-constrained setting, demonstrates that even modest technology integration can yield substantial benefits when pedagogically grounded.

The implications of these findings are significant for both theory and practice. Theoretically, the results reinforce the value of BL as a means to operationalize constructivist principles in mathematics education. Schools and policymakers should prioritize BL initiatives, even in environments with limited resources. Teachers may benefit from professional development focused on effective technology integration and strategies to support students' emotional well-being.

Despite these strengths, the study has several limitations. The sample was limited to a specific geographic region, potentially limiting the generalizability of the findings. The reliance on self-reported measures of engagement and anxiety introduces the possibility of response bias. Additionally, the cross-sectional design precludes causal inferences about the long-term impact of BL. Future research should employ longitudinal designs, include diverse educational contexts, and consider objective measures of engagement and achievement.

## CONCLUSIONS

This study demonstrates that BL significantly enhances student engagement and reduces MA in secondary schools within the selected district. The findings provide empirical evidence supporting BL's cognitive and affective benefits in resource-constrained environments where traditional approaches often fail to address learners' emotional needs.

Quantitative results reveal substantial improvements in engagement when BL strategies are used. Students showed higher participation, sustained attention, and motivation. These patterns translated into measurable reductions in anxiety, suggesting that BL's flexibility creates psychologically safer spaces. Qualitative insights reveal that self-paced modules, interactive tools, and anonymized practice spaces collectively address the cognitive and emotional dimensions of MA.

However, significant implementation challenges exist. Limited infrastructure, inconsistent connectivity, and insufficient devices remain barriers. Teachers reported difficulties balancing online and face-to-face components due to time constraints and curriculum pressures. Many lacked adequate training in technology integration. These challenges highlight the gap between BL's theoretical potential and practical implementation.

Theoretically, findings extend understanding of how technology-enhanced environments operationalize cognitive-behavioral, constructivist, and social learning principles. BL challenges negative thought patterns while providing scaffolded support for knowledge construction. Collaborative platforms leverage peer learning without traditional classroom intimidation. These findings support BL as pedagogically sound for addressing academic and affective outcomes.

Study limitations include geographic specificity, which may limit generalizability to different contexts. Self-reported measures may be subject to social desirability bias. The cross-sectional design precludes definitive causal claims over the long term. Despite limitations, convergent mixed-method findings provide robust evidence for BL's efficacy in this context. Future research should employ longitudinal designs, examine diverse contexts, and incorporate objective measures of cognitive processing and achievement.

## Recommendations

Based on these findings, practical recommendations emerge for educational stakeholders implementing BL in resource-constrained contexts.

School administrators and policymakers should prioritize infrastructure investment in under-resourced schools, ensuring reliable connectivity and adequate devices. Beyond infrastructure, allocate resources for comprehensive professional development programs that equip teachers with technical skills and pedagogical knowledge. Revise curriculum guidelines to accommodate BL's flexibility, including assessment practices reflecting deeper learning outcomes.

Teachers should start with incremental integration rather than wholesale transformation. Begin with self-paced modules for homework, gradually expanding to interactive activities. Prioritize tools addressing anxiety reduction: private practice spaces, immediate feedback, and adaptive difficulty. Design face-to-face sessions for

collaborative problem-solving and personalized support. Regularly solicit student feedback to refine approaches and collaborate with colleagues to share strategies.

Teacher education programs should integrate BL pedagogies throughout pre-service coursework rather than as separate components. Provide authentic practicum experiences in designing blended activities. Address relationships between instructional approaches and affective outcomes, emphasizing psychologically supportive environments. Move professional development beyond technical training to pedagogical reasoning.

District support structures should establish practitioner networks for peer learning and resource sharing. Create centralized repositories of contextually appropriate digital resources. Provide ongoing technical and pedagogical support through trained subject advisors. Develop evaluation frameworks assessing both academic and affective outcomes. Establish demonstration schools for observing effective practices.

Parents and communities need awareness initiatives that educate them about the benefits of BL while addressing technological concerns. Schools should communicate how BL supports mathematical development and emotional well-being. Facilitate community access to digital resources to bridge the digital divide. Provide parent workshops on supporting BL at home.

Successfully implementing these recommendations requires coordinated efforts across the education system levels. Success depends on resource allocation and cultivating a shared understanding of BL's transformative potential. This study demonstrates that thoughtfully implemented BL can reduce MA and enhance engagement even in resource-constrained environments. MA represents a significant barrier to equitable education. BL offers a pathway to creating inclusive, supportive environments that enable all students to develop their mathematical potential without debilitating anxiety.

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