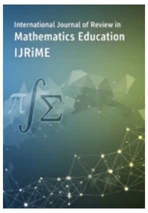

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A Systematic Critical Review: Flipped Learning and Its Impact on Self-Efficacy in Mathematics Education

Naufal Ishartono[1,✉], Rizky Oktaviana Eko Putri[2], Kristof Fenyvesi[3], Manuel O. Malonisio[4]

[1]Faculty of Education and Teacher Training, Universitas Muhammadiyah Surakarta, Indonesia
[2]Faculty of Education, University of Malaya, Malaysia
[3]Finnish Institute for Educational Research, University of Jyväskylä, Finland
[4]College of Teacher Education, Aklan State University, Banga, Aklan, Philippines

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Abstract

Although the flipped learning model has been widely recognized to improve student engagement, its specific pedagogical effectiveness on self-efficacy in the context of abstraction-laden mathematics education has not been explored in depth. In addition, there has been no critical study that dissects the ambiguity of empirical findings related to operational challenges and cognitive burdens faced by students and educators in the field. Therefore, this critical review research aims to investigate the impact of the implementation of flipped learning on mathematical self-efficacy while identifying methodological and operational challenges in practice. The study adopted the PRISMA framework and the PICO search strategy to curate and critically evaluate 10 highly reputable empirical articles published in the 2020–2025 time frame from the Scopus, Web of Science, and ERIC databases. The results of the synthesis showed that flipped learning was significantly able to significantly improve math self-efficacy, mitigate anxiety, and serve as an equity intervention for low-performing students, especially when supported by self-regulated cognitive strategies (SRCS) and interactive media in the pre-grade phase. However, this success was severely limited by significant challenges, including students' difficulties in understanding abstract concepts independently, spikes in workload, as well as the scarcity of digital literacy and time constraints experienced by educators. Theoretically and practically, these findings provide an essential foundation for educators and policymakers to integrate pedagogical scaffolding and assistive technologies, such as AI-driven chatbots, to minimize students' cognitive barriers and design a more responsive and equitable future math learning ecosystem.

Keywords: flipped learning, critical review, PRISMA, PICO

✉***Corresponding Author:***
Naufal Ishartono, Jl. A. Yani, Pabelan, Kartasura, Sukoharjo, Jawa Tengah 57169 Indonesia
Email: naufal.ishartono@ums.ac.id

1. Introduction

Many previous studies have aimed to improve the quality of mathematics learning comprehensively, but mathematics education globally currently still faces serious challenges related to low academic achievement and lack of student involvement in the classroom (Ishartono et al., 2022). The latest data report from the Programme for International Student

Assessment (PISA) in 2022 shows a significant decline in mathematics literacy scores in various countries, where low performance is strongly correlated with high anxiety and lack of confidence in students' basic mathematical abilities (OECD, 2023). This real condition highlights a fundamental problem that a crisis of confidence in students is an absolute prerequisite that educators must solve before exploring advanced cognitive strategies. Therefore, the right pedagogical approach is needed to solve the crisis.

By definition, mathematical self-efficacy is an individual's belief in his or her capacity to plan and execute a series of actions necessary to solve mathematical problems (Zakariya, 2022), while flipped learning is defined as a pedagogical approach that flips traditional teaching models by transmitting material outside the classroom through asynchronous digital media (Wang, 2022). The flipped learning model is empirically claimed to be able to improve students' self-efficacy and thinking skills in a structured and sustainable manner (Wei et al., 2020). The main reason is that this approach provides cognitive autonomy and flexibility for students to process information according to their respective comprehension speeds without social pressure before class begins (Snead, 2022). This is evidenced by experimental studies that show that the implementation of interactive media-assisted flipped learning has been shown to stimulate learning independence and lower math anxiety levels by more than 40% in classroom environments with limited resources (Yu et al., 2024). Thus, flipped learning offers a very promising pedagogical solution to directly address the low self-efficacy of today's students' mathematics.

Although the empirical literature on flipped learning and self-efficacy is growing rapidly, the critical review approach is an essential solution in this study to dissect the existing literature . Critical review allows researchers to not only aggregate quantitative data but also conduct an in-depth evaluation of the methodological quality, pedagogical rationality, and contextual biases of previous studies (Kraus et al., 2020). This evaluative approach is indispensable to unravel the ambiguity of empirical findings in the field so that this research can produce a comprehensive conceptual synthesis related to the effectiveness of flipped learning.

Several previous review studies and research have attempted to explore this domain. A systematic review by Algarni (2025) evaluated the pedagogical impact of flipped learning on students' self-efficacy across age groups and subject domains on a macro scale. In addition, experimental research by Buhl-Wiggers et al. (2023) reviewed the challenges of student resistance to flipped classrooms and their effect on academic achievement. Furthermore, a study by Cuetos (2023) explores the stimulation of the flipped classroom model on student performance at the university level. However, there have been no critical review studies that specifically dissect and critique the pedagogical mechanism of flipped learning and the relevance of its direct impact on self-efficacy exclusively in the context of mathematics education. This research has the crucial benefit of providing a new theoretical framework and evidence-based practical recommendations for policymakers and educators to design a precise flipped learning ecosystem that is free from methodological bias.

Based on the rationalization above, this critical review research aims to investigate the impact of flipped learning on mathematics self-efficacy by formulating the following research questions:

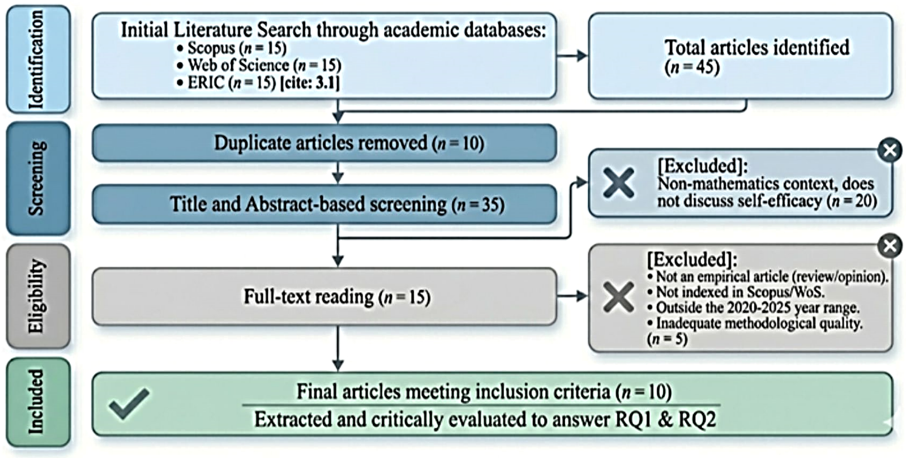

Figure 1. PRISMA Steps

- ***RQ1***: *How does the application of flipped learning affect students' self-efficacy in mathematics learning?*
- ***RQ2***: *What are the challenges faced by teachers and students in the implementation of flipped learning in mathematics classrooms?*

2. Method

Researh Design

This study uses a systematic critical review approach to evaluate and synthesize the literature in depth on the impact of flipped learning on self-efficacy in the context of mathematics education. In contrast to traditional systematic reviews that focus on aggregation of final results, the critical review method is designed to dissect methodological quality, identify research gaps, and critique the pedagogical rationality of the existing literature (Lo, 2020). To ensure a rigorous, transparent, and replicable article selection process, this study adopted the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guideline (Moher et al., 2009).

Figure 1 illustrates a four-phase systematic literature review process, broken down into Identification, Screening, Eligibility, and Inclusion. During the initial "Identification" phase, a literature search was conducted across three academic databases—Scopus, Web of Science, and ERIC—yielding 15 articles from each, culminating in a total of 45 identified records. The process then advanced to the "Screening" phase, beginning with the removal of 10 duplicate articles. The remaining 35 articles underwent a title and abstract-based screening, which resulted in the exclusion of 20 articles because they either lacked a mathematics context or failed to discuss self-efficacy.

Following the initial screening, the remaining 15 articles entered the "Eligibility" phase, which involved a comprehensive full-text reading. At this stage, 5 additional articles were excluded based on specific criteria: they were not empirical articles (such as reviews or opinions), were not indexed in Scopus or Web of Science, were published outside the designated 2020–2025-time range or possessed inadequate methodological quality. Ultimately, the "Included" phase confirms that exactly 10 final articles met all the necessary inclusion criteria. These selected articles were then extracted and critically evaluated to answer the study's primary research questions, denoted as RQ1 and RQ2.

Table 1. PICO-based keywords

Aspect	Description	Keywords
Population (P)	Students or students who are studying mathematics	students, pre-service mathematics teachers, pupils, mathematics education
Intervention (I)	Implementation of a reverse learning model	flipped learning, flipped classroom, inverted classroom
Outcome (O)	Mathematical self-efficacy	mathematics self-efficacy, self-belief, math confidence.

ALL ("flipped learning" OR "flipped classroom" AND "self-efficacy" AND "mathematics")

Show less

Figure 2. Sample of implemented string

Literature Search Strategy and PICO Framework

A comprehensive literature search was conducted on three highly reputable academic databases, namely Scopus, Web of Science (WoS), and ERIC, to find quality articles relevant to the topic (Janibek Saukhanov & Kudiyarov Kishibay, 2023). To formulate precise search keywords, the search strategy was built using the PICO (Population, Intervention, Comparison, Outcome) principle (Cooke et al., 2012), wherein in this study, the Comparison aspect was not used because the research was not comparing with anything. The results can be seen with the following details on Table 1:

This keyword combination is associated with Boolean operators (AND/OR) to optimize search results on the database engine, where examples are as follows on Figure 2:

Inclusion Criteria

To maintain the novelty and quality of the data synthesis, the articles netted must meet strict inclusion criteria. Inclusion criteria include: (1) empirical research articles (quantitative, qualitative, or mixed-methods); (2) issued within the last five years (2020–2025); (3) published in a peer-reviewed journal indexed by Scopus or WoS; (4) focus on the evaluation of flipped learning and its impact specifically on mathematical self-efficacy; and (5) written in English. In contrast, the exclusion criteria include: (1) articles in the form of opinions, book chapters, proceedings without rigorous review, or literature review documents (to avoid duplication of data); and (2) research that measures self-efficacy in general without the specific context of mathematics education.

Data Extraction and Critical Assessment

Articles that pass the final selection are not only extracted from their main findings but also critically evaluated. The extraction process involves tabulating data regarding the research design, sample characteristics, self-efficacy measurement instruments used, and the validity of findings. Critical appraisal is carried out by examining the potential bias of the sample, the weaknesses of the psychometric instruments used to measure self-efficacy, and the pedagogical context of the flipped learning integration.

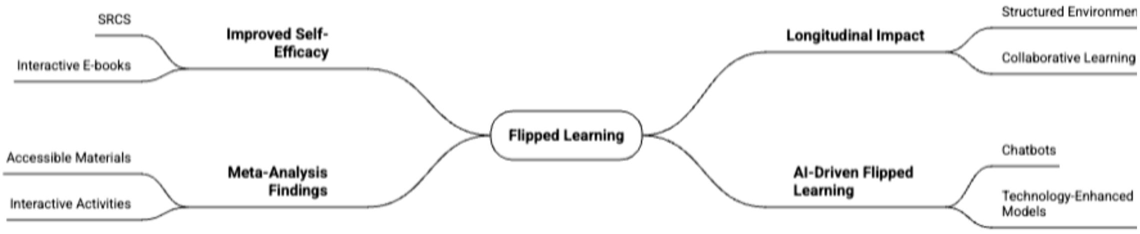

Figure 3. Impact of flipped learning on mathematics self-efficacy

3. Results and Discussion

Result

RQ1: *How does the application of flipped learning affect students' self-efficacy in mathematics learning?*

Overall, empirical evidence from various recent literature studies confirms that the implementation of the flipped learning model has a significant positive impact on improving students' self-efficacy in mathematics learning (see Figure 3). This pedagogical model, which moves direct instructional delivery outside the classroom (usually through video or digital materials) and uses class time for active and collaborative learning, seems to address the root cause of students' low confidence in math. Compared to traditional lecture-based models where students often feel passive and isolated when faced with difficulties, flipped learning environments offer a more dynamic support structure that is responsive to students' individual needs.

One of the main mechanisms identified contributing to this increase in self-efficacy is the emphasis on structured pre-class preparation. A study by Han et al. (2025) on seventh-graders highlights the importance of integrating Self-Regulated Cognitive Strategies (SRCS) in the pre-grade learning phase. Researchers found that when students were equipped with strategies for managing their self-paced learning before face-to-face meetings, they developed stronger confidence in their ability to master complex math material. This shows that flipped learning is not just about moving lectures but about equipping students with metacognitive skills to learn independently.

Furthermore, the integration of metacognitive strategies in pre-class activities has proven crucial in reducing math anxiety, which is often the antithesis of self-efficacy. When students feel better prepared through directed and self-directed learning, they enter the classroom with lower levels of stress and higher cognitive readiness to participate in advanced discussions and problem-solving. Han et al. (2025) assert that effective pre-class preparation creates a strong psychological foundation, allowing students to view math challenges as learning opportunities rather than as threats to their abilities.

Another crucial aspect of the success of this model lies in the use of interactive digital learning tools to bridge the learning space. Gwo-Jen Hwang & Chiu-Lin Lai (2017) demonstrate that flipped learning approaches that utilize interactive e-books significantly facilitate and connect learning outside the classroom with in-class activities. These tools allow students to actively interact with learning materials, conduct self-assessments, and receive hands-on feedback, all of which are powerful sources of information for building self-efficacy. The ability to control the pace of self-learning in this digital environment helps students build a solid conceptual understanding before applying it in the classroom.

It is important to note that the benefits of improving self-efficacy through this interactive e-book-based approach are not uniform among all students, but they provide the most transformative impact for certain groups. Gwo-Jen Hwang & Chiu-Lin Lai (2017) found key findings that this approach is particularly beneficial for students who have lower levels of initial self-efficacy. These findings are particularly pedagogically significant, as they show that flipped learning can serve as an equity intervention, helping students most vulnerable to math failure to rebuild their confidence and catch up academically from their peers.

The evidence for the positive impact of flipped learning is not only limited to short-term studies, but is also confirmed through longitudinal analysis. A one-year study conducted by Nokelainen et al. (2025) on first-year engineering students revealed very important findings regarding the stability of self-efficacy over time. Traditionally, in challenging advanced math courses, students' self-efficacy has often declined sharply as the complexity of the material increases. However, the study found that the flipped learning model successfully mitigated the drastic decline.

Nokelainen et al. (2025) identified that a structured and collaborative learning environment in a flipped learning model is a key factor in maintaining high levels of self-efficacy at the college level. Instead of relying on a passive lecture model, these engineering students engage in classroom activities that emphasize teamwork and practical application of mathematical concepts. This structure not only strengthens the understanding of the content but also fosters a feeling of social and academic competence, which together maintains students' confidence in their mathematical abilities despite being faced with a tough curriculum.

To reinforce these individual findings, a systematic review of 44 studies by Algarni (2025) provides confirmation of a global synthesis regarding the effectiveness of this model. The review confirms that flipped classrooms significantly improve the self-efficacy of students across different age groups, ranging from elementary to higher education, and across a wide range of disciplines, with very strong effects observed in the domain of mathematics. This meta-analysis identified two key determinants of success: the accessibility of pre-class materials (ensuring students can learn anywhere and anytime) and the interactivity of in-class activities that encourage active engagement.

Finally, the future of flipped learning and its impact on self-efficacy is increasingly enriched by the latest technological innovations, such as artificiais intelligence (AI). Jeong & González-Gómez (2021) explore the integration of AI tools, specifically chatbots, in reverse classroom model mathematics education for prospective teachers. This study shows that the use of chatbots as interactive learning assistants available 24/7 can provide instant and personalized support during both the pre-classroom and in-class phases. This pedagogy-driven integration of AI has been shown to have a positive influence on the self-efficacy of prospective teachers, which in turn will have an impact on how they teach mathematics in the future. This demonstrates the great potential of technology-enhanced flipped models to create a more responsive and empowering learning ecosystem.

RQ2: *What are the challenges faced by teachers and students in the implementation of flipped learning in mathematics classrooms?*

Table 2. Challenges in the Implementation of Flipped Learning in Mathematics Education

Stakeholder Category	Specific Challenge	Academic Description & Pedagogical Impact	Key References
Student	**Difficulties with Pre-Class Preparation**	Students frequently struggle to autonomously assimilate instructional materials prior to class. This is particularly evident when encountering abstract and high-level mathematical concepts without immediate instructor guidance, which can lead to early cognitive misconceptions.	(Hwang & Lai, 2017; Lai & Hwang, 2016)
Student	**High Demand for Self-Regulation**	The flipped model shifts the locus of learning management from the teacher to the student. Learners with underdeveloped self-regulation skills face significant hurdles in self-motivation, time management, and comprehension monitoring, making them highly susceptible to academic disorientation.	(Lai & Hwang, 2016)
Student	**Pedagogical Unfamiliarity and Resistance**	Accustomed to traditional, passive lecture formats, students often experience cognitive dissonance and anxiety when transitioning to an active learning paradigm. This abrupt shift in role expectations frequently triggers initial resistance and confusion.	(Lo et al., 2017)
Student	**Increased Academic Workload**	The mandate to engage with digital resources (e.g., instructional videos, interactive modules) outside of formal school hours drastically increases students' independent study time. This substantial workload risks inducing academic burnout and diminishing intrinsic motivation.	(Kim et al., 2024)
Teacher	**Technical and Logistical Demands**	Educators face steep technical learning curves, including the creation, editing, and curation of high-quality multimedia content. The lack of professional development in digital literacy exacerbates the difficulty of orchestrating a seamless flipped ecosystem.	(Algarni, 2025; Maarif et al., 2022; Umam et al., 2019)
General / Shared	**Time-Intensive Nature**	Both stakeholders experience a substantial drain on time. Teachers must invest exorbitant hours in instructional design and video production, while students bear the dual burden of pre-class preparation and in-class participation, threatening the model's longitudinal sustainability.	(Maarif et al., 2022; Umam et al., 2019)
General / Systemic	**Infrastructure and Accessibility Limitations**	The efficacy of flipped learning is entirely contingent upon reliable internet connectivity and adequate digital hardware. In under-resourced educational settings, these infrastructural deficits can paralyze implementation and inadvertently exacerbate the digital divide.	(Elhilal, 2025; Lo et al., 2017)

Although flipped learning offers a range of significant benefits in improving self-efficacy and student engagement, a literature review shows that its implementation in the mathematics classroom is inseparable from a variety of operational and pedagogical constraints (see Table 2). These challenges cover a broad spectrum, ranging from cognitive and psychological barriers at the student level, the technical and logistical burdens faced by educators, to infrastructure limitations in general. Identifying and understanding these barriers is a crucial step for policymakers and education practitioners to comprehensively evaluate the effectiveness of these models and design appropriate mitigation strategies.

At the student level, one of the most fundamental challenges centers on the difficulty in conducting pre-class preparation. In the flipped learning model, students are required to construct initial understanding independently through digital materials before entering the classroom. However, the literature confirms that many students experience significant difficulties in understanding instructional material autonomously, especially when they are faced with mathematical concepts that are highly abstract in nature and require a high level of reasoning (Hwang & Lai, 2017; Lai & Hwang, 2016). The absence of direct guidance or assistance from teachers in this crucial phase often leads to initial misconceptions that hinder the process of further assimilation of knowledge.

Closely related to the obstacles of pre-class preparation, the next challenge leads to the high demands of self-regulation. The inverted learning model inherently shifts the responsibility of learning management from the teacher to the students' shoulders. Students are required to independently motivate themselves, allocate time, and monitor their level of understanding. Unfortunately, students who do not yet have mature self-regulation skills are particularly vulnerable to disorientation and difficulty managing their learning effectively in this ecosystem (Lai & Hwang, 2016). This risks backfire, where students who are less independent will fall further behind academically before the face-to-face discussion session begins.

In addition to cognitive burden and independence, psychological obstacles in the form of students' unfamiliarity with this pedagogical model are also prominent obstacles (Setianingsih et al., 2026). The majority of students have for years been conditioned in a conventional learning model that positions them as passive recipients of information. Therefore, this sudden paradigm shift towards highly active learning and demanding autonomous participation often triggers confusion, anxiety, and even initial resistance from students (Lo et al., 2017). It takes a clear transition phase and pedagogical scaffolding for students to adapt and accept the expectations of their new role.

The logical consequence of the demands of independent preparation and role adaptation is the spike in workload that is clearly felt by students (Chen et al., 2026). The implementation of flipped learning practically requires students to invest much more time outside of formal school hours to watch instructional videos, read modules, and complete formative quizzes. For some students, especially those who take advanced courses or have a busy schedule, the addition of these autonomous learning hours can feel very burdensome, which ultimately has the potential to trigger academic burnout and turn off intrinsic learning motivation (Kim et al., 2024).

From the perspective of educators, teachers and lecturers are faced with very demanding technical and logistical challenges (Surur et al., 2026). Designing an effective flipped learning ecosystem requires not only pedagogical mastery, but also advanced digital literacy. Educators often grapple with difficulties in creating, editing, and ensuring the quality of learning video content, as well as managing various interconnected digital devices and platforms (Algarni, 2025; Maarif et al., 2022; Umam et al., 2019). The lack of professional training related to educational multimedia production is often a major factor that hinders teachers in providing ideal pre-class materials that are technically free.

Those logistical and technical demands ultimately boil down to the most common problem complained about: time inefficiency. Both students and educators consistently report that the flipped learning approach is very time-consuming. For teachers, the instructional design phase, video production, and preparation of interactive in-classroom activities requires a dedication of preparation time that goes far beyond traditional teaching preparation (Maarif et al., 2022; Umam et al., 2019). At the same time, students should also put in extra effort to engage with

Table 3. Summary of the findings

Aspect	Findings	Citation
Impact on Self-Efficacy	Significant improvement in self-efficacy, especially with structured pre-class and in-class activities.	(Algarni, 2025; Han et al., 2025; Hwang & Lai, 2017; Jeong & González-Gómez, 2021; Nokelainen et al., 2025)
Student Challenges	Difficulty with pre-class preparation, unfamiliarity with the model, increased workload.	(Hwang & Lai, 2017; Kim et al., 2024; Lai & Hwang, 2016; Lo et al., 2017)
Teacher Challenges	Technical issues, time-intensive preparation, and infrastructure limitations.	(Algarni, 2025; Lo et al., 2017; Maarif et al., 2022; Umam et al., 2019)

the material before class starts. This double time burden is often a serious threat to the sustainability of the implementation of this model in long-term curriculum.

Finally, systemic challenges in the form of limited technological infrastructure are still macro barriers that cannot be ignored. The success of flipped learning depends entirely on the availability of stable internet access and adequate ownership of digital devices in the student's home environment. The literature notes that limited infrastructure and lack of access to reliable digital resources can discourage the implementation of this model, especially in institutions or regions with under-resourced settings (Elhilal, 2025; Lo et al., 2017). Without mitigating the digital divide, flipped learning has the potential to exacerbate polarization and inequality in mathematics education.

Discussion

Based on the results of the literature analysis on RQ1 and RQ2, the main findings of this critical review confirm that the implementation of flipped learning acts as a double-edged sword in the mathematics education ecosystem. On the one hand, this model has been convincingly proven to be able to significantly improve students' mathematical self-efficacy through an emphasis on self-regulated cognitive strategies (SRCS) in the pre-classroom phase and the use of interactive digital media that facilitates learning autonomy (Han et al., 2025; Hwang & Lai, 2017). On the other hand, this increase in self-efficacy does not occur automatically, but rather relies heavily on the ability of institutions and educators to mitigate various operational challenges. Cognitive barriers in the form of high self-regulation demands for students, spikes in workload, scarcity of digital literacy among teachers, and limitations in network infrastructure are often inhibiting factors that trigger resistance and anxiety, rather than building confidence (Kim et al., 2024; Lo et al., 2017) (see Table 3 for details).

The findings of this critical review are in line with and expanding on the previous systematic review literature. A meta-analysis by Algarni (2025) has previously confirmed that flipped learning universally spurs self-efficacy across disciplines, but this study provides novelty by highlighting that in the specific context of mathematics—which is loaded with abstract objects—such success is highly susceptible to initial misconceptions in the absence of strong pedagogical scaffolding (Lai & Hwang, 2016). Furthermore, a review by Zheng et al. (2020) on STEM disciplines found that learning motivation increases through flipped classrooms, but the findings in this study provide a critical perspective that such increased motivation is often reduced by time inefficiencies and the overwhelming technical burden on educators (Maarif et al., 2022; Umam et al., 2019). Thus, this study proves that the psychological factor of students (self-efficacy) cannot be separated from the infrastructure support and pedagogical readiness of teachers.

Theoretically, the findings of this study strengthen the theory of self-regulation in the digital environment, where learning independence outside the classroom is directly proportional to the increase in self-efficacy in the classroom (Palalas & Wark, 2020; Zhou et al., 2022). In practical terms, this study provides important implications for educators and policymakers. To minimize cognitive barriers in the pre-class phase, educators are recommended to integrate dynamic mathematics software (such as GeoGebra) into interactive videos or modules, so that students can independently visualize mathematical abstractions before class begins (Hwang & Lai, 2017). In addition, the findings on infrastructure and technical challenges emphasize the urgency of having real institutional support mechanisms—such as multimedia production training for teachers and the provision of digital access subsidies—especially to ensure equity in the implementation of flipped learning in under-resourced secondary mathematics classrooms (Elhilal, 2025).

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4. Conclusion

This critical review research succeeded in synthesizing a pedagogical mechanism of flipped learning that significantly improves students' mathematical self-efficacy through strengthening self-regulation strategies and the use of interactive media, which effectively answers the research objective to dissect the influence of this model on student confidence. The study's key findings reveal that although this model has been shown to mitigate declining self-efficacy in complex math materials and is an equity intervention for students with low self-efficacy, its success is severely limited by students' cognitive barriers to understanding mathematical abstraction independently, workload spikes, and digital infrastructure gaps. Therefore, further research is recommended to conduct longitudinal investigations regarding the adaptation of students' cognitive load and explore the potential of artificial intelligence (AI-driven chatbots) as virtual tutors to provide real-time feedback while reducing the technical workload of educators in the inverted classroom ecosystem.

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Conflict of Interest	:	The authors declare no conflict of interest.
Additional Information	:	Additional information is available for this paper.
AI Declaration Statement	:	The authors use Grammarly to check all the grammar, Gemini.ai to generate the PRISMA diagram, and Napkin AI to generate Figure 3.

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