

From Traditional to Digital: A Mini Review on Flipped Classroom in Mathematics Education

Amelia Defrianti Putri¹, Dadang Juandi^{2*}, Margaretha Madha Melissa³, Dilham Fardian⁴, Al Jupri⁵, and Turmudi⁶

^{1,2*,4,5,6} Universitas Pendidikan Indonesia, Bandung, Indonesia

³Hiroshima University, Hiroshima, Japan

*Corresponding author

Email: ameliadefrianti@upi.edu¹, dadang.juandi@upi.edu^{2*}, madha.melissa@gmail.com³, dilhamfardian@upi.edu⁴, aljumri@upi.edu⁵, turmudi@upi.edu⁶

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ABSTRACT

The flipped classroom is an instructional innovation that has been increasingly implemented in mathematics education. This model transforms traditional instruction by delivering learning materials outside the classroom through videos or reading resources, while class time is devoted to interactive activities such as discussion and problem solving. This mini-review aims to analyze the implementation of the flipped classroom in mathematics education, its impact on student engagement and learning outcomes, the challenges encountered, and strategies for effective implementation. The study adopts a mini-review approach with a systematic study selection process. Articles were retrieved from Scopus, Web of Science, and Google Scholar, covering publications from 2015 to 2024. Of the 134 articles identified, 27 studies were selected through title, abstract, and full-text screening. The findings indicate that flipped classroom implementation varies across educational levels. At the primary level, its effectiveness depends on scaffolding and adult support, whereas at the secondary and higher education levels, the flipped classroom enhances student engagement, conceptual understanding, and learning outcomes, despite challenges related to self-regulated learning readiness and unequal access to technology. Compared to traditional instruction, the flipped classroom emphasizes learner autonomy, in-class problem-solving activities, and the use of digital technologies, while requiring strong instructional design and institutional support to be effective.

ABSTRAK

Model pembelajaran *flipped classroom* merupakan inovasi pembelajaran yang semakin banyak diterapkan dalam pendidikan matematika. Model ini mengubah pendekatan tradisional dengan menempatkan materi pembelajaran di luar kelas melalui video atau bahan bacaan, sementara waktu di kelas digunakan untuk kegiatan interaktif seperti diskusi dan pemecahan masalah. Penelitian ini bertujuan untuk menganalisis penerapan *flipped classroom* dalam pendidikan matematika, dampaknya terhadap keterlibatan siswa dan hasil belajar, tantangan yang dihadapi, serta strategi optimal untuk penerapannya. Penelitian ini menggunakan pendekatan *mini-review* dengan proses seleksi studi yang sistematis. Artikel diperoleh dari basis data *Scopus*, *Web of Science*, dan *Google Scholar* dengan rentang publikasi tahun 2015–2024. Dari 134 artikel yang teridentifikasi, 27 studi dipilih melalui proses penyaringan judul, abstrak, dan teks

lengkap. Hasil kajian menunjukkan bahwa implementasi *flipped classroom* bervariasi antar jenjang pendidikan. Pada pendidikan dasar, keberhasilan model ini bergantung pada scaffolding dan dukungan orang dewasa, sedangkan pada pendidikan menengah dan tinggi *flipped classroom* mendukung keterlibatan siswa, pemahaman konsep, dan hasil belajar, meskipun masih menghadapi kendala seperti kesiapan belajar mandiri dan kesenjangan akses teknologi. Dibandingkan dengan pembelajaran tradisional, *flipped classroom* menekankan otonomi belajar, aktivitas pemecahan masalah di kelas, dan pemanfaatan teknologi digital, namun memerlukan desain instruksional dan dukungan institusional yang kuat agar efektif.

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INTRODUCTION

The flipped classroom has become an increasingly popular instructional model in the educational context in recent years (Lai & Hwang, 2016). This model reverses the traditional approach by placing direct instruction outside the classroom through digital learning resources such as videos and reading materials, while class time is used for discussions, problem-solving, and collaborative activities. Flipped classroom aims to improve student engagement, enhance learning outcomes, and provide flexibility and personalization in the learning process (Güler et al., 2023; Haavold, 2019). At the global level, efforts to improve educational quality are closely aligned with the Sustainable Development Goals (SDGs), particularly SDG 4, which emphasizes inclusive and equitable quality education and highlights the strategic role of digital technologies in enhancing teaching and learning processes. In Indonesia, this global orientation is reflected in the increasing integration of digital technologies into classroom practices, supported by government initiatives and further accelerated by the COVID-19 pandemic, which necessitated the widespread adoption of digital learning modalities (Machmud et al., 2024). These developments have created a learning environment in which technology-enhanced instructional models are not only feasible but increasingly encouraged within formal education systems.

In this context, the rapid digital transformation in education has strengthened the relevance of flipped classroom practices (Bego et al., 2022). Increased access to technology, supported by Learning Management Systems (LMS), instructional videos, artificial intelligence, and various educational applications, has enabled more interactive and flexible learning environments (Fardian et al., 2025; Putri et al., 2025). In mathematics education, digitalization facilitates access to multimedia content, the use of simulation-based tools to explore mathematical concepts, and participation in data-driven learning environments. The adoption of this model accelerated during the COVID-19 pandemic, when digital learning became a necessity rather than an optional support mechanism (Ishartono et al., 2022). Consequently, the flipped classroom has become even more relevant for subjects requiring deeper conceptual understanding, such as mathematics.

Mathematics is often perceived as a challenging subject due to its abstract and conceptual nature (Leuyacc & Parejas, 2021; Nusantara et al., 2025; Fardian et al., 2025). Traditional lecture-based teaching methods tend to limit active student engagement and reduce opportunities for students to explore concepts in depth. In traditional methods, instruction is delivered in class through lectures, followed by exercises and assignments that students must complete at home (Mncube & Maphalala, 2023). This model often restricts active participation, particularly in subjects like mathematics, which require exploration of

concepts and application in various contexts. In contrast, the flipped classroom reverses this approach by providing students access to foundational material before class through videos, online modules, or reading materials (Hashim et al., 2024; Sari et al., 2019; Juandi et al., 2025). This difference reflects a fundamental shift in how learning activities are structured, moving the focus of classroom time from content delivery to active engagement and application.

To provide a clearer understanding of how the flipped classroom model differs from the traditional approach, the following **Figure 1** illustrates the shift of learning activities from in-class lectures to pre-class independent learning and in-class interactive sessions. The class time, which is usually used for lectures, can be shifted to interactive activities, such as group discussions, problem-solving, or direct guidance from the teacher. This model not only promotes cognitive, behavioral, and emotional student engagement but also enhances learning outcomes by giving students more opportunities to understand the material before the class begins (Gong et al., 2024).

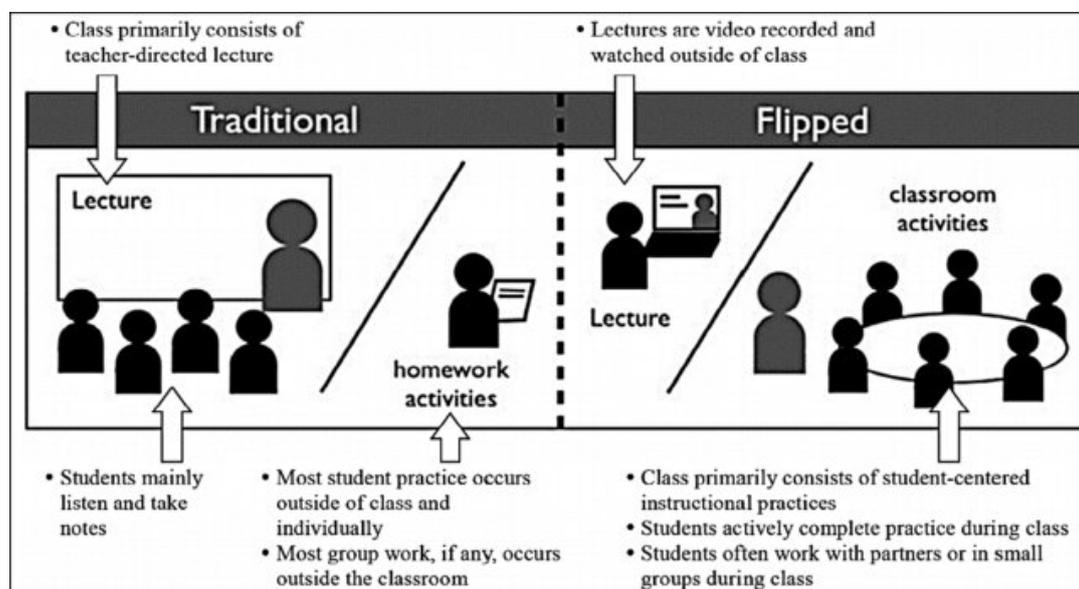


Figure 1. Flipped Classroom Model (Chun & Sathappan, 2020)

Previous research has shown that the flipped classroom can improve students' cognitive, behavioral, and emotional engagement (Putri et al., 2025). In Europe, studies conducted in Belgium, Italy, Bulgaria, Slovenia, Poland, and the Netherlands report positive perceptions from both students and teachers, particularly regarding increased engagement and active learning (De Jaegher, 2020). In the Czech Republic, the flipped classroom is reported to promote student-centered learning and support competence development (Koribská et al., 2022). Similarly, studies from Spain, particularly in vocational education, confirm the suitability of the flipped classroom across diverse learning settings, emphasizing the role of technology use and active teaching methodologies in successful adoption (Villalba et al., 2018). In Asian contexts, such as Saudi Arabia, the adoption of the flipped classroom emphasizes the need for active learning approaches while also highlighting challenges related to infrastructural and cultural readiness (Alshehri, 2017). In Turkey, the flipped classroom has been implemented in higher education, with students reporting benefits such as improved motivation and more permanent learning, despite challenges related to instructional design and technical issues (Şahin, 2020). In India, studies in business

education show that the flipped classroom improves learning performance, convenience, and interaction, although the absence of prerequisite knowledge and the need for sustained implementation remain concerns (Sandhu et al., [2021](#)).

Although a substantial body of research has documented the benefits of the flipped classroom across different educational contexts, existing studies tend to examine specific outcomes in isolation, such as student engagement or academic performance. In mathematics education in particular, there remains a lack of integrative reviews that synthesize evidence on multiple interrelated aspects, including student engagement, learning outcomes, learning flexibility, and implementation challenges. This fragmented focus limits a comprehensive understanding of how the flipped classroom can be effectively implemented and sustained in mathematics learning contexts. To address this gap, this mini-review aims to briefly examine the existing literature on the flipped classroom in mathematics education, focusing on its impact on student engagement, learning outcomes, learning flexibility, and implementation challenges. By understanding these various aspects, it is hoped that educators will gain insights on how to implement the flipped classroom method more effectively and optimally.

Accordingly, this mini-review provides a synthesis of the existing literature on the flipped classroom in mathematics education by addressing the following research questions: 1) how is the flipped classroom implemented in mathematics education across different educational contexts? 2) how does the flipped classroom differ from traditional instruction in mathematics education?

METHOD

This mini-review employed a structured literature review approach to synthesize empirical research on the implementation of the flipped classroom in mathematics education. The review process was conducted following the principles of transparency and rigor recommended for evidence synthesis studies, with the reporting of identification, screening, eligibility, and inclusion stages guided by the PRISMA 2020 statement. The use of PRISMA ensured that the search and selection process was systematic, reproducible, and clearly documented, particularly in reporting included and excluded studies along with explicit reasons for exclusion (Page et al., [2021](#)).

The literature search was carried out using three major academic databases, namely Scopus, Web of Science, and Google Scholar, which are widely recognized as comprehensive sources for high-quality educational and interdisciplinary research. The search covered publications from 2015 to 2024 to capture recent advances in flipped classroom pedagogy and digital learning environments in mathematics education. A combination of Boolean operators and keyword phrases was applied to enhance search sensitivity and specificity, including “flipped classroom” AND “mathematics education,” “flipped learning” AND “student engagement,” “flipped classroom” AND “learning outcomes,” and “active learning” AND “mathematics.” This strategy is consistent with recommended practices for systematic and semi-systematic reviews in education research, where iterative keyword refinement is necessary to balance inclusiveness and relevance (Gough et al., [2017](#)).

The initial search yielded 134 records. Duplicate records were removed, followed by a relevance screening based on titles and abstracts. This stage aimed to exclude studies that clearly did not align with the focus on mathematics education or flipped classroom implementation. After this screening process, 62 articles were retained for full-text assessment. Full-text screening was then conducted to evaluate methodological suitability

and relevance to the review objectives. As recommended by PRISMA 2020, articles excluded at this stage were documented with explicit reasons, including lack of focus on mathematics education, absence of empirical data, unavailability of full-text articles, or other methodological limitations (Page et al., [2021](#)). Following this process, 27 studies met all inclusion criteria and were selected for detailed analysis. The process of study identification, screening, eligibility assessment, and final inclusion is summarized in **Figure 2**.

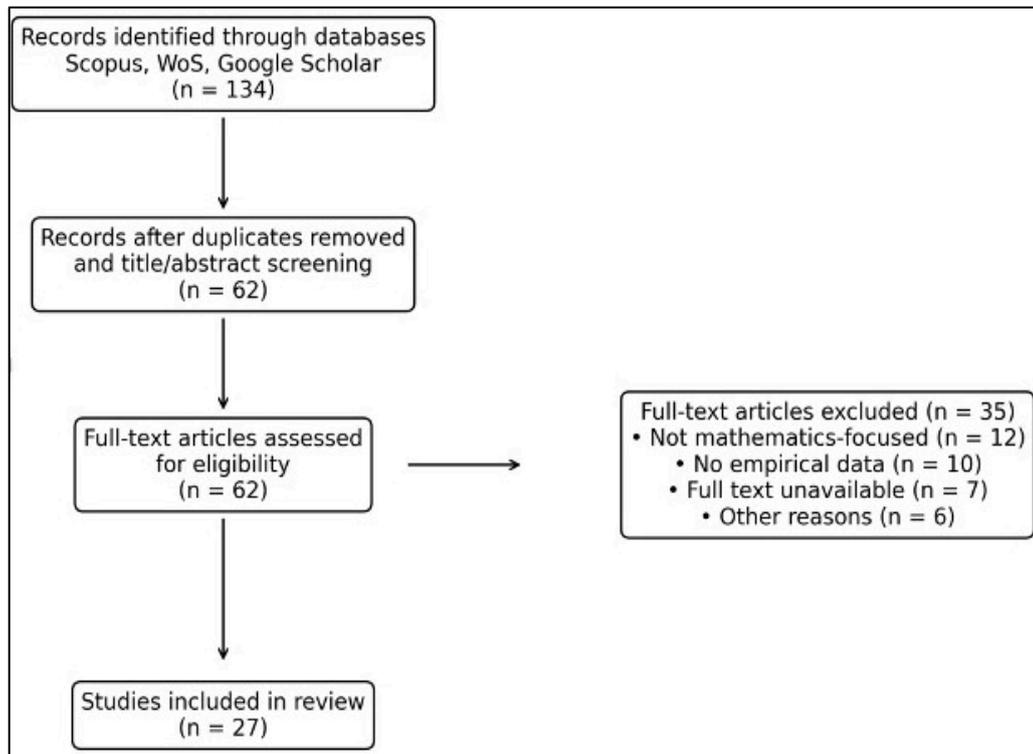


Figure 2. PRISMA flow diagram of the identification, screening, eligibility, and inclusion of studies in this mini-review.

Based on **Figure 2**, the inclusion criteria required that studies empirically investigate flipped classroom or flipped learning models in mathematics education at the school or higher education level. Eligible studies employed quantitative, qualitative, or mixed-methods designs and examined outcomes related to student engagement, learning achievement, or implementation challenges. Studies were excluded if they were purely theoretical, focused on non-mathematics disciplines, or lacked sufficient empirical evidence. These criteria were defined a priori to reduce selection bias and ensure methodological consistency across the reviewed studies.

Data extraction was conducted using a structured procedure to ensure comparability across studies, capturing information on research objectives, educational context, participant characteristics, flipped classroom design features, methodological approach, data collection instruments, and key findings. Due to heterogeneity in study designs and outcome measures, a narrative synthesis approach was applied to integrate findings, which is recommended when meta-analysis is not feasible (Popay et al., [2006](#)). The synthesis involved organizing results into recurring thematic patterns related to implementation practices, student engagement, learning outcomes, and reported challenges, following established principles of thematic analysis and evidence synthesis (Braun & Clarke, [2006](#); Gough et al., [2017](#)).

RESULTS AND DISCUSSIONS

To address research question 1 (RQ1, this section synthesizes findings from the selected studies to describe implementation patterns of the flipped classroom in mathematics education across different educational contexts. The reviewed literature indicates that the flipped classroom has been implemented at various educational levels, with adaptations shaped by students' developmental characteristics, the abstract nature of mathematical content, and contextual constraints (Putri et al., [2024b](#)). At the elementary school level, mathematics learning is typically concrete and highly structured, focusing on fundamental numeracy skills, basic operations, and intuitive concept-building. Students at this stage rely heavily on teacher guidance because their capacity for independent learning is still developing. Altemueller and Lindquist ([2017](#)) reported that although the flipped classroom is rarely implemented in elementary settings, this approach can enhance student participation when sufficient scaffolding is provided by teachers and parents. However, one of the primary challenges at this level is students' dependence on parental assistance to access and understand pre-class materials, which may limit equitable participation.

At the secondary school level, mathematics learning becomes increasingly abstract and conceptual. Students are introduced to algebraic reasoning, geometric proof, and multi-step problem solving, requiring both procedural fluency and conceptual understanding. Flipped classroom models at this stage allow students to preview foundational content before class, enabling classroom time to be used for collaborative discussions, guided problem solving, and application of concepts to more complex tasks. Research by Strelan et al. ([2020](#)) shows that this model increases learning motivation and supports differentiated instruction, as students can learn at their own pace. Nevertheless, unequal access to digital devices and stable internet connections remains a substantial barrier for secondary students, potentially limiting the effectiveness and inclusiveness of flipped classroom implementation.

In higher education, mathematics instruction emphasizes advanced abstraction, formal notation, and rigorous analytical thinking. University students are generally expected to manage their learning more autonomously, making the flipped classroom particularly suitable. Flipped classroom implementation in university-level mathematics has been associated with higher engagement, improved academic performance, and greater satisfaction compared to traditional lectures (Al-Samarraie et al., [2020](#); Chellapan & van der Meer, [2016](#)). Students benefit from the opportunity to examine theoretical explanations before class and use classroom sessions for deeper conceptual inquiry. However, procrastination remains a significant challenge at this level. Walsh ([2024](#)) found that some students delay accessing pre-class materials, reducing the intended benefits of the model. This finding highlights that while university students possess the cognitive maturity needed for flipped learning, self-regulated learning skills vary widely and must be intentionally supported.

In addition to general education contexts, the flipped classroom has also been implemented in inclusive education settings, where students with diverse learning needs require instructional approaches that offer flexibility, individualized pacing, and multimodal content. In mathematics learning, students with special educational needs often struggle with abstract concepts, rapid instruction, and the uniform pacing typically found in traditional classrooms. Altemueller and Lindquist ([2017](#)) found that the flipped classroom model provides meaningful advantages for such learners by allowing them to access instructional videos and materials repeatedly at their own pace before class.

This opportunity to preview and review mathematical explanations helps reduce cognitive load and supports deeper comprehension, particularly for learners who need more

time to process information. During in-class sessions, the freed instructional time can be used by teachers to provide targeted support, differentiated guidance, and small-group interventions, which are essential components of inclusive mathematics instruction. However, the effectiveness of flipped classrooms in inclusive settings depends heavily on the availability of accessible digital materials, parental or caregiver support, and teachers' ability to design content that accommodates diverse learning profiles. These factors indicate that while the flipped classroom has strong potential to support inclusive mathematics learning, successful implementation requires intentional planning and adequate institutional support.

Flipped classroom has consistently been linked to improved academic performance in mathematics compared to traditional learning methods. Various studies show that students who learn through the flipped classroom model achieve higher exam scores than those who learn through conventional lecture-based methods (Güler et al., [2023](#); Haavold, [2019](#)). A meta-analysis conducted by Strelan et al. ([2020](#)) found that flipped classroom generally improve the level of concept understanding and academic outcomes, especially for students who actively participate in class discussions. A study by Sari et al. ([2019](#)) also found that the use of video-based flipped classroom significantly improved students' understanding of mathematical concepts, particularly in subjects that require in-depth understanding of abstract concepts.

Some studies also highlight that flipped classrooms increase student engagement, which directly impacts their academic outcomes. Cuetos ([2023](#)) shows that student motivation increases when they feel in control of their own learning pace, leading to better understanding of mathematical concepts. However, the effectiveness of a flipped classroom is not always uniform across all educational contexts. A study by Fung et al. ([2024](#)) found that the effectiveness of a flipped classroom heavily depends on local design and student participation. If students do not actively participate in learning the material before class, the positive effects of a flipped classroom become much smaller (Buhl-Wiggers et al., [2023](#)). From a technological perspective, the use of digital tools such as GeoGebra and other dynamic geometry software in flipped classrooms has proven to enhance the understanding of mathematical concepts. Research by Kreis et al. ([2024](#)) found that the use of technology in flipped classrooms allows students to be more active in exploring mathematical concepts through interactive simulations, leading to a deeper understanding and better problem-solving abilities.

Although flipped classroom generally improve academic outcomes, some studies suggest that its long-term impact is still unclear. Fernández-Martín et al. ([2020](#)) emphasize that although flipped classroom can lead to improved academic outcomes in the short term, more longitudinal studies are needed to evaluate whether these positive effects persist in the long term compared to traditional learning methods.

Although the flipped classroom offers various benefits, its implementation in mathematics education presents several distinctive challenges. Mathematics is inherently abstract and conceptually dense, requiring learners to understand prerequisite concepts before progressing to more complex ideas. When students encounter pre-class materials independently, they may struggle to grasp foundational explanations without immediate guidance, especially in topics that involve symbolic representations, multi-step procedures, or spatial reasoning (Bego et al., [2022](#)). This difficulty is particularly evident among students who lack strong prior knowledge, making it harder for them to follow the intended learning sequence.

Students' readiness for independent learning further complicates the implementation of flipped models in mathematics. Nielsen (2023) notes that some students find it difficult to interpret mathematical explanations in videos or readings without teacher scaffolding. This issue is amplified by procrastination, where students delay engaging with pre-class materials, resulting in insufficient preparation for in-class problem solving (Walsh, 2024). Given that mathematical understanding builds cumulatively, gaps in preparation can significantly hinder the effectiveness of classroom activities.

In addition to cognitive demands, mathematics learning requires well-structured scaffolding that helps students move from concrete examples to abstract reasoning. Research by Vaičiūnienė and Kazlauskienė (2023) shows that many students still struggle with time management, self-regulation, and self-efficacy, all of which are essential for engaging with complex mathematical content independently. Hao (2016) similarly found that while students may have positive attitudes toward flipped learning, many do not feel adequately supported in developing the autonomous learning skills required to understand mathematics outside class. This indicates that stronger instructional scaffolds, including guided notes, structured prompts, and step-by-step conceptual explanations, are crucial when applying flipped classroom models to mathematics learning.

Challenges are also evident from the teachers' perspective. Designing high-quality mathematical explanations, preparing conceptual visualization tools, and creating pre-class materials that effectively break down abstract ideas demand considerably more effort than traditional teaching approaches. Chellapan and Van der Meer (2016) highlight that insufficient teacher training in digital pedagogy and mathematical scaffolding limits the effective implementation of flipped models. Moreover, Mncube and Maphalala (2023) found that institutional policies often fail to support the technological and pedagogical infrastructure needed for flipped mathematics instruction.

Overall, the success of flipped classrooms in mathematics depends not only on student readiness and technological access but also on the provision of strong conceptual scaffolding and continuous support (Herman et al., 2025). Chew et al. (2020) emphasize that many teachers are not yet equipped to guide students in developing the independent learning skills necessary to comprehend complex mathematical content before class. This highlights the need for targeted professional development and institutional support to strengthen flipped classroom practices in mathematics education.

To enhance the effectiveness of flipped classrooms in mathematics education, several strategies can be applied based on previous research findings. One key strategy is to design more structured pre-class activities to help students understand basic concepts before face-to-face sessions. Providing well-designed instructional videos and lecture notes has been shown to help students master concepts earlier and prepare them for class discussions (Song, 2020). Additionally, incorporating interactive elements such as quizzes and exercises in pre-class materials can increase student engagement and help them identify areas of difficulty before class (Ustinova et al., 2021).

Optimizing in-class activities is also crucial for the success of a flipped classroom. Face-to-face time should focus on active learning, such as group discussions, problem-solving, and collaborative work that allows students to apply concepts they have learned previously. Some studies show that combining a flipped classroom with a problem-based approach can enhance the understanding of mathematical concepts more deeply (Leuyacc & Parejas, 2021). In this process, the teacher's role becomes more of a facilitator who guides students through conceptual challenges and encourages them to work together to find solutions (Gong et al., 2024).

Integrating the flipped classroom with other pedagogical models can also improve its effectiveness. For example, inquiry-based learning has been shown to strengthen students' critical thinking skills as they are encouraged to research and find answers on their own (Schallert et al., [2022](#)). Furthermore, applying self-regulated learning strategies, such as goal-setting and time management, can help students become more independent in understanding material (Lai & Hwang, [2016](#)). By building more directed learning habits, flipped classroom can provide long-term benefits in improving student confidence and autonomy in learning. Ongoing formative assessments are also important in flipped classroom to monitor students' progress and ensure that they truly understand the material being learned (Fardian et al., [2025](#)). The use of periodic quizzes before class can help students assess their understanding of pre-class material and provide an opportunity for teachers to adjust their classroom approach (Hung et al., [2019](#)). Additionally, feedback from teachers and peers during class discussions can increase student motivation and reinforce their understanding of the concepts learned (Fung et al., [2021](#)).

The use of technology can also support the success of flipped classrooms by providing platforms that facilitate students' access to materials and interaction with teachers and peers. The use of learning management systems like MOODLE allows teachers to systematically distribute pre-class materials and collect assignments from students (Hashim et al., [2024](#)). Additionally, e-schoolbags have proven to help students organize notes and access learning materials in a more structured way, supporting the success of flipped classroom in creating a more flexible and effective learning experience (Putri et al., [2024a](#)).

To address challenges in implementing flipped classroom, strategies focused on continuous improvement based on student feedback are necessary. Studies show that flipped classrooms that undergo gradual adjustments based on student performance data are more successful in improving learning outcomes compared to models that do not undergo changes (Bego et al., [2022](#)). Additionally, it is important to ensure that students are truly prepared to learn with this model. Providing initial training on how to manage time and understand self-directed learning concepts can help students adapt to the flipped classroom method (Lai & Hwang, [2016](#)). Teachers also need to be given more in-depth training in designing digital learning materials and developing skills to guide students in the self-learning process (Chew et al., [2020](#)). By applying the right strategies, flipped classroom in mathematics education can be more optimal in enhancing student engagement, concept understanding, and overall academic outcomes.

The implementation of flipped classroom in mathematics education has shown positive impacts across educational levels, yet the strategies required for effective application differ according to students' developmental characteristics. At the primary education level, mathematics learning is still concrete and highly dependent on teacher scaffolding. Although research indicates that the flipped classroom can improve engagement and academic performance at this level, its success relies heavily on continuous support from teachers and parents (Altemueller & Lindquist, [2017](#)). Bego et al. ([2022](#)) highlight that dependence on parental assistance may worsen access to materials because not all families have the time, resources, or digital literacy needed to support early learners. These findings suggest that the flipped model at the primary level requires structured guidance, simplified materials, and strong adult involvement.

At the secondary education level, mathematics content becomes more abstract, and students begin developing greater autonomy in learning. Flipped classroom strategies at this stage tend to focus on promoting motivation, collaboration, and conceptual understanding. Studies such as Strelan et al. ([2020](#)) show promising outcomes, as students can use pre-class

content to prepare for problem solving and group activities during class. However, unequal access to technological devices and internet connectivity remains a challenge (Fung et al., 2024). This digital divide complicates implementation because consistent engagement with pre-class materials is essential for success. Consequently, strategies at the secondary level must balance increasing student independence with ensuring technological accessibility and equitable learning conditions.

At the higher education level, the flipped classroom is widely adopted and generally yields strong outcomes due to students' greater cognitive maturity and independence. Research by Chellapan & Van der Meer (2016) demonstrates improvements in engagement and satisfaction among university learners. Nevertheless, procrastination is a significant challenge at this level. Walsh (2024) notes that many university students delay viewing pre-class materials despite having the skills to manage their learning. This indicates that even at higher levels, structured accountability mechanisms such as pre-class quizzes, checkpoints, or graded preparation tasks remain necessary to ensure that students meaningfully engage with mathematical content. These strategies are critical because advanced mathematics relies heavily on prerequisite knowledge, and unprepared students may struggle during in-class discussions and problem-solving sessions.

Overall, differences in cognitive development, prior knowledge, and readiness for self-directed learning across educational levels require tailored strategies when implementing the flipped classroom. Primary students need strong scaffolding and adult assistance, secondary students need balanced support and equitable technological access, and university students need structured accountability to sustain preparation and engagement. Clarifying these distinctions strengthens the understanding of how flipped classroom models should be adapted for mathematics instruction across different learning contexts.

Technology plays a crucial role in the success of flipped classroom, especially in the context of mathematics learning. Digital tools like GeoGebra and other dynamic geometry software allow students to interact more actively with mathematical concepts, which can improve their understanding of more abstract material (Kreis et al., 2024). However, despite the effectiveness of these technologies in supporting learning, research by Vaičiūnienė and Kazlauskienė (2023) shows that not all students possess the necessary skills to use these digital tools optimally. This highlights a gap in students' digital skills, which can reduce the effectiveness of flipped classroom if adequate training is not provided to help students master the use of this technology (Putri et al., 2024).

One of the main challenges in implementing flipped classroom is students' readiness to learn independently. Research by Vaičiūnienė and Kazlauskienė (2023) highlights that many students struggle to develop the self-learning skills required for success in this model. Skills such as time management, self-regulation, and independence in learning are major challenges for students who are often not accustomed to this type of learning. This aligns with findings by Hao (2016), who stated that while most students have a positive attitude toward flipped classroom, only a few feel that this method fully meets their learning needs. This suggests that while students may have a positive outlook on flipped classroom, they still need additional support to develop the necessary skills to function independently in this learning model.

Support from educational institutions is crucial for the success of flipped classroom. Mncube and Maphalala (2023) note that the slow adoption of technology in educational systems hinders the implementation of this learning model. Educational institutions need to provide support through policies that encourage the use of technology and offer adequate

training for teachers and students to better adapt to the flipped classroom approach. This should be accompanied by policies that ensure equal access for all students so that they can actively participate in this learning model.

To address research question 2 (RQ2), a comparative analysis was conducted to identify key pedagogical dimensions that differentiate flipped classroom and traditional instructional approaches in mathematics education. The analysis focused on recurring themes emerging from the reviewed studies, including learning processes, instructional support, and implementation constraints. **Table 1** summarizes the pedagogical dimensions that consistently emerged across the reviewed studies. These dimensions reflect both instructional practices and contextual factors that influence the effectiveness of flipped classroom implementation in mathematics education. The identified dimensions form the basis for a structured comparison with traditional classroom instruction.

Table 1. Pedagogical dimensions derived from the review findings

Pedagogical Dimension	Evidence from Reviewed Studies	Relevance to Mathematics Education
Learner autonomy	Differences in students' ability to manage pre-class learning across educational levels (Altemueller & Lindquist, 2017; Walsh, 2024)	Mathematical learning requires cumulative understanding; insufficient autonomy may hinder preparation
Scaffolding intensity	Strong need for teacher and parental support at elementary and inclusive levels (Altemueller & Lindquist, 2017; Vaičiūnienė & Kazlauskienė, 2023)	Abstract concepts require guided explanations and structured support
In-class active problem solving	Classroom time used for collaborative discussion and guided problem solving (Strelan et al., 2020; Gong et al., 2024)	Supports application of mathematical concepts and higher-order thinking
Use of digital tools	Use of videos, LMS, GeoGebra, and simulations to support pre-class learning (Kreis et al., 2024; Hashim et al., 2024)	Enhances visualization and understanding of abstract mathematical ideas
Support for conceptual understanding	Reduced cognitive load through pre-class review and repeated access to materials (Sari et al., 2019; Fernández-Martín et al., 2020)	Essential for mastering symbolic and abstract mathematical content
Implementation challenges	Issues related to student readiness, procrastination, access to technology, and teacher preparation (Bego et al., 2022; Chellapan & Van der Meer, 2016)	Directly affects the sustainability and effectiveness of flipped classroom implementation

Based on the pedagogical dimensions identified in **Table 1**, a synthesis-based comparison between traditional and flipped classroom models is presented in **Figure 3**.

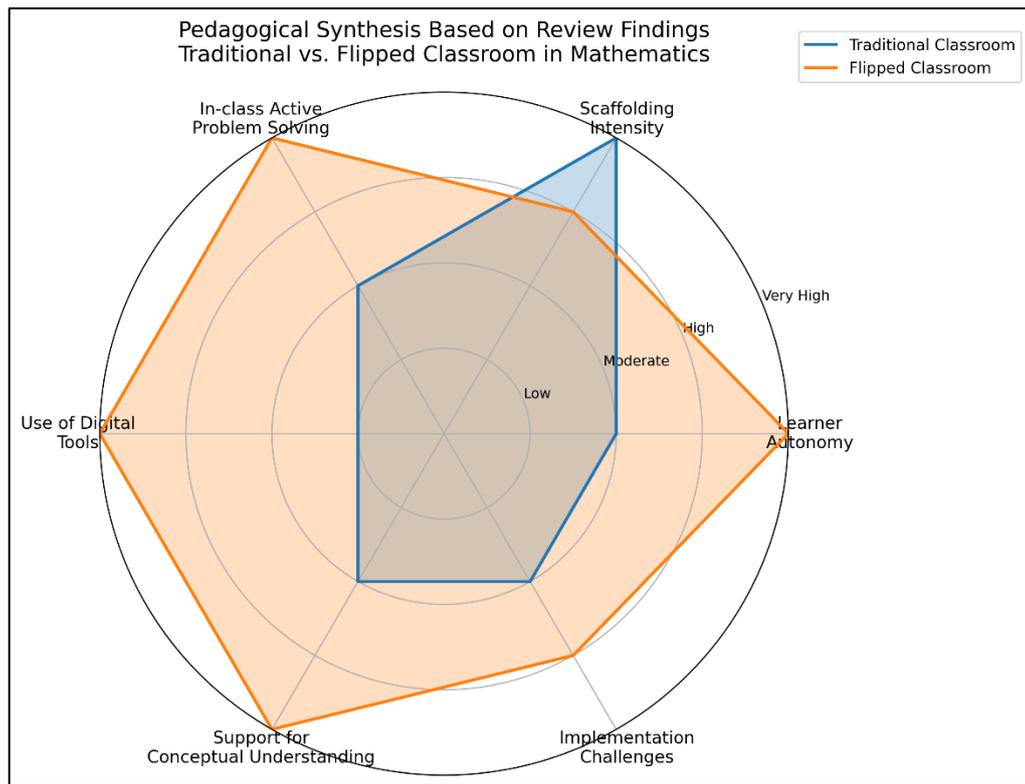


Figure 3. A synthesis-based pedagogical comparison between traditional and flipped classroom models in mathematics education.

Based on **Figure 3**, although the flipped classroom has proven to increase student engagement and academic outcomes, its success depends heavily on students' readiness, access to technology, teacher training, and institutional support. Challenges such as students' readiness for self-directed learning, technological gaps, and limitations in teacher training must be addressed for flipped classroom to be implemented more effectively. Continuous adjustments and improvements based on feedback from students and teachers will further enhance the effectiveness of flipped classroom in mathematics education.

CONCLUSIONS

This mini-review addressed two research questions concerning the implementation and pedagogical characteristics of the flipped classroom in mathematics education. In response to RQ1, the findings indicate that the flipped classroom has been implemented across different educational levels with varying forms of adaptation. At the primary level, successful implementation relies heavily on strong instructional scaffolding and adult support, given students' limited readiness for independent learning. At the secondary level, flipped classroom models support motivation, collaboration, and conceptual understanding, although their effectiveness is often constrained by unequal access to digital resources. In higher education, the flipped classroom is more widely adopted and generally yields positive outcomes due to students' greater autonomy, yet challenges such as procrastination and inconsistent engagement with pre-class materials remain evident. These variations highlight that effective implementation of the flipped classroom in mathematics education must be carefully aligned with learners' developmental readiness, access to technology, and contextual support systems.

With regard to RQ2, the review demonstrates that the flipped classroom differs from traditional instruction by placing greater emphasis on learner autonomy, in-class active problem solving, and the use of digital tools to support conceptual understanding. Compared to traditional lecture-based approaches, flipped classrooms provide more opportunities for students to engage with mathematical concepts through collaborative activities and guided problem-solving during class time. However, the findings also reveal that flipped classroom implementation involves higher levels of instructional complexity, including increased demands for well-designed pre-class materials, effective scaffolding, and teacher preparedness. These characteristics suggest that while flipped classrooms offer clear pedagogical advantages for mathematics learning, their effectiveness is not automatic and depends on intentional instructional design.

Taken together, these findings suggest that the flipped classroom holds substantial potential for enhancing engagement, conceptual understanding, and learning outcomes in mathematics education, provided that appropriate instructional and institutional conditions are in place. Rather than functioning as a universally effective model, the flipped classroom requires deliberate instructional design, support for students' self-regulated learning, and equitable access to technological resources. Future research should therefore focus on identifying mathematics-specific scaffolding strategies, examining interventions that strengthen students' readiness for independent learning, and investigating the long-term effects of flipped classroom implementation across educational levels.

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