# Beyond the Blackboard: Reimagining Math Education through Flipped Classrooms, AR, and GeoGebra

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## Abstract

*This systematic literature review investigates the learning outcomes of implementing flipped learning integrated with Augmented Reality and GeoGebra in mathematics education. Following the PRISMA guidelines, a comprehensive search was conducted in Scopus database using specific search terms related to flipped learning, augmented reality, and GeoGebra in educational contexts from 2015 to 2026. The initial search yielded 67 articles, which were screened based on inclusion criteria including empirical studies, publication year, English language, and methodological approach. After the screening process, 49 articles were excluded as not relevant. Further eligibility assessment of the remaining18 articles led to the exclusion of 10 articles (4 non-primary research articles and 6 non-full-text articles), resulting in 8 final articles for review. The analysis reveals several key findings: (1) the integration of AR and GeoGebra in flipped learning environments significantly enhances students' mathematical understanding and problem-solving skills; (2) students demonstrate improved self-regulated learning capabilities and engagement in mathematical concepts; (3) the combination of these technologies supports personalized learning experiences and active participation; and (4) while implementation challenges exist, particularly in technical infrastructure and initial adaption, the overall impact on learning outcomes is positive. This review contributes to the growing body of knowledge on technology-enhanced mathematics education and provides practical insight for educators implementing flipped learning with digital tools.*

**KEYWORDS:** *Flipped learning, augmented reality, GeoGebra, learning outcomes*

## Abstrak

Tinjauan literatur sistematis ini menyelidiki hasil pembelajaran dari implementasi pembelajaran terbalik (flipped learning) yang terintegrasi dengan Augmented Reality dan GeoGebra dalam pendidikan matematika. Mengikuti pedoman PRISMA, pencarian komprehensif dilakukan di basis data Scopus menggunakan istilah pencarian spesifik yang terkait dengan pembelajaran terbalik, augmented reality, dan GeoGebra dalam konteks pendidikan dari tahun 2015 hingga 2026. Pencarian awal menghasilkan 67 artikel, yang kemudian disaring berdasarkan kriteria inklusi termasuk studi empiris, tahun publikasi, bahasa Inggris, dan pendekatan metodologis. Setelah proses penyaringan, 49 artikel dikeluarkan karena tidak relevan. Penilaian kelayakan lebih lanjut dari 18 artikel yang tersisa menyebabkan pengecualian 10 artikel (4 artikel penelitian non-primer dan 6 artikel non-teks lengkap), sehingga menghasilkan 8 artikel akhir untuk ditinjau. Analisis mengungkapkan beberapa temuan kunci: (1) integrasi AR dan GeoGebra dalam lingkungan pembelajaran terbalik secara signifikan meningkatkan pemahaman matematika dan keterampilan pemecahan masalah siswa; (2) siswa menunjukkan peningkatan kemampuan belajar mandiri dan keterlibatan dalam konsep matematika; (3) kombinasi teknologi ini mendukung pengalaman belajar yang dipersonalisasi dan partisipasi aktif; dan (4) meskipun terdapat tantangan implementasi, khususnya dalam infrastruktur teknis dan adaptasi awal, dampak keseluruhan terhadap hasil belajar adalah positif. Tinjauan ini berkontribusi pada semakin banyaknya pengetahuan tentang pendidikan matematika yang ditingkatkan dengan teknologi dan memberikan wawasan praktis bagi pendidik yang menerapkan pembelajaran terbalik dengan alat digital.

## INTRODUCTION

Mathematics education has consistently faced significant challenges in engaging students and promoting deep conceptual understanding. Traditional pedagogical approaches often fail to address diverse learning needs and the complex nature of mathematical concepts, resulting in low student motivation and persistent learning difficulties (Egara & Mosimege, 2024). This challenge is particularly evident in spatial geometry, where students generally show unsatisfactory results in solving problems related to flat-sided spatial geometry, with only 21% able to solve the problems (Safitri, Raharjo, et al., 2024) . The implementation of appropriate mathematics teaching approaches by teachers would boost the learners' eagerness to learn, as mathematics researchers have been seeking ways to increase students' achievement and interest in mathematical concepts (Egara & Mosimege, 2024). In response to these challenges, educational technology has emerged as a transformative force, offering innovative possibilities for enhancing mathematics instruction and improving learning outcomes.

The flipped classroom model has gained significant attention as pedagogical innovation that reserves the traditional instructional paradigm. The flipped classroom (FC) in an innovative pedagogy with the potential to engage students in mathematics education using hybrid education combined with online and face-to-face learning (Cevikbas & Kaiser, 2023). In this model, direct instruction is transferred from the setting of group instruction (the classroom) to the setting for individual instruction, and the resulting group space is transformed into a lively, interactive learning environment where the teacher helps students apply ideas and actively engage with the course material (Egara & Mosimege, 2024). Research has demonstrated that the flipped learning approach has recently gained popularity as an educational innovation in educational technology, especially as it applies to higher education (Baig & Yadegaridehkordi, 2023), with studies showing positive effects on student achievement and engagement (Kumar Bhagat, 2016) (Fung et al., 2021a).

Augmented Reality (AR) technology has emerged as a powerful tool for

mathematics education, offering immersive and interactive learning experiences that bridge the gap between abstract mathematical concepts and concrete understanding. AR technology possesses distinctive features that set it apart from other technologies, involving the integration of the real and virtual worlds in a seamless environment, real-time interactivity, and three-dimensional (3D) visualizations (Ivan & Maat, 2024). In the last decade, the usage of Augmented reality (AR) has proliferated especially in the educational sector (Radu et al., 2023), with studies indicating that AR technology can significantly increase student satisfaction and behavior in education (Akbar et al., 2025). Research has shown that AR enables students to visualize complex mathematical relationships, manipulative virtual spatial reasoning and improving conceptual understanding (Ahmad & Junaini, 2020).

Simultaneously, GeoGebra has established itself as a versatile and widely-adopted mathematical software that integrates geometry, algebra, statistics, and calculus in a single platform. GeoGebra is a dynamic geometry software integrated into mathematics education (Ishartono et al., 2022a), offering dynamic and interactive capabilities that allow students to explore mathematical concepts through visualization, experimentation, and discovery. Meta-analytic research has demonstrated that students exposed to GeoGebra-based learning outperformed math abilities, initially equivalent to 82% of students in traditional classrooms (Juandi et al., 2021). Studies have consistently shown that GeoGebra software is more effective when the treatment duration is set to less than or equal to four weeks, and providing classrooms with sufficient numbers of computers allowed students use them individually (Juandi et al., 2021).

The integration of flipped learning with AR and GeoGebra represents a convergence of pedagogical innovation and technological advancement that holds significant promise for mathematics education. The use of augmented reality (AR) with GeoGebra allows for the contextualization of mathematical operations in real-world situations, where the teacher presents questions or problems that students solve using visualization and experimentation software (Iparraguirre-Villanueva et al., 2024). This combination potentially addresses multiple learning challenges simultaneously: the flipped model promotes active learning and personalized instruction, AR enhance visualization and engagement, GeoGebra provides powerful mathematical tools for exploration and discovery. Recent studies have shown promising results, with 70% of

students achieving and outstanding level of performance and a positive attitude towards mathematics observed in 100% of students when using GeoGebra 3D calculator with AR (Iparraguirre-Villanueva et al., 2024).

Previous research has explored these technologies individually, with systematic reviews demonstrating the benefits of flipped learning in various educational contexts (Cevikbas & Kaiser, 2023), the potential of AR in enhancing spatial understanding (Herliandry et al., 2021), and the effectiveness of GeoGebra in supporting mathematical exploration (Juandi et al., 2021). Results indicated that the effect of flipped classroom in mathematics is still ambiguous in terms of student academic performance and perceptions (Fung et al., 2021b), highlighting the need for more comprehensive analysis of implementation strategies. Similarly, only limited articles have systematically reviewed the research trends in the implementation of AR for learning mathematics (Radu et al., 2023), indicating a gap in understanding optimal integration approaches. While augmented reality has been extensively studied in mathematics learning, research findings on Mobile Augmented Reality (MAR) are still scarce, both in terms of teaching and mathematical learning media (Safitri, Wibawa, et al., 2024), representing a significant gap in understanding mobile-specific AR implementations that can be used anywhere to make learning more accessible and enjoyable.

The rapid advancement of educational technology and the increasing availability of digital tools have created new opportunities and challenges for mathematics educators. The COVID-19 pandemic has accelerated the adoption of digital learning technologies, making it more urgent to understand their effectiveness, can provide opportunities during the pandemic for teacher and students to redefine learning spaces, removing barriers between the home and school and making learning more accessible (Cevikbas & Kaiser, 2023). As educational institutions continue to invest in technology-enhanced learning environments, there is a pressing need for evidence-based guidance on the most effective combinations of pedagogical approaches and technological tools.

Furthermore, research has indicated that by implementing Augmented Reality (AR) activities in flipped classroom scenarios, inquiry-based learning can be fostered, but designing such sequences can be challenging for educators (Schallert & Lavicza, 2019). Studies have also shown that the average problem-solving score using the Flipped Classroom model with Augmented Reality is significantly higher than traditional

approaches (Cahyaningrum & Hadi, 2023), demonstrating the potential benefits of this integrated approach. To address these gaps in the literature, this systematic literature review is guided by four research questions: (1) How do flipped classrooms enhance mathematics learning outcomes when integrated with AR and GeoGebra technologies? (2) What are the specific benefits of AR and GeoGebra integration in flipped classroom environments? (3) How do these integrated approaches impact student engagement and motivation? (4) What challenges and limitations exist in implementing these integrated approaches? These questions collectively examine the effectiveness, benefits, student experiences, and practical considerations of implementing technology-enhanced flipped classrooms in mathematics education.

This systematic literature review aims to address this gap by comprehensively examining the existing empirical evidence on the integration of flipped learning with AR and GeoGebra in mathematics education. By following rigorous systematic review methodology consistent with PRISMA guidelines, this study seeks to provide a comprehensive understanding of how these technologies work together to enhance mathematics learning outcomes. The findings of this review will contribute to the growing body of knowledge on technology-enhanced mathematics education and provide practical insights for educators, researchers, and policymakers.

The significance of this review extends beyond theoretical understanding to practical application. As mathematics educators increasingly seek evidence-based approaches to improve student learning outcomes, this systematic review will provide valuable insights into the effectiveness, implementation challenges, and best practices associated with integrating flipped learning, AR, and GeoGebra. The findings will inform curriculum development, teacher training programs, and educational technology adoption decisions, ultimately contributing to the advancement of mathematics education in the digital age.

**METHODS**

A systematic literature review was conducted following the PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page et al., 2021) to identify, analyze, and synthesize relevant studies on flipped learning with augmented reality and GeoGebra in mathematics education. The PRISMA 2020

statement replaces the 2009 statement and includes new reporting guidance that reflects advanced in methods to identify, select, appraise, and synthesize studies (Page et al., 2021). The review process consisted of four distinct phases: identification, screening, eligibility assessment, and inclusion, as recommended by the updated guidelines.

**Search Strategy**

A comprehensive literature search was conducted using the Scopus database, selected for its extensive coverage of peer-reviewed academic literature in education and technology. The search strategy employed a Boelean search string that systematically combined key terms related to flipped learning, augmented reality, and GeoGebra in educational contexts. The search was limited to articles published between 2015 and 2026, written in English, and in their final publication stage.

The comprehensive search string was constructed as follows: TITLE-ABS-KEY (("flip" OR "flipped" OR "invert" OR "inverted" OR "reverse" OR "backwards") AND ("teaching" OR "classroom" OR "learning" OR "pedagogy") AND ("augmented reality" OR "geogebra")) AND PUBYEAR > 2015 AND PUBYEAR < 2026 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (LANGUAGE, "English")). This comprehensive search strategy ensured the inclusion of all relevant studies while maintaining specificity to the research focus and allowing for variations in terminology used across different studies.

**Inclusion and Exclusion Criteria**

The selection criteria were established a priori to maintain objectively and reduce selection bias (Green & Higgins, 2024). Studies were included or excluded based on the following predetermined criteria:

**Inclusion Criteria:**

1.  Empirical research articles published in peer-reviewed journals

2.  Studies published between 2015 and 2026 to capture recent technological developments

3.  Articles written in English language

4.  Research focusing on mathematics education at any educational level (primary,

secondary, or tertiary)

5. Studies investigating flipped classroom approaches integrated with augmented reality and/or GeoGebra

6. Articles with clearly defined research methodology and reported learning outcomes

7. Final publication stage only (excluding conference proceedings and disertations)

**Exclusion Criteria:**

1. Non empirical studies (theoretical papers, opinion pieces, editorials, reviews)

2. Conference papers, book chapters, and disertations

3. Studies not specifically focused on mathematics education

4. Articles without clear integration of flipped learning with AR or GeoGebra

5. Duplicate publications identified through reference management

6. Studies with insufficient methodological information or unclear research objectives

7. Articles not available in full text after institutional access attempts.

**Study Selection Process**

The article selection process followed a systematics four-stage approach as recommended by PRISMA 2020 guidelines and illustrated in the PRISMA flow diagram (figure 1). Two independent reviewers (P.T.S and M.S.S) conducted the screening process to minimize selection bias and ensure reliability (Green & Higgins, 2024). Disagreement were resolved through discussion, and when consensus could not be reached, a third reviewer (M.) was consulted for final arbitration (Cumpston et al., 2019).

**Stage 1 – Identification:** The initial database search yielded 67 articles from Scopus using the predetermined search string. All citations were imported into Mendeley reference management software for deduplication and organization.

**Stage 2 – Screening:** All 67 articles underwent title and abstract screening based on the inclusion and exclusion criteria. During this stage, 49 articles were excluded for the following reasons: not related to mathematics education (n=18), did not involve flipped classroom methodology (n=15), lacked integration of AR and GeoGebra (n=12), and

duplicate or non-English articles (n=4). Inter-reviewer agreement was assessed using Cohen's kappa coefficient ($\kappa = 0.87$), indicating substantial agreement.

**Stage 3 – Eligibility Assessment:** The remaining 18 articles were assessed for eligibility through full-text review. Articles were evaluated for methodological rigor, clear research objectives, and explicit integration of flipped learning with AR and GeoGebra in Mathematics education contexts.

**Stage 4 – Final Inclusion:** Following the eligibility assessment, 10 articles were excluded: 4 articles were identified as non-primary research (reviews or meta-analyses) and 6 articles were excluded due to unavailable full-text access or insufficient methodological details. This resulted in a final selection of 8 articles that met all criteria for in-depth analysis.
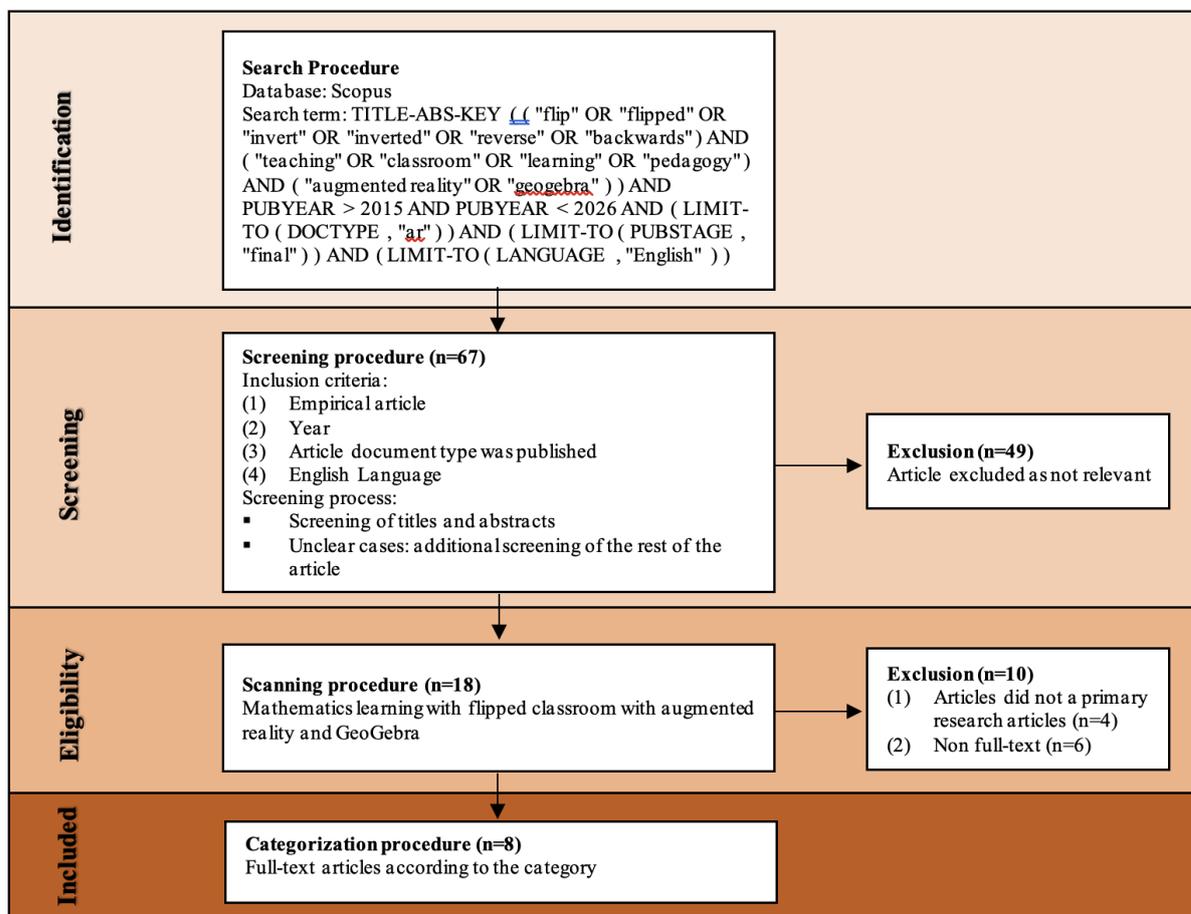


**Figure 1**. PRISMA Flow Diagram of the Selection Process

**Data Extraction and Analysis**

A standardized data extraction form was developed based on recommendations from the Cochrane handbook for Systematic Reviews of Interventions (Green & Higgins, 2024) and pilot tested on three randomly selected studies to ensure consistency and completeness (Büchter et al., 2020). The data extraction form was refined based on the pilot testing results before implementation across all included studies, following best practices for systematics review data collection (Green & Higgins, 2024). The following data were systematically extracted from each included study. The first is analyzing research studies that integrate Augmented Reality (AR) technology with GeoGebra in flipped classroom environments, a comprehensive approach is required that encompasses various critical aspects. Study characteristics must be evaluated by considering the author's identity, year of publication, country of origin, publishing journal, study design employed, and duration of intervention conducted. This aspect is essential for understanding the context and methodological quality of the research. Participant demographics, captured small size, educational level, age range, and gender distribution.

Technology integration was examined through AR technology types, GeoGebra applications, implementation approaches, and technical requirements. Pedagogical approaches were analyzed covering flipped classroom variants, pre-class and in-class activities, and assessment method employed. Learning outcomes were categorized into three dimensions: cognitive outcomes (achievement, problem-solving, conceptual understanding), affective outcomes (motivation, engagement, attitudes), and behavioural outcomes (participation, self-regulation). Assessment methods included standardized tests, researcher-developed instruments, observation protocols, and surveys. Key findings were extracted focusing on primary results, statistical significance, practical significance, and effect sizes where reported. Implementation factors encompassed success factors, challenges, teacher preparation requirements, and technological infrastructure needs. Study limitations and future research recommendations were also documented.

This framework enabled systematic comparison across studies and identification of patterns in AR-GeoGebra implementation effectiveness within flipped classroom contexts. Data extraction was conducted independently by two researchers with disagreements resolved through discussion to ensure reliability and consistency of the analysis process. Data extraction was performed independently by two reviewers (P.T.S.

and M.S.S) using a standardized electronic form, with discrepancies resolved through discussion and consultation with the third reviewer (M.) when necessary (Pieper et al., 2021).

**Quality Assessment**

The methodological quality of included studies was assessed using appropriate quality assessment tools based on study design (Drukker et al., 2021). For quantitative studies, the effective Public Health Practice Project (EPHPP) Quality Assessment Tool for Quantitative Studies was employed (Armijo-Olivo et al., 2012). This tool evaluates six domains: selection bias, study design, confounders, blinding, data collection methods, and withdrawals/dropouts. Each domain is rated as strong, moderate, or weak, with an overall quality rating derived from the component ratings.

For qualitative studies, the Critical Appraisal Skills Programme (CASP) Qualitative Research Checklist was used (Long et al., 2020). This 10-item checklist evaluates the clarity of research aims, appropriateness of qualitative methodology, research design, recruitment strategy, data collection, relationship between researcher and participants, ethical considerations, data analysis, findings presentation, and research value. Mix-method studies were assessed using appropriate frameworks that consider both quantitative and qualitative components of the research design (Nha HONG et al., 2018). Quality assessment was conducted independently by two reviewers, with disagreements resolved through discussion and third-party consultation when necessary.

**Data Synthesis**

Given the anticipated heterogeneity in study design, interventions, and outcome measures, a narrative synthesis approach was employed to integrate findings from the included studies (Popay & Britten, 2005). The synthesis was organized thematically around key research questions examining learning outcomes associated with the integration of flipped learning, AR, and GeoGebra in mathematics education, implementation strategies and pedagogical approaches, factors facilitating or hindering successful integration, and student-teacher experiences and perceptions. The narrative synthesis followed systematic procedures including preliminary synthesis, exploration of relationships within and between studies, and assessment of the robustness of the

synthesis (Green & Higgins, 2024).

Where studies reported sufficient quantitative data, effect sizes were calculated and presented descriptively, trough formal meta-analysis was not conducted due to heterogeneity in interventions and outcome measures. This systematic approach ensured a comprehensive and unbiased review of the literature while maintaining focus on high-quality, peer-reviewed research in the field, allowing for a trough examination of how, flipped learning, augmented reality, and GeoGebra are integrated in mathematics education and their collective impact on learning outcomes.

## RESULT AND DISCUSSION

### Results

### Overview of Selected Studies

This systematic literature review analyzed eight studies published between 2020-2024 investigating the integration of flipped classroom with AR and GeoGebra technologies in mathematics education. The studies encompassed various educational levels with sample sizes ranging from 30 to 442 participants across diverse contexts including Luxembourg, Indonesia, Spain, and Vietnam.

### Academic Performance Improvements

The quantitative evidence demonstrates substantial improvements in mathematics learning outcomes. Kreis et al. (2024) reported highly significant improvements with $F_{(5,191.42)} = 17.25$, $p < 0.0001$, documenting mean scores improving from approximately 11 to 16-17 on a 20-point scale (Kreis et al., 2024). Nguyen et al. (2023) found significant differences between experimental and control groups (Sig.2-tailed = 0.010) with a moderate effect size of 0.64 (Thi Tan Nguyen et al., 2023a). wong et al (2024) reported a 24.8% increase in academic performance using VARTeL technology(Wong et al., 2024). Moral- Sánchez et.al. (2022) achieved remarkable transformation from 50% failure rate in traditional methods 100% pass rate with gamified STEM approach including AR elements (Moral-Sánchez et al., 2022). These consistent improvements across diverse contexts provide robust evidence for the effectiveness of integrated approaches.

### Technology Integration Benefits

**GeoGebra Integration:** Weinhandl et al. (2020) identified four essential design categories for successful implementation: clear task definition, feedback mechanisms, context recognition, and single-source learning environments (Weinhandl et al., 2020). Ishartono et al. (2022) demonstrated that GeoGebra-integrated Flipped Learning achieved 69% effectiveness compared to conventional approaches (61%) and traditional learning (54%) (Ishartono et al., 2022b).

**Augmented Reality Implementation:** Pozo- Sánchez et al. (2021) found AR significantly improved motivation (M = 3.09) vs 2.64, p < 0.01), student-content interaction (M = 3.00 vs 2.59, p < 0.05), and problem resolution abilities (M = 3.04 vs 2.64, p < 0.05) compared to traditional flipped learning (Pozo-Sánchez et al., 2021).

## Student Engagement and Motivation

Multiple studies documented significant improvements in student engagement. Nguyen et al. (2023) reported exceptional satisfaction rates: 97.3% enjoyed the integrated method, 91.9% felt it helped them learn more effectively, and 97.3% wanted similar methods in other subjects (Thi Tan Nguyen et al., 2023b). Moral- Sánchez et al. (2022) provided evidence through 319 Classcraft comments and reported No. absenteeism during 12 sessions, with students continuing activities beyond class time (Moral-Sánchez et al., 2022).

## Implementation Challenges

Studies identified consistent challenges including varied mathematical backgrounds requiring additional support (Kreis et al., 2024), technical insfrastructure needs, and teacher preparation requirements. Wong et al. (2024) noted that students found "VR controls still wonky" and simulations not meeting real-world standards (Wong et al., 2024). Lavicza et al. (2022) emphasized that rapid technology changes create challenges for both teachers and reseachers (Lavicza et al., 2022).

## Discussion

## Theoretical and Practical Implications

The findings support constructivist learning theories and validate the TPACK framework in mathematics education. The consistent improvements in academic

performance across diverse contexts suggest that integrated flipped classrooms with AR and GeoGebra address fundamental pedagogic needs. Effect size ranging from moderate (0.64) to large (1.40) provide empirical support for technology-enhanced approaches. The three-phase implementation model emerges from the studies: (1) pre-class interactive GeoGebra engagement, (2) in-class collaborative problem-solving with AR tools, and (3) post-class authentic assessment. This framework provides practical guidance while emphasizing the importance of teacher professional development and community-based support systems.

**Future Research Directions**

The studies primarily focus on geometry topics, indicating need for boarder mathematical domain investigations. Future research should develop comprehensive assessment frameworks capturing multi-dimensional benefits and explore long-term sustainability. The COVID-19 context studies demonstrate effectiveness in hybrid environments, suggesting investigation of optimal physical-digital learning space combinations. Future research should consider design research approaches that allow for systematic development and validation of educational interventions. The development of Local Instructional Theory (LIT) through iterative design processes provides a framework for creating effective technology-enhanced learning environments (Yuspira et al., 2024)
.

**Limitations and Recommendations**

While evidence strongly supports integrated approaches, limitations include varied sample size, different duration periods, and diverse cultural contexts affecting generalizability. For practitioners, gradual implementation following established phase models is recommended, with adequate teacher preparation and technological infrastructure while maintaining pedagogical effectiveness focus. The integration of flipped classrooms with AR and GeoGebra technologies significantly enhances mathematics learning outcomes, providing robust foundation for educational practice and policy development in contemporary mathematics education.

**CONCLUSION**

This systematic literature review demonstrates that integrating flipped classrooms with Augmented Reality (AR) and GeoGebra significantly enhances mathematics learning outcomes. Following PRISMA 2020 guidelines, eight empirical studies from 2020-2024 were analyzed, revealing consistent improvements in academic performance, problem-solving abilities, and student engagement across diverse educational contexts. The quantitative evidence shows substantial learning gains with effect size ranging from moderate (0.64) to large (1.40). notable achievements include Kreis et al. (2024) documenting mean score improvements from 11 to 16-17 on a 20-point scale (Kreis et al., 2024), and Moral- Sánchez et al. (2022) achieving complete transformation from 50% failure rate to 100% pass rate (Moral-Sánchez et al., 2022). These findings provide robust support for technology-enhanced mathematics education that addresses traditional pedagogical challenges. AR technology proves particurlarly effective in enhancing student motivation and visualization capabilities, while GeoGebra provides powerful tools for mathematical exploration through dynamic geometry and interactive features. The combination creates comprehensive learning environments supporting both individual and collaborative learning, with Nguyen et al. (2023) reporting 97.3% student satisfaction and desire to use similar methods in other subjects (Thi Tan Nguyen et al., 2023a).

The findings validate constructivist learning theories and support the TPACK framework in mathematics education. The three-phase implementation model (pre-class interactive engagement, in-class collaborative problem-solving, post-class authentic assessment) provides practical guidance for educators. However, successful implementation requires adequate teacher professional development and community-based support systems to address technical challenges and rapid technological changes. While imoplementation challenges exist, including infrastucture requirements and varied student backgrounds, the consistent positive outcomes across Luxembourg, Indonesia, Spain, and Vietnam demonstrate the generalizability of these approaches. Future research should explore boarder mathematical domains beyond geometry, develop comprehensive assesment frameworks, and investigate long-term sustainability in post-pandemic educational environments.

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