

BLENDED LEARNING AND EMERGING TECHNOLOGIES IN MATHEMATICS EDUCATION: A COMPREHENSIVE STRUCTURED REVIEW

NURSAADAH JAILANI¹, ROSLINDA ROSLI², MUHAMMAD SOFWAN MAHMUD³

¹²³Faculty of Education, Research Centre of STEM Enculturation, Universiti Kebangsaan Malaysia
E-mail: ¹p109514@siswa.ukm.edu.my, ²roslinda@ukm.edu.my, ³sofwanmahmud@ukm.edu.my

ABSTRACT

Studies on blended learning and emerging technologies have transformed mathematics teaching and learning through innovative educational approaches. However, integrating these methods presents challenges, including technological hardships, instructional design complexities, and the need for appropriate digital tools. This study conducted a systematic literature review to analyse the features, issues, and prospects of implementing new technologies in mathematics education using thematic analysis. An empirical review was conducted using Scopus and Web of Science (WoS) databases, selecting scholarly publications from 2023 to 2024. The study followed the PRISMA framework, identifying 33 primary studies, which were categorized into three themes using data analysis: (1) blended learning and flipped classroom models, (2) virtual and embodied learning environments, and (3) teacher perspectives, professional development, and student learning experiences. Findings indicate that blended learning enhance student interest, attitude, and achievement, yet their effectiveness critically depends on teachers' technological and pedagogical content knowledge (TPACK) and institutional support. Additionally, the increasing use of artificial intelligence (AI) in mathematics education presents opportunities but also challenges, including implementation limitations, expertise gaps, and funding constraints. This study highlights the critical role of professional development in preparing educators to support blended learning effectively. Several recommendations are proposed for stakeholders to overcome challenges and maximize the benefits of emerging technologies. Findings provide valuable insights for researchers, educators, and policymakers in enhancing mathematics education to meet 21st-century learning demands.

Keywords: *Blended Learning, Digital Tools, Mathematics Technologies, Mathematics Teaching Innovations, Teacher Technology Proficiency.*

1. INTRODUCTION

Blended learning is a one of solution for mathematics education that combines face-to-face communication with digital technology tools. This approach has been increasingly adopted in educational institutions, specifically colleges and high schools. Moreover, blended learning has been associated with increased student interest and improved learning outcomes due to the multiple modes of access and diverse approaches it offers in mathematics instruction [1], [2], [3]. Integrating technologies such as Moodle and other programmes, has enhanced students' perceptions of mathematics, making the subject more approachable and enjoyable [4].

The application of technology in blended learning has also contributed to improvements in mathematics teaching, including the development

of flipped classrooms, hybrid models, and online practice platforms, thereby enhancing students' thinking skills, self-regulation, and problem-solving abilities [2], [3]. Consequently, the effective use of such technologies requires mathematics teachers to possess a high level of technological proficiency. For example, teachers must be capable of integrating technology into the teaching and learning of mathematics process to improve student achievement [4], [5].

However, the shift towards blended learning in mathematics teaching is not without challenges. The Technology Pedagogical Content Knowledge (TPACK) framework highlights essential aspects of technological readiness, encompassing challenges related to technological infrastructure, digital competencies and access to professional development opportunities [6], [7]. In addition, students need greater support, especially when

guided by teachers who are struggling or students in low-income urban school areas [4]. Addressing these issues is critical to improving the delivery of blended learning and ensuring equitable benefits from technological integration for all students. While several studies have explored aspects of blended learning in mathematics education, few have comprehensively synthesised how mathematics teachers' technological readiness and support structures influence its implementation. This review addresses that gap by systematically analysing current literature to identify influencing factors and practical implications.

2. LITERATURE REVIEW

Incorporating face-to-face teaching enhanced by information technology is called blended learning, which is a revolution in mathematics education. The primary features of the multimedia environment that integrates IT tools and innovations change the context of teaching-learning mathematics education involving 21st-century skills and technologies [8], [9], [10]. Numerous studies have proven that digital technologies could enhance mathematics learning by leveraging tools, such as virtual manipulatives, dynamic Geometry tools, and artificial intelligence-based learning tools [11], [12]. Such instruments encourage meaningful and student-centred practices, which engage learners with more profound and conceptual interactions.

Studies also demonstrated that blended learning solutions enhance critical thinking skills and team-based problem-solving, as well as the flexibility of the learning solutions [13], [14], [15]. For example, incorporating adaptive learning technologies allows individual learners to provide meaningful differentiation and instant feedback and support [16], [17]. Additionally, virtual and augmented realities as tools are valuable assets in creating plausible, comprehensible concepts through interactive creations that enable the concrete pits of mathematics. Nevertheless, the effectiveness of such technological interventions depends on teachers' technological and pedagogical content knowledge, which underlines the need for rigorous professional development efforts to enhance the application of such innovations [11], [18].

Multiple barriers exist in applying the blended learning system in mathematics education [19], [20]. For instance, limited resource access, weak

institutional support for integrating digital technology, and insufficient teacher training [21]. Furthermore, current studies demand more attention to examining the long-term effects of these tools on students' learning achievements and improving the best practice-based guidelines for curricula implementation [22]. Another implication of teacher self-efficacy is how various emerging technologies are implemented and how the overall instructional process is organised in blended environments, which is essential to student engagement [23].

The present study emphasised how teachers' technology expertise impacts effective blended learning [24], [25]. Efficient technological competence is the general awareness of the utilisation of the tools and the ability to incorporate them into practice to enhance mathematics learning [12], [26]. Teachers with a higher technology competency tend to provide an instructive manner in integrating technology into teaching by providing an appealing and innovative learning environment [27], [28]. Consequently, teacher training strategies must focus on using technology and effective teaching methodologies to enhance the possibilities of blended learning [29], [30]. More research is required on the interplay of technology prowess and teaching performance and the critical role of comprehensive approaches to facilitate teachers in applying technologies to develop mathematics learning experiences [31].

The use of emerging technologies in supporting blended learning to teach mathematics can transform mathematics education, provided the challenges of implementation are overcome [5], [25]. More research should emphasise increasing resource availability, improving teacher training, and explaining the effective technology usage rules [32], [33]. A structured review demonstrated a general view of the current and future development of blended learning and the issues for establishing a scientific basis for developing new techniques in teaching mathematics. However, existing reviews have not systematically mapped how technology competency and professional development intersect in shaping effective blended mathematics teaching. This review addresses that gap.

3. RESEARCH QUESTIONS

Research questions (RQs) are crucial in systematic literature reviews (SLRs) as they define the study's direction and establish clear inclusion

criteria. Well-structured RQs enhance focus, relevance, and credibility by guiding the review process, preventing ambiguity, and enabling meaningful outcomes. They systematise data, identify patterns, correlations, and gaps in the literature, ensuring the review remains aligned with its objectives. Additionally, well-defined RQs allow other scholars to replicate or build upon the study, contributing to the broader knowledge base.

This study adopts [34], PICO framework, which consists of Population (P), Interest (I), and Context (Co). The Population (P) includes mathematics teachers and students, while the Interest (I) focuses on the impact of blended learning and emerging technologies on teaching and learning. The Context (Co) refers to mathematics education. This approach supports the study's aim to explore key factors influencing the integration of blended learning technologies in mathematics education particularly from the teacher and student perspectives, as identified in the literature gap. Based on this approach, the research question is: "What are the impacts of blended learning and emerging technologies in mathematics education on instructional models, virtual learning environments, and teacher and student experiences?"

4. METHODOLOGY

This paper follows the Preferred Reporting Item for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to perform systematic literature reviews [35]. The PRISMA flow chart provides a structured framework for systematically searching, evaluating, and including studies in research synthesis. This method minimises bias and enhances the overall study quality, with a preference for randomised designs. To address these objectives, the current study used two

comprehensive databases, WoS and Scopus. The PRISMA approach was also organised into four stages: identification, screening, eligibility, and data extraction, thus ensuring a thorough and methodical review process.

The identification phase began with a comprehensive search across selected databases to collect all relevant articles. The screening phase subsequently applied specific criteria to exclude unrelated or insufficient quality studies. The remaining studies were thoroughly examined during the eligibility phase to ensure the established inclusion criteria were met. This process involved data selection, analysis, and final synthesis, which provided a summary of findings from the selected studies. These steps are critical for deriving reliable and meaningful conclusions that contribute to organisational insights. Summarily, the PRISMA framework ensures theoretical and methodological accuracy throughout the systematic review process, which supports knowledge advancement and guides future research and practice. To minimise bias and enhance rigour, this review applied predefined inclusion and exclusion criteria during the screening phase. In addition, critique criteria such as relevance to the research question, methodological transparency, and clarity of results were used to determine study eligibility. Potential threats to validity such as publication bias, limited generalisability and varying study quality were addressed by using multiple databases and transparent selection procedures.

4.1 Identification

The identification phase of the systematic literature review (SLR) emphasised a rigorous search for articles relevant to each question, considering Scopus and WoS as the primary sources of articles. Initially, 315 records were

Table 1: Keywords and Strategy to Search for Information Keywords

Database search string	
Scopus	TITLE-ABS-KEY (("blended learn*" OR "blended strategy*" OR "blended education" OR "b-learn*" OR "blended-learn*" OR "blend* learn*" OR "blended e-learn*" OR "blended learn* environment" OR "online learn*" OR "online teach*" OR "flip* teach*" OR "flip* learn*" OR "hybrid learn*" OR "hybrid teach*") AND ("technolog*" OR "artificial intelligen*" OR "virtual reality" OR "digital technolog*" OR "digital tool*") AND ("mathematic* educat*" OR "mathematic* teach*" OR "mathematic* learn*"))
WoS	("blended learn*" OR "blended strategy*" OR "blended education" OR "b-learn*" OR "blended-learn*" OR "blend* learn*" OR "blended e-learn*" OR "blended learn* environment" OR "online learn*" OR "online teach*" OR "flip* teach*" OR "flip* learn*" OR "hybrid learn*" OR "hybrid teach*") AND ("mathematic* technolog*" OR "technolog*" OR "artificial intelligen*" OR "virtual reality" OR "digital technolog*" OR "digital tool*") AND ("mathematic* educat*" OR "mathematic* teach*" OR "mathematic* teach* innovat*")

screened through Scopus. The search employed diverse terms using appropriate keywords and Boolean operators, focusing on blended learning and emerging technologies in mathematics education as shown in Table 1. Meanwhile, the WoS search resulted in 188 records. This database is unique for its high methodological standards concerning article indexing, specifically in educational research and technological publications. The same search keywords and Boolean combinations were both databases to ensure consistency and comparability. The search strategy was designed to minimise selection bias and ensure a broad coverage of relevant literature. In total, 503 records were initially identified,

reflecting the scope of current research on blended learning and emerging technologies in mathematics education. At this phase, 21 duplicate records were removed, resulting in 482 records that proceeded to the screening phase (Figure 1).

4.2 Screening

The first step of screening involved reviewing the titles and abstracts of the 482 identified records. A total of 402 records were excluded for not meeting the established inclusion criteria, which required articles to be written in English, published after 2023, and focused on blended learning or emerging technologies in the context of mathematics education. Excluded documents

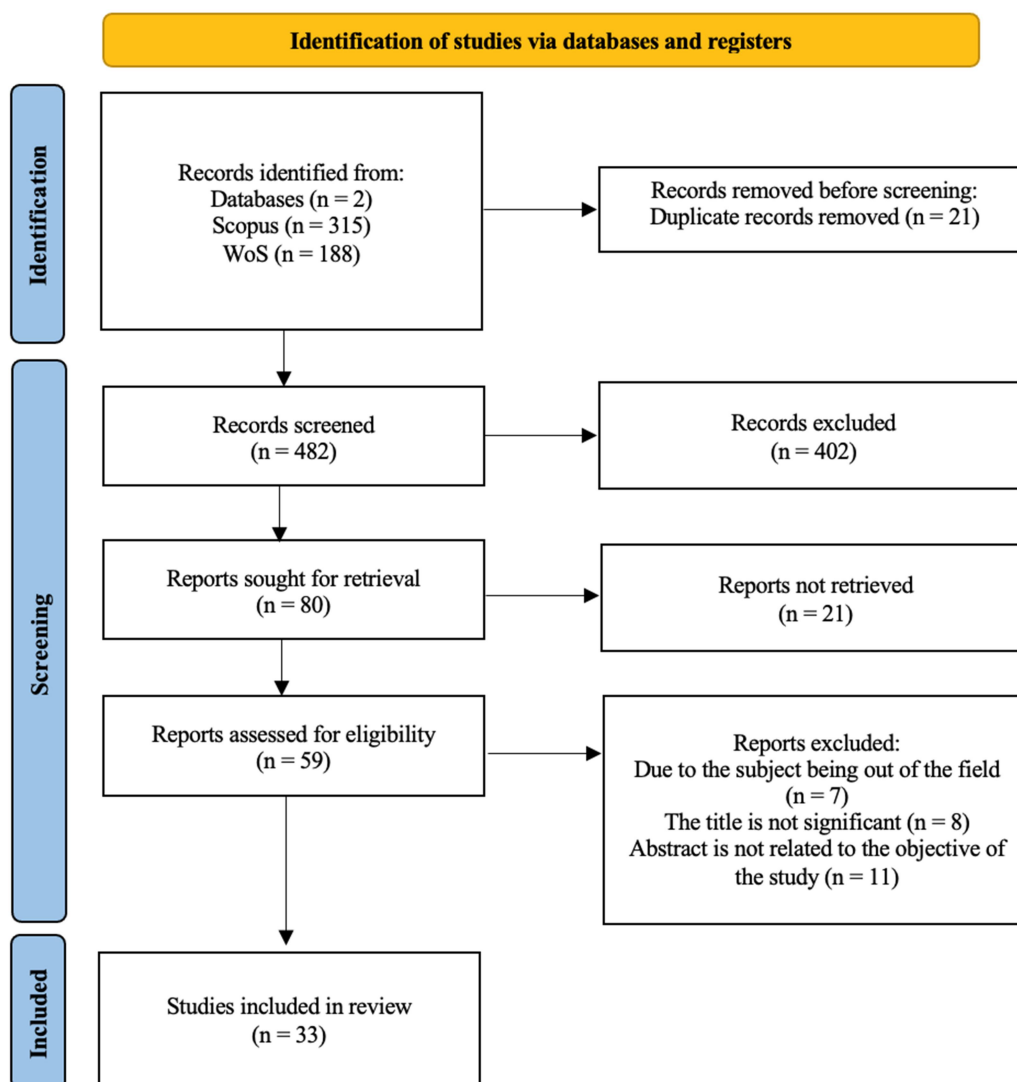


Figure 1: PRISMA flow diagram

include conference papers, review articles, book chapters and records listed as “In Press”.

Following the title and abstract screening, 80 records were shortlisted for full-text retrieval. However, 21 of these reports could not be retrieved due to access limitations, including subscription paywalls and unavailable digital versions. The remaining 59 full-text articles were assessed thoroughly to determine their eligibility. The evaluation focused on the relevance of the articles' content to the review objectives. Any articles that lacked focus on mathematics education, used vague or non-substantial titles, or had abstracts misaligned with the research questions were excluded.

This multi-step screening ensured a consistent and transparent process aligned with the review's methodological rigour. Out of the 59 full-text articles reviewed, 26 were excluded. Specifically, 7 articles were rejected because the subject matter was outside the scope of the review. Another 8 articles were excluded due to titles that lacked significant relevance, and 11 more were excluded because their abstracts did not align with the study's objectives. This strict screening phase minimised the risk of inclusion bias and strengthened the validity of the selected sample. As a result, 33 high-quality and contextually relevant studies advanced to the eligibility stage.

4.3 Included, Data Abstraction and Analysis

Following the screening and eligibility processes, a total of 33 studies met all inclusion criteria and were selected for the final review. These studies provided substantial insights into the integration of blended learning and emerging technologies within mathematics education. An integrative analysis approach was applied to organize findings and identify emerging patterns across the studies, which included quantitative, qualitative, and mixed methods research. Data from all 33 eligible publications were coded for theme generation. To ensure analytical rigour, the primary author developed initial themes based on consistent patterns aligned with the research questions. Co-authors reviewed and refined the preliminary codes, and through collaborative discussions, achieved consistent theme interpretation and enhanced the credibility of the analysis. Final adjustments were made to improve clarity, conceptual alignment and coherence in presenting the findings.

4.4 Quality of Appraisal

Based on [37] guideline, the quality of primary studies must be assessed and compared quantitatively once they are selected. The present study adopted the quality assessment framework by [38] which outlines six criteria for the SLR. Each criterion is evaluated using a scoring system: “Yes” (Y) for full compliance, which earns 1 point; “Partly” (P) for partial compliance with some limitations, which earns 0.5 points; and “No” (N) for non-compliance, which earns 0 points. The quality of the selected studies was assessed using six criteria to ensure a comprehensive and objective evaluation:

QA1: Is the purpose of the study clearly stated?

QA2: Is the interest and usefulness of the work presented?

QA3: Is the study methodology established?

QA4: Are the concepts of the approach clearly defined?

QA5: Is the work compared and measured with other similar work?

QA6: Are the limitations of the work mentioned?

These criteria provided a structured approach for evaluating the clarity, relevance, and methodological quality of each study. Each specialist assessed the studies based on these criteria and summarised the results to determine the final rating. A study was required to obtain a total score above 3.0, calculated from the combined ratings of all three experts to proceed to the next stage. Therefore, only studies that met the quality threshold were included in the subsequent phase of the review. Table 2 demonstrates the quality assessment for the selected papers.

5. RESULTS

The findings of this systematic review are organised into three overarching themes, each encompassing several subthemes that synthesise the results from the 33 selected studies in mathematics education. These themes highlight key concepts and innovative practices related to the implementation of digital and blended learning approaches.

The first theme explores Blended Learning and Flipped Classroom Models, addressing their benefits, limitations, and instructional strategies. The second theme focuses on Virtual and Embodied Learning Environments, examining the influence of tools such as virtual reality and AI-driven platforms on students' learning. The third theme examines Teacher Perspectives, Professional

Development, and Student Learning Experiences, revealing how teacher expertise, institutional support, and training initiatives affect the successful integration of technology.

Together, these themes offer a comprehensive understanding of how digital innovations are reshaping mathematics education, highlighting what contributes to effective implementation and what challenges persist despite technological advancements.

Table 2: Quality assessment for selected papers

No	Author	QA 1	QA 2	QA 3	QA 4	QA 5	QA 6	Total Mark	%
1	[39]	1	1	1	1	1	1	6	100
2	[40]	1	1	1	1	0	0.5	4.5	75
3	[41]	1	1	1	1	0.5	0.5	5	83
4	[42]	1	1	1	0.5	0	0.5	4	67
5	[43]	1	1	1	1	0.5	0.5	5	83
6	[44]	1	1	1	0.5	0.5	1	5	83
7	[45]	1	1	0.5	1	0.5	1	5	83
8	[46]	1	0.5	1	1	0.5	0.5	4.5	75
9	[47]	1	1	1	1	1	1	6	100
10	[48]	1	1	1	1	0.5	0.5	5	83
11	[49]	1	1	1	1	0.5	0.5	5	83
12	[50]	1	1	1	1	1	1	6	100
13	[51]	1	1	1	1	0	1	5	83
14	[52]	1	1	1	1	0.5	0.5	5	83
15	[53]	1	0.5	0.5	0.5	0.5	0.5	3.5	58
16	[54]	1	1	1	1	1	0.5	5.5	92
17	[55]	1	1	1	1	1	0.5	5.5	92
18	[56]	1	1	1	1	0.5	1	5.5	92
19	[57]	1	1	1	0.5	0	0.5	4.5	75
20	[58]	1	1	1	1	0.5	0.5	5	83
21	[59]	1	0.5	1	0.5	0.5	0.5	4	67
22	[60]	1	0.5	1	1	1	0.5	5	83
23	[61]	1	1	1	1	0.5	0.5	5	83
24	[62]	1	1	1	1	0.5	1	5.5	92
25	[63]	1	1	1	1	1	0.5	5.5	92
26	[64]	1	1	1	1	0	0.5	4.5	75
27	[65]	1	1	1	1	0.5	1	5.5	92
28	[66]	1	0.5	1	1	0.5	0.5	4.5	75
29	[67]	1	0.5	1	1	0.5	0.5	4.5	75
30	[68]	1	1	1	1	0	0.5	4.5	75
31	[69]	1	1	1	1	0	0.5	4.5	75
32	[70]	1	1	1	1	0.5	0.5	5	83
33	[71]	1	1	1	1	0.5	0.5	5	83

5.1 Theme 1: Blended learning and Flipped Classroom Models

The integration of classroom teaching with digital tools is a growing trend in modern mathematics education, offering the potential to enhance learning outcomes through the combination of face-to-face and online approaches. This model enables the creation of adaptive learning environments, where learners experience tailored instruction effective across varied learning levels. Within this theme, three critical sub-themes emerge. The first sub-theme, Effectiveness and

Student Outcomes, explores how blended and flipped classroom models impact achievement, interest, and learning skills. The second, Pedagogical Strategies and Implementation, discusses integration approaches, curriculum design, and teacher professional development. The third, Student Perception and Satisfaction, analyses learner attitudes, feedback, and technology acceptance. These categories provide a comprehensive perspective on the implementation, experience, and advancement of blended learning practices in mathematics education.

5.1.1 Effectiveness and student outcomes

Studies reveal that blended and flipped classroom models positively impact student performance and participation in mathematics. The author [39] highlighted that delivering 3D trigonometry by combining both approaches improved subject performance. The mean difference was 19.2% among the 12th-grade students, where using digital materials enhanced the students' conceptual learning and problem-solving abilities. Similarly, the author [41] examined elementary students' perception of the flipped classroom model post-pandemic and revealed although several students were sceptical, most had positive attitudes regarding the classroom teacher's directions. European participants identified students' digital skills and the effective use of flipped learning in practice despite the issues, such as the increased load on teachers and the need to form independent learning activities. The author [40] devised e-learning remedial videos that taught fractions, which were effective and practical and received positive student feedback. These tools demonstrated how targeted interventions can increase accessibility and engagement in mathematics instruction. The author [42] employed deep learning to promote a blended teaching and learning model that improves students' performance and interest in mathematics classes in secondary schools within ethnic regions. Overall, these findings reinforce the value of blended and flipped models in improving learning outcomes by promoting resource accessibility, content personalisation, and active engagement.

5.1.2 Pedagogical strategies and implementation

The current trends towards blended and flipped classrooms have developed new teaching-learning strategies that enhance student learning.

The author [44] emphasised the role of Professional Teacher Education (PTE) programmes in reshaping instructional practices through collaborative online learning communities. This finding reveals the variation in teachers’ ICT readiness and the need for continuous professional development. The author [45] discussed flipped learning technologies in higher education, specifically the students’ manageability and transformation of the conventional teaching method. Likewise, the author [43] promoted a technology-integrated approach among engineering students, improving mathematical problem-solving through group-based ICT sessions. These findings underscore the importance of clear implementation strategies, supportive teacher training, and purposeful design of resources to ensure effective adoption of blended and flipped classroom methods.

5.1.3 Student perception and satisfaction

Understanding student attitudes toward blended learning is vital for refining instructional delivery. The author [48] investigated polytechnic students’ satisfaction with technology-aided learning in Bangladesh and discovered that self-efficacy and social interaction positively affected the students’ attitudes despite some initial reluctance. The author [49] outlined the advantages and disadvantages of online and blended learning and emphasised teachers’ benefits and appreciation of blended and traditional forms of teaching with challenges, such as insufficient online tools and trainers’ preparation. The author [46] investigated ICT impacts on ESP learning for pre-service mathematics teachers in Ukraine and concluded that teachers’ communication abilities improved even in conflict situations such as war. Machine

these studies emphasised the significance of reducing technological challenges, increasing student self-competency, and applying learning technologies within blended and flipped classroom environments.

5.2 Theme 2: Virtual and Embodied Learning Environments

The current forms of virtual educational environments are increasingly replacing traditional models by offering immersive, interactive educational experiences in mathematics. These transformative designs leverage technology to create learning contexts that replicate or simulate real-world scenarios, thereby engaging students both cognitively and emotionally. This theme comprises two main sub-themes. Embodied and Sensory Learning, which explores how physical movement, gestures, and touch can anchor mathematical understanding. Virtual Reality and Interactive Simulations, which focus on student experimentation and concept mastery in digitally replicated environments. Both sub-themes demonstrate how these emerging approaches translate abstract concepts into experiential, practice-based learning opportunities.

5.2.1 Embodied and sensory learning

Physical and multisensory teaching and learning contexts have been demonstrated in mathematics education using movement and actions to enhance the meaning of concepts. The author [52] explained how building sine graph concepts in distance learning using sensory-motor experiences is possible. Observably, students characterised by tables based on embodied activities discovered new

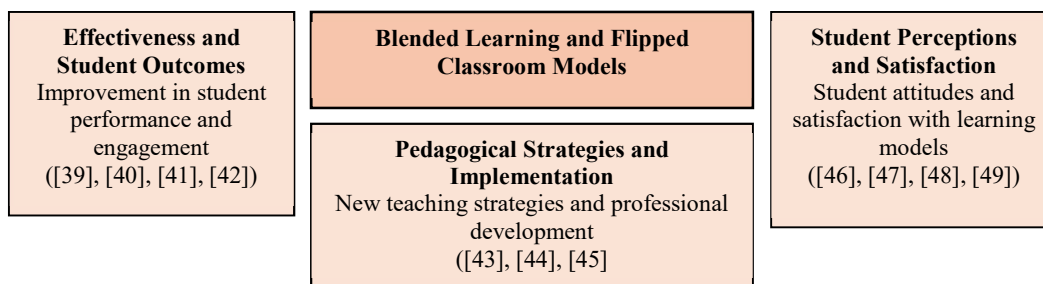


Figure 1: Theme 1 Blended learning and flipped classroom models

learning was applied by the author [47] to categorise mathematics test questions in terms of difficulty to provide optimised tasks to adaptive systems. These results support using data to deliver content relevant to a specific student. Conclusively,

movement patterns that aided mathematics problem-solving with additional teacher assistance. Similarly, the author [53] highlighted both the potential and limitations of applying embodied cognition theory in virtual learning environments,

emphasising that many body-based learning activities cannot be fully replicated in remote contexts. Nevertheless, through the strategic use of digital tools, embodied reasoning was effectively embedded in teaching practices, even without physical movement. The author [50] further expanded on this concept by introducing MOVES-NL, an AI-driven hybrid teaching system that integrates real-time student feedback with movement-based interaction. Another system incorporated whole-body movement and reinforcement learning to support the teaching of integer arithmetic, demonstrating the feasibility of blending AI and human facilitation. These systems respond dynamically to students' learning needs, encourage mathematical thinking, and offer valuable design guidance for future technology-enhanced instruction. The author [51] examined how locus conceptions could be taught using virtual environments supported by metaverse technology. The results revealed that fully developed virtual scenes enhance students' knowledge, although some issues could be more technical. These studies highlighted the positive impact of embodied and sensory learning technologies in mathematics learning technologies, along with the importance of innovation and teaching support for higher achievement.

5.2.2 Virtual reality and interactive simulations

Virtual reality (VR) and interactive simulations offer unique and exciting learning forms that help simplify complex mathematical concepts. The author [55] discussed the implementation and effectiveness of VR modules when teaching multivariable calculus. They discovered that animated icons advance students' conceptual awareness, and dynamic graphics lessons are vital for enhancement. The author [54] investigated manipulative-based interventions for teaching equivalent fractions to students with disabilities or those at academic risk. These virtual interventions, when paired with explicit instruction and a structured sequence, contributed to improved

mathematical accuracy and learner independence. The author [57] suggested that WhatsApp provided emotional support and collaborative learning despite raising concerns about distractions during high school Mathematics teaching. Additionally, the author [56] extended knowledge of interactive simulations by analysing the role of teacher noticing in online professional development. The transformative potential of VR and interactive simulations in mathematics education was demonstrated, which emphasised the need for well-designed tools and comprehensive support to ensure success. These studies suggest the potential of VR and interactive simulations in transforming mathematics education, which require adequate tools and supportive systems to succeed.

5.3 Theme 3: Teacher Perspectives, Professional Development and Student Learning Experiences

This theme focuses on teachers' roles, expertise, and training, which directly impact instructional quality and student learning outcomes. The first sub-theme is Teacher Knowledge, technological pedagogical content knowledge (TPACK) and Adaptation, analyses TPACK and how teachers modify their practices to incorporate technology. The second subtheme is Self-Efficacy, Attitudes, and Teacher Competence, which focuses on teachers' confidence, attitude, and competence while teaching in technology-integrated settings and how these impact their performance in contributing to the learning environments. The last subtheme is Student Engagement, Preparedness, and Learning Outcomes. The subtopics cover the disposition of teachers and instructional practices and their influence on student engagement, willingness to learn, and the accomplishment of learning objectives. These subthemes revealed a symbiotic nature of teacher professional development, instructional and learning environment quality, students' active engagement, and achievement of purposeful learning outcomes in educational practice.

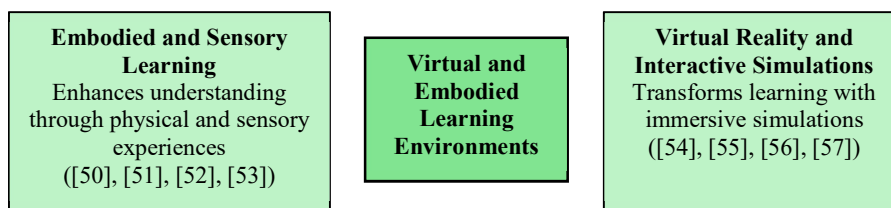


Figure 2: Theme 2 Virtual and embodied learning environment

5.3.1 Teacher knowledge, TPACK and adaptation

The current study established specific patterns of change and technology incorporation in the teaching and learning of mathematics via specific teacher characteristics and professional development. The author [58] determined the impact of classroom-related factors, such as gender, age, and years of teaching experience, on mathematics teachers’ TPACK in an online learning setting. Differences in technology envisioning were evident, with male teachers demonstrating higher confidence in using technology, while more experienced teachers exhibited stronger pedagogical content knowledge, suggesting that both gender and experience shape distinct aspects of TPACK development. The author [59] stated that their university-based online training shapes pre-service teachers’ evolving perceptions of the online mathematics teaching and learning environment. This suggests a need for systematic, scaffolded training in teacher education programmes.

The author [61] analysed teachers’ adaptation processes in Nepal before, during, and after the pandemic, emphasising that challenges of technology use continue even when people familiarise themselves with such technologies during the pandemic. Moreover, integrating these devices remains challenging in face-to-face teaching despite the teachers’ increased technology awareness. The author [60] studied the evolution of digital technologies and highlighted the transformation of mathematics classrooms by applying AI and multimodal tools. Nonetheless,

necessitates the reconceptualisation of learning spaces and teachers’ ongoing professional development. The author [62] examined teachers’ emergency remote teaching adjustment and highlighted their challenges in integrating research and problem-solving practices into an online model. Collectively, these investigations underlined the need for targeted training to equip teachers with the skills to utilise technology effectively.

5.3.2 Self-efficacy, attitudes and teacher competence

Adopting technology in mathematics classroom teaching is significantly impacted by teachers’ beliefs and perceptions of the technology. The author [65] stressed the significance of self-efficacy, perceived enjoyment, and ease of use in determining student satisfaction in a virtual learning environment. Resultantly, ICT adoption by teachers with content knowledge accelerates a positive learning environment. The author [64] discovered that although many teachers possess average technical competence in conducting online classes, they manage issues, such as motivating students to participate and issues arising from inequalities in access to teaching materials. The author [67] examined middle school mathematics teachers and discussed their use of online platforms during the COVID-19 pandemic. The results revealed that enhanced implementation yielded better results when paired with coach support where experience is a critical factor influencing the former. The author [66] investigated exemplification in mathematics education and disclosed that teachers shift their approach by

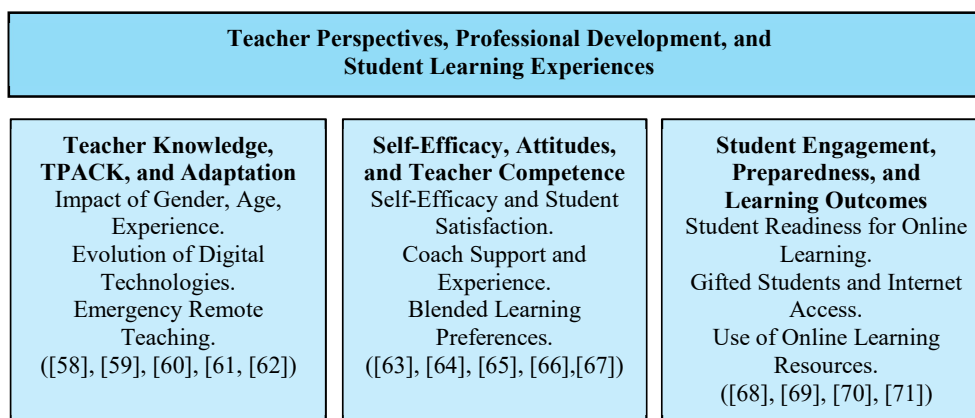


Figure 3: Theme 3 Teacher perspectives, professional development and student learning experiences

comprehending and integrating these technologies concentrating on conceptual examples instead of

procedural ones, therefore requiring higher technological pedagogical skills.

The author [63] distinguished between before, during, and after the pandemic teaching management styles in the United Arab Emirates and discovered that blended learning yielded the best academic results and was well-received by teachers despite the majority preferring face-to-face. These studies highlighted the relationship between teacher self-efficacy, attitudes, and effective technology implementation in improving student learning. These sub-themes also emphasised the relationship between teacher development, instructional quality, and student-centred learning experiences in gaining significant educational outcomes.

5.3.3 Student engagement, preparedness and learning outcomes

The sudden transition to online learning exposed varying levels of student readiness and engagement, influenced in part by teacher support and learning conditions. According to the author [69], first-year mathematics students were moderately prepared for a fully online learning delivery mode, which impacted their performance. The present study outlined the importance of role of learner autonomy and suitable technology tools. The author [71] focused on gifted mathematics students and found that while online learning reduced some social inequalities, rural students still struggled with internet and device access. The author [68] discussed intentional self-organisation to meet student needs in higher mathematics learning and research. Notably, the quarantine restrictions enhanced the learner's independent learning skills. Furthermore, learners in the online environment utilise time inefficiently and manage their study skills poorly, which outlined the teacher's role in structuring independent work.

The author [70] analysed vocational school students' voluntary use of online learning resources and reported high engagement, particularly with materials that supported relational repetition. However, slight variations in resource usage were observed across different vocational fields, suggesting that discipline-specific customisation could further enhance student engagement. Summarily, these findings highlight the importance of equipping students with self-regulation skills and ensuring equitable access to essential learning resources. Such measures are critical to supporting effective learning in both

online and blended mathematics education environments.

6. DISCUSSION

This section discusses the impact of blended learning and emerging technologies through three key areas: the effectiveness of blended learning and flipped classroom models in enhancing student engagement and learning, the role of virtual and embodied learning environments, including interactive simulations, VR, and sensory learning, in improving mathematical understanding, and the influence of teacher perspectives, professional development, and institutional support on the successful implementation of blended and virtual learning approaches.

Blended learning and flipped classroom models consistently enhance student engagement, participation, and learning outcomes in mathematics education. Students exposed to these approaches demonstrated improved conceptual understanding and problem-solving abilities due to increased access to digital content and structured opportunities for self-regulated learning [72], [73]. The integration of in-class teacher guidance provides structured reinforcement, addressing digital scepticism while fostering a more interactive learning environment [72]. However, challenges such as increased teacher workload and student struggles with self-regulated learning persist, requiring scaffolded support and adaptive instructional strategies [74].

The pedagogical effectiveness of blended learning depends on the quality of instructional design [13], [75]. Successful implementations leverage video-based instruction, interactive simulations, and collaborative problem-solving activities, which enhance student motivation and learning retention [76]. Nonetheless, disparities in technological access and student digital literacy highlight the need for institutional support and equitable infrastructure to maximise the benefits of blended learning in diverse educational settings [77].

Emerging virtual and embodied learning technologies, such as interactive simulations, VR, and sensory-motor learning, have reshaped mathematics education by providing immersive learning experiences [78]. Sensory learning activities, including tablet-based problem-solving interfaces, support cognitive development by

engaging both motor skills and conceptual understanding [79]. However, full comprehension still relies on teacher mediation, as students may struggle with independent interpretation of digital simulations.

Blended learning environments that integrate AI-driven interactions and physical learning activities have shown potential in improving arithmetic skills, student motivation, and self-assessment abilities [7], [24]. Additionally, studies on virtual immersive learning demonstrate that immersive environments can deepen conceptual understanding but are hindered by technical challenges and accessibility issues. The success of virtual learning models depends on effective instructional design, teacher facilitation, and well-structured digital interactions to ensure meaningful engagement and improved learning outcomes [80].

Teacher attitudes, confidence, and professional development significantly influence the successful implementation of blended and virtual learning models [81], [82], [83]. Teachers with higher self-efficacy in digital instruction tend to create more engaging and student-centered learning environments, while those lacking sufficient training struggle to fully integrate technology into their pedagogy [32]. Structured exposure to technology-enhanced teaching strategies in pre-service and in-service professional development has proven essential in building digital competence and pedagogical adaptability [84].

The effectiveness of blended learning also depends on teachers' ability to facilitate student engagement and self-regulation [19], [85]. While blended learning models offer flexibility and personalized instruction, challenges remain in ensuring equitable access, maintaining student motivation, and addressing technological barriers. Moreover, the shift to digital instruction highlighted the need for stronger institutional support, teacher training, and student digital literacy development to sustain effective long-term technology integration [86], [87].

7. LIMITATIONS

This study limited into blended learning and emerging technologies in mathematics education. First, the scope was constrained by the availability of recent, peer-reviewed literature, which may not

fully reflect the rapid pace of technological innovation. Second, the variability in research methodologies among the selected studies limits direct comparisons of effectiveness across different learning environments.

Additionally, most studies focus on short-term impacts, leaving gaps in understanding long-term student engagement and academic outcomes. Future research should explore longitudinal studies and examine the sustainability and scalability of technology-enhanced learning models in diverse educational contexts.

8. RECOMMENDATIONS

To enhance the impact of blended learning and digital technologies, educational stakeholders must implement strategic support systems. First, institutions should invest in structured teacher training programmes grounded in TPACK to improve digital pedagogical competence. Second, addressing technological disparities, especially those affecting marginalised communities, requires ensuring equitable access to digital tools and stable internet connectivity.

Policymakers should support evidence-based integration of VR, AI, and interactive learning platforms into curricula. Further studies should focus on long-term student engagement and achievement metrics, particularly in underrepresented educational settings. Strengthening collaboration between educators, researchers, and technology developers is essential to refine and expand effective technology-enhanced learning models.

9. CONCLUSION

This review underscores the importance of addressing digital access barriers, nurturing teacher self-efficacy, and implementing responsive instructional strategies to improve blended learning environments in mathematics education. Thoughtfully designed interventions and consistent pedagogical support are vital for maximising the effectiveness of immersive and interactive tools in mathematics education.

Moreover, equipping students with self-regulation skills and ensuring equitable access to technology is critical for achieving improved learning outcomes and higher satisfaction in digital and blended contexts. These approaches create a

more supportive, engaging, and successful learning environment, which empowers educators and students to leverage the full potential of modern educational technologies.

10. ACKNOWLEDGEMENT

This study was conducted under the Fundamental Research Grant Scheme FRGS/1/2023/SSI07/UKM/02/1, funded by the Ministry of Higher Education Malaysia.

REFERENCES:

- [1] C. Attard and K. Holmes, "An exploration of teacher and student perceptions of blended learning in four secondary mathematics classrooms", *Mathematics Education Research Journal*, Vol. 34, 2022, pp. 719–740.
- [2] Y. Helsa, Darhim, D. Juandi, and Turmudi, "Blended learning in teaching mathematics", *AKSIOMA: Jurnal Program Studi Pendidikan Matematika*, Vol. 10, No. 2, 2021, pp. 733–743.
- [3] D. H. Tong, B. P. Uyen, and L. K. Ngan, "The application of blended learning in mathematics teacher education: Protocol for a systematic review", *PLoS One*, Vol. 18, 2023, pp. xx-xx.
- [4] J. C. Anglum, L. M. Desimone, and K. L. Hill, "Integrating Computer-Based Curricula in the Classroom: Lessons from a Blended Learning Intervention", *Teach Coll Rec*, Vol. 122, No. 1, 2020.
- [5] D. Polly and A. R. Casto, "Blended Learning in Mathematics", *Advances in Early Childhood and K-12 Education*, 2019, pp. xx-xx.
- [6] D. H. Tong, B. P. Uyen, and K. N. Lu, "Blended Learning in Mathematics Teacher Education: A Systematic Review", *International Journal of Emerging Technologies in Learning (iJET)*, Vol. 18, No. 17, 2023, pp. 196–222.
- [7] D. H. Tong, B. P. Uyen, and L. K. Ngan, "The effectiveness of blended learning on students' academic achievement, self-study skills and learning attitudes: A quasi-experiment study in teaching the conventions for coordinates in the plane", *Heliyon*, Vol. 8, No. 12, 2022, pp. 1-14
- [8] B. O. Kizi Djumanova and K. S. Ugli Makhmudov, "Roles of teachers in education of the 21st century", *Science Education (Dordr)*, Vol. 1, No. 3, 2020, pp. 554–557.
- [9] M. Haviz and I. M. Maris, "Measuring mathematics and science teachers' perception on thinking and acting in 21st-century learning", *Journal for the Education of Gifted Young Scientists*, Vol. 8, No. 4, 2020, pp. 1319–1328.
- [10] Z. K. Szabo, P. Körtesi, J. Guncaga, D. Szabo, and R. Neag, "Examples of problem-solving strategies in mathematics education supporting the sustainability of 21st-century skills", *Sustainability (Switzerland)*, Vol. 12, No. 23, 2020, pp. 1-28.
- [11] J. Aliyu, S. Osman, M. F. Daud, and J. A. Kumar, "Mathematics teachers' pedagogy through technology: A systematic literature review", *International Journal of Learning, Teaching and Educational Research*, Vol. 20, No. 1, 2021, pp. 323–341.
- [12] C. R. Rakes et al., "Teaching Mathematics with Technology: TPACK and Effective Teaching Practices", *Education Sciences (Basel)*, Vol. 12, No. 2, 2022, pp. xx-xx.
- [13] H. Abuhassna, N. T. Van, N. Yahaya, M. A. Z. M. Zakaria, and F. Awae, "Strategies for Successful Blended Learning— A Bibliometric Analysis and Reviews", *International Journal of Interactive Mobile Technologies*, Vol. 16, No. 13, 2022, pp. 66–80.
- [14] M. Jamaluddin, M. Mustaji, and B. S. Bahri, "Effect of Blended Learning Models and Self-Efficacy on Mathematical Problem-Solving Ability", *International Journal of Learning, Teaching and Educational Research*, Vol. 21, No. 7, 2022, pp. 127–144.
- [15] A. S. Putri, Z. K. Prasetyo, L. A. Purwastuti, A. K. Prodjosantoso, and H. Putranta, "Effectiveness of STEAM-based blended learning on students' critical and creative thinking skills", *International Journal of Evaluation and Research in Education*, Vol. 12, No. 1, 2023, pp. 44–52.
- [16] S. Adipat, "Developing Technological Pedagogical Content Knowledge (TPACK) through Technology-Enhanced Content and Language-Integrated Learning (T-CLIL) Instruction", *Education and Information Technologies (Dordr)*, Vol. 26, No. 5, 2021, pp. 6461–6477.
- [17] F. Kayalar, "Importance of Enriched Virtual Learning Model in Hybrid Teaching Application", *Proceedings of IAC in Budapest*, 2021, pp. 23–28.

- [18] N. S. Abu Bakar, S. M. Maat, and R. Rosli, "Mathematics teacher's self-efficacy of technology integration and technological pedagogical content knowledge", *Journal on Mathematics Education*, Vol. 11, No. 2, 2020, pp. 256–276.
- [19] S. D. Govindarajan and S. G. Choo, "The Implication of Practising Blended Learning, and Conventional Learning Towards Student's Achievement and Attitude", *International Journal of Education and Pedagogy (IJEAP)*, Vol. 4, No. 1, 2022, pp. 72–90.
- [20] S. R. V. Chandra, "Blended Learning: A New Hybrid Teaching Methodology", *Jrsp-Elt*, Vol. 13, No. 13, 2019, pp. 2456–8104.
- [21] S. I. Al-Ayed and A. A. Al-Tit, "Factors affecting the adoption of blended learning strategy", *International Journal of Data and Network Science*, Vol. 5, No. 3, 2021, pp. 267–274.
- [22] C. R. Graham, J. Borup, C. R. Short, and L. Archambault, "K-12 blended teaching: A guide to personalized learning and online integration", *EdTech Books*, 2021.
- [23] E. D. Peteros, "Impact of pre-service teachers' self-regulation and self-efficacy on their mathematics performance in blended learning", *Journal of Education and Learning*, Vol. 18, No. 2, 2024, pp. 526–534.
- [24] S. Lyakhova and M. Joubert, "Post-16 Further Mathematics blended learning: Learner self-regulation, mathematical resilience and technology", *Teaching Mathematics and its Applications*, Vol. 41, No. 1, 2022, pp. 51–68.
- [25] W. Winarso and T. Udin, "Implementing Blended Learning within the TPMK Framework to Enhance Mathematics Teachers' Competence", *Edelweiss Applied Science and Technology*, Vol. 8, No. 4, 2024, pp. 2292–2305.
- [26] I. G. Ratnayake, "Teaching algebra with digital technology: Factors influencing secondary mathematics teachers' task development and implementation", *Bulletin of the Australian Mathematical Society*, Vol. 101, No. 2, 2020, pp. 350–352.
- [27] J. Njiku, V. Mutarutinya, and J. F. Maniraho, "Exploring Mathematics Teachers' Technology Integration Self-Efficacy and Influencing Factors", *Journal of Learning for Development*, Vol. 9, No. 2, 2022, pp. 279–290.
- [28] D. Thurm and B. Barzel, "Effects of a professional development program for teaching mathematics with technology on teachers' beliefs, self-efficacy and practices", *ZDM - Mathematics Education*, 2020, pp. 1411-1422.
- [29] R. Capone, "Blended Learning and Student-centered Active Learning Environment: a Case Study with STEM Undergraduate Students", *Canadian Journal of Science, Mathematics and Technology Education*, Vol. 22, No. 1, 2022, pp. 210–236.
- [30] C. Khairunnisak, R. Johar, S. Maulina, C. M. Zubainur, and E. Maidiyah, "Teachers' understanding of realistic mathematics education through a blended professional development workshop on designing learning trajectory", *International Journal of Mathematics Education in Science and Technology*, Vol. 55, No. 4, 2024, pp. 805–828.
- [31] A. Estapa, D. Schmidt-Crawford, A. Ash, and E. Sahin, "Elementary Teachers' Approach to Responsive Teaching in a Self-Regulated Mathematics Environment", *Contemporary Issues in Technology and Teacher Education (CITE Journal)*, Vol. 22, No. 2, 2022.
- [32] M. Nührenbörger, F. B. Wember, T. Wollenweber, D. Frischemeier, L. Korten, and C. Selter, "Development of teachers' attitudes and self-efficacy expectations for inclusive mathematics instruction: effects of online and blended learning programs", *Journal of Mathematics Teacher Education*, 2024, pp. 151-177
- [33] V. Volodavchyk et al., "Effectiveness of blended learning technologies in higher educational institutions", *Journal for Educators, Teachers and Trainers*, Vol. 13, No. 3, 2022, pp. 177–195.
- [34] C. Lockwood, Z. Munn, and K. Porritt, "Qualitative research synthesis: Methodological guidance for systematic reviewers utilizing meta-aggregation", *International Journal of Evidence-Based Healthcare*, Vol. 13, No. 3, 2015, pp. 179–187.
- [35] M. J. Page et al., "The PRISMA 2020 statement: An updated guideline for reporting systematic reviews", *Systematic Reviews*, Vol. 10, No. 89, 2021, pp. 1–11.
- [36] N. R. Haddaway, Page, C. C. Pritchard, and L. A. McGuinness, "PRISMA2020: An R package and Shiny app for producing PRISMA 2020-compliant flow diagrams, with interactivity for optimized digital transparency and Open Synthesis", *Campbell Systematic Review*, Vol. 18, No. 2, 2022, pp. e1230.

- [37] B. Kitchenham, "Guidelines for performing Systematic Literature Reviews in Software Engineering", *Technical Report*, 2007.
- [38] A. Abouzahra, A. Sabraoui, and K. Afdel, "Model composition in Model Driven Engineering: A systematic literature review", *Information and Software Technology*, 2020, pp. xx-xx.
- [39] J. Baidoo and K. Luneta, "Implementing blended learning to enhance the teaching of 3-dimensional trigonometry", *Journal of Education and e-Learning Research*, Vol. 11, No. 2, 2024, pp. 332–344.
- [40] R. Johar, A. R. Moulina, Mailizar, M. Lestari, and Y. Away, "Development of E-Learning-based remedial videos on fractions in middle school", *Mathematics Education Journal*, Vol. 18, No. 1, 2024, pp. 97–112.
- [41] A. Nuryadin, K. Karlimah, D. A. M. Lidinillah, and I. F. Apriani, "Blended Learning after the Pandemic: The Flipped Classroom as an Alternative Learning Model for Elementary Classrooms", *Participatory Educational Research*, Vol. 10, No. 3, 2023, pp. 209–225.
- [42] S. Xu and C. Pan, "Deep learning algorithm-oriented blended teaching in secondary school mathematics courses in ethnic areas", *Applied Mathematics and Nonlinear Sciences*, Vol. 9, No. 1, 2024.
- [43] D. Anitha and D. Kavitha, "Improving problem-solving skills through technology-assisted collaborative learning in a first-year engineering mathematics course", *Interactive Technology and Smart Education*, Vol. 20, No. 4, 2023, pp. 534–553.
- [44] C. Matitaputty, T. Nusantara, and E. Hidayanto, "How mathematics teachers' special knowledge is changing: A case study in the Professional Teacher Education program", *Journal on Mathematics Education*, Vol. 15, No. 2, 2024, pp. 545–574.
- [45] O. Papach, V. Motorina, Y. Zubitsova, and T. Pakhomova, "Technologies of flipped learning in the professional activity of lecturers of higher educational institutions", *Conhecimento & Diversidade*, Vol. 15, No. 40, 2023, pp. 591–607.
- [46] N. Dmitrenko, Y. Koliadych, L. Melnyk, and O. Voloshyna, "The use of ICT in learning ESP by pre-service teachers of Mathematics in wartime", *Texto Livre-Linguagem e Tecnologia*, Vol. 17, 2024, .
- [47] G. I. Kim, S. Kim, and B. Jang, "Classification of mathematical test questions using machine learning on datasets of learning management system questions", *PLoS One*, Vol. 18, No. 10, 2023, e0286989.
- [48] N. Y. S. Sadam and M. A. Al Mamun, "Polytechnic students' perceived satisfaction of using technology in the learning process: The context of Bangladesh TVET", *Heliyon*, Vol. 10, No. 16, 2024.
- [49] I. Skliarova, I. Meireles, T. Tchemisova, I. Cacao, and N. Martins, "Teachers' Appreciation of Benefits and Shortcomings of Online and Blended Higher STEM Education", *Education Sciences (Basel)*, Vol. 13, No. 4, 2023, pp. 338.
- [50] G. Cosentino, J. Anton, K. Sharma, M. Gelsomini, M. Giannakos, and D. Abrahamson, "Hybrid teaching intelligence: Lessons learned from an embodied mathematics learning experience", *British Journal of Education Technology*, Vol. 56, 2024, pp. 621-649.
- [51] C. K. Lo, D. T. K. Ng, and F. Ng, "Observing Mathematical Properties in the Virtual World: An Exploratory Study of Online Independent Learning of Locus Concepts", *International Journal of Science and Mathematics Education*, 2024, pp. 37-58
- [52] A. Shvarts and G. van Helden, "Embodied learning at a distance: from sensory-motor experience to constructing and understanding a sine graph", *Mathematical Thinking and Learning*, Vol. 25, No. 4, 2023, pp. 409–437.
- [53] C. Smith, "Embodied learning in a virtual mathematics classroom: an example lesson", *International Journal of Mathematics Education in Science and Technology*, Vol. 55, No. 4, 2024, pp. 1084–1095.
- [54] E. C. Bouck and H. Long, "Online Delivery of a Manipulative-Based Intervention Package for Finding Equivalent Fractions", *Journal of Behavioral Education*, Vol. 32, No. 2, 2023, pp. 313–333.
- [55] S. R. Jones, N. E. Long, and J. J. Becnel, "Design of virtual reality modules for multivariable calculus and an examination of student noticing within them", *Research in Mathematics Education*, Vol. 25, No. 2, 2023, pp. 219–242.
- [56] S. Larison, J. Richards, and M. G. Sherin, "Tools for supporting teacher noticing about classroom video in online professional development", *Journal of Mathematics Teacher Education*, Vol. 27, No. 2, 2024, pp. 139–161.

- [57] R. Segal and Y. Biton, "Teaching and learning high-school mathematics via WhatsApp: teachers' perspectives", *Learning Environments Research*, Vol 27, 2024, pp. 863-891
- [58] D. Apriandi, H. Retnawati, and A. M. Abadi, "Mathematics teachers' TPACK in online learning during the COVID-19 pandemic based on demographic factors", *Perspektivy Nauki i Obrazovania*, Vol. 63, No. 3, 2023, pp. 637–650.
- [59] F. Dilling and A. Vogler, "Pre-service Teachers' Reflections on Attitudes Towards Teaching and Learning Mathematics with Online Platforms at School: A Case Study in the Context of a University Online Training", *Technology, Knowledge and Learning*, Vol. 28, No. 3, 2023, pp. 1401–1424.
- [60] J. Engelbrecht and M. C. Borba, "Recent developments in using digital technology in mathematics education", *ZDM-Mathematics Education*, Vol. 56, No. 2, 2024, pp. 281–292.
- [61] D. R. Joshi, J. Khanal, and R. H. Dhakal, "From Resistance to Resilience: Teachers' Adaptation Process to Mediating Digital Devices in Pre-COVID-19, during COVID-19, and Post-COVID-19 Classrooms in Nepal", *Education Sciences (Basel)*, Vol. 13, No. 5, 2023, pp. 509.
- [62] A. Klemer, M. Merdler, and Y. Peled, "Perceptions, attitudes and approaches of mathematics teachers to remote teaching in an emergency", *International Journal of Mathematics Education in Science and Technology*, 2024, pp. 1-20.
- [63] H. H. Ayob and T. I. Hamada, "Teaching mathematics in an EFL context at higher education; before, during and after the COVID-19 pandemic: a comparative study", *Journal of Applied Research in Higher Education*, Vol. 16, No. 5, 2024, pp. 2262-2272.
- [64] R. Kunwar, J. K. Pokhrel, B. Khanal, and H. P. Sapkota, "A Case Study on Effectiveness of Online Teaching and Learning Mathematics: Teacher's Perspective", *Mathematics Teaching-Research Journal*, Vol. 15, No. 2, 2023, pp. 143–165.
- [65] D. Y. Millones-Liza, E. E. García-Salirrosas, J. A. Apaza-Cáceres, and R. Á. Norabuena-Díaz, "Influence of Self-Efficacy, Perceived Enjoyment and Ease of Use on Mathematics Learning Satisfaction in Virtual Environments", *Journal of Educational and Social Research*, Vol. 14, No. 3, 2024, pp. 47–59.
- [66] E. Sevimli, "Exemplification process in online education: a longitudinal study of mathematics teachers", *Learning Environments Research*, Vol. 26, No. 2, 2023, pp. 491–514.
- [67] E. B. Witherspoon et al., "Teacher Use of an Online Platform to Support Independent Practice in Middle School Mathematics During COVID-19 Disruptions", *AERA Open*, Vol. 10, 2024, pp. 23328584241230054.
- [68] N. Danyliuk, O. Horokhova, and M. Nazarenko, "Students' Self-Organization in Higher Mathematics Learning: Features and Challenges During Quarantine Restrictions", *Youth Voice Journal*, Vol. 2, No. Special Issue, 2023, pp. 7–20.
- [69] W. Morton and R. Durandt, "Learning first-year mathematics fully online: Were students prepared, how did they respond?", *Eurasia Journal of Mathematics, Science and Technology Education*, Vol. 19, No. 6, 2023, pp. em2272.
- [71] G. Xu, P. Jiang, and B. Xiong, "The Impact of Online Education on Gifted Mathematics Students from Different Family Backgrounds", *Sustainability (Switzerland)*, Vol. 16, No. 19, 2024, pp. 2071-1050.
- [72] C. H. Fung, M. Besser, and K. K. Poon, "Systematic Literature Review of Flipped Classroom in Mathematics", *Eurasia Journal of Mathematics, Science and Technology Education*, Vol. 17, No. 6, 2021, pp. 1-17.
- [73] J. Gong, S. Cai, and M. Cheng, "Exploring the Effectiveness of Flipped Classroom on STEM Student Achievement: A Meta-analysis", *Technology, Knowledge and Learning*, Vol. 29, No. 2, 2024, pp. 1129–1150.
- [74] R. Weinhandl, Z. Lavicza, and T. Houghton, "Designing online learning environments for flipped approaches in professional mathematics teacher development", *Journal of Information Technology Education: Research*, Vol. 19, 2020, pp. 315–337.
- [75] A. Bahri, I. S. Idris, H. Muis, M. Arifuddin, and M. J. N. Fikri, "Blended Learning Integrated with Innovative Learning Strategy to Improve Self-Regulated Learning", *International Journal of Instruction*, Vol. 14, No. 1, 2020, pp. 779–794.
- [76] X. Pan, "Technology Acceptance, Technological Self-Efficacy, and Attitude Toward Technology-Based Self-Directed

- Learning: Learning Motivation as a Mediator”, *Frontiers in Psychology*, Vol. 11, 2020, pp. 564294.
- [77] X. Han, “Study of the Reform of College Mathematics Blended Teaching Supported by Intelligent Technology”, *Wireless Communications and Mobile Computing*, 2022, pp. 9685652.
- [78] A. Suksakorn and A. Tubtiang, “The acceptance and effectiveness of interactive online learning in virtual face-to-face learning technology”, *International Journal of Innovation and Learning*, Vol. 27, No. 2, 2020, pp. 135–158.
- [79] H. E. Rudyanto, Marsigit, M. N. Wangid, and S. Gembong, “The use of bring your own device-based learning to measure student algebraic thinking ability”, *International Journal of Emerging Technologies in Learning*, Vol. 14, No. 23, 2019, pp. 233–241.
- [80] E. Kormos and L. Julio, “Contrasting instructional technology adoption in K-12 education to promote digital equity”, *International Journal of Web-Based Learning and Teaching Technologies*, Vol. 15, No. 3, 2020, pp. 19–30.
- [81] A. Garone, B. Bruggeman, B. Philipsen, B. Pynoo, J. Tondeur, and K. Struyven, “Evaluating professional development for blended learning in higher education: a synthesis of qualitative evidence”, *Education and Information Technologies*, Vol. 27, No. 6, 2022, pp. 7599–7628.
- [82] K. E. Yudt, B. E. Sawyer, and S. B. Shera, “Preservice elementary teachers’ mathematical achievement and attitudes: A study of blended learning”, *Journal of Mathematics Teacher Education*, Vol. 27, No. 3, 2024, pp. 355–377.
- [83] L. Ye, M. Kuang, and S. Liu, “ICT Self-Efficacy, Organizational Support, Attitudes, and the Use of Blended Learning: An Exploratory Study Based on English Teachers in Basic Education”, *Frontiers in Psychology*, Vol. 13, 2022, pp. 941535.
- [84] J. Naidoo and A. Singh-Pillay, “Exploring Mathematics Teachers’ Professional Development: Embracing the Fourth Industrial Revolution”, *Universal Journal of Educational Research*, Vol. 8, No. 6, 2020, pp. 2501–2508.
- [85] R. V. Staddon, “A supported flipped learning model for mathematics gives safety nets for online and blended learning”, *Computers and Education Open*, Vol. 3, 2022, pp. 100106.
- [86] E. Geraniou and U. T. Jankvist, “Mathematical Digital Competencies for Teaching”, University of Duisburg-Essen (Germany), July 2019, pp. 368-375.
- [87] S. Zhao and J. Song, “What kind of support do teachers really need in a blended learning context?”, *Australasian Journal of Educational Technology*, Vol. 37, No. 4, 2021, pp. 116–129.