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Meta-analysis of flipped classroom model to promote mathematical higher-order thinking

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ABSTRACT

Numerous studies have explored how the flipped classroom affects satisfaction, learning outcomes, and attitudes of both teachers and students. However, there is a gap in research regarding its impact on higher-order thinking. This meta-analysis aims to fill this gap by assessing the effect size of the flipped classroom model on students' mathematical higher-order thinking. Data from 30 primary studies, including journal articles, proceedings, theses, and dissertations, were analyzed using Comprehensive Meta-Analysis (CMA) Version 4 Software. These studies included 1,043 students in the experimental groups and 970 in the control groups. The analysis revealed a pooled effect size of 1.094, indicating a significant positive impact. Notably, the effect size remained consistent across various educational levels, sample sizes, years of study, types of learning media, and higher-order thinking indicators. This suggests the versatility and effectiveness of the flipped classroom model across different educational settings, including middle school, high school, and college, regardless of class size or learning media used.

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1. INTRODUCTION

Higher-order thinking skills are crucial for students to handle new challenges in the 21st-century [1]. By improving these skills, students can develop abilities relevant to global needs and challenges. Additionally, higher-order thinking impacts their academic achievements [2], including mathematics [3]. Therefore, schools at all educational levels are expected to facilitate students' enhancement of higher-order thinking through mathematics learning.

Higher-order thinking learning, covering critical thinking, creative thinking, problem-solving, and reasoning abilities, will strengthen students' minds and guide them in generating more alternative solutions and ideas for situations or problems they encounter. Despite its importance, the level of higher-order thinking in Indonesia is relatively low. This is evident from the results of international studies like the Trends in International Mathematics and Science Study (TIMSS) and the Programme for International Student Assessment (PISA), an international study indicating unsatisfactory academic achievements among Indonesian students, particularly in mathematics [4], [5]. Notably, these assessments involve higher-order thinking skills (HOTS) such as creative thinking, critical thinking, reasoning, and problem-solving. Thus, improving higher-order thinking is vital in the field of mathematics education.

Various factors affect students' knowledge and skills, including the classroom learning process conducted by teachers. An educator's effectiveness in managing learning is closely related to students' success in absorbing knowledge, honing skills, and applying them in everyday problem-solving. To foster thinking skills development, mathematics teachers should provide active and interactive learning experiences [6]–[10], include problem-solving [11], and utilize technology [12]–[14]. Additionally, learning strategies should cater to diverse student needs [15]. To meet these demands, educators could consider using interactive learning methods like the flipped classroom model, suitable for 21st-century students who favor digital technology and social media [16]. The flipped classroom integrates technology effectively, combining the advantages of face-to-face and online learning to engage students actively [17], [18].

Active learning outside the classroom occurs when students independently engage in preparation before in-class meetings, while active learning within the classroom involves collaborative discussions among students. In contrast to traditional approaches, where content delivery precedes assignments outside class, the flipped classroom reverses this sequence. Students learn the conceptual material before class through videos or other learning media and engage in collaborative problem-solving discussions during class. Two key components of the flipped classroom are interactive group learning in class and individual computer-based learning outside [19]. Interactive, technology-based learning has been proven to provide meaningful learning experiences, motivating students to explore mathematical concepts [20]. Moreover, the flipped classroom can address misconceptions [21] through in-class discussions and promote higher-order thinking [22].

To date, numerous studies have examined the flipped classroom's impact on higher-order thinking such as critical thinking, reasoning, creative thinking, and problem-solving. While some show a significant positive effect, others report nonsignificant effects, indicating a lack of clarity on its impact in math education. Hence, a comprehensive review of existing research is necessary to clarify the flipped classroom's effect on higher-order thinking in mathematics education. A meta-analysis is a systematic study capable of accurately summarizing evidence [23]. It combines data from previous studies, enhancing the likelihood of generalizing results. While several meta-analyses related to the flipped classroom exist, most do not specifically focus on mathematics education and are limited to learning outcomes. Therefore, conducting a meta-analysis specifically on this model regarding 21st-century skills development [24], intersecting with higher-order thinking in mathematics education, is recommended.

Conducting a meta-analysis concerning the impact of the flipped classroom model on higher-order thinking skills is essential for establishing clarity, accuracy, and a comprehensive understanding of its effects based on existing research. The extent of the impact of an intervention in a meta-analysis is indicated by a measure called the effect size [25]. If the effect size of the flipped classroom model on higher-order thinking remains consistent across all included studies, a meta-analysis can confirm a strong effect across various sampled populations and provide a more precise estimate of the overall effect size. Consequently, researchers, practitioners, and particularly teachers can have assurance that implementing the flipped classroom model in mathematics education can indeed have a strong influence students' higher-order thinking. However, if the effect size varies across all included studies, a meta-analysis can still be beneficial for reporting the range of effects and identifying factors associated with variations in the effect size. In this scenario, researchers, practitioners, and teachers can observe the broad range of effects that the flipped classroom model will have on students' higher-order thinking. Additionally, teachers can consider implementing the flipped classroom model by identifying specific factors affecting its impact ratios. Based on the provided description, there is a need to comprehensively examine the overall effect of the flipped classroom model on students' higher-order thinking and review its effects across various study characteristics. Specifically, this study's research question would be: how does the flipped classroom model affect students' mathematical higher-order thinking?

2. METHOD

This research aims to analyze and evaluate statistical data from several primary studies related to the impact of the flipped classroom model on students' higher-order thinking. Meta-analysis is employed to achieve this objective.

> *"Meta-analysis is defined as the statistical analysis of a large collection of results from individual studies for the purpose of integrating findings. It connotes a rigorous alternative to the casual, narrative discussions of research studies which typify our attempts to make sense of the rapidly expanding literature,"* [23].

The steps in the meta-analysis method include: i) formulating the research problem; ii) literature search; iii) coding; iv) statistical analysis; and v) representation and interpretation of results [25], [26]. In addition to the overall analysis of studies, several characteristics are considered in this research to examine whether the intervention will achieve a higher effectiveness under certain conditions. The characteristics or moderator variables include educational level, sample size, study year, learning media types, and higher-order thinking indicators.

The inclusion criteria used to determine the research sample are based on the populations, interventions, comparators, outcomes, and study designs (PICOS) elements. The flow diagram of PICOS is presented in Figure 1. Populations; students from elementary school, junior high school, senior high school, and university in Indonesia. Interventions; the implementation of the flipped classroom model in mathematics education. Comparators; conventional teaching methods or other instructional models. Outcomes; higher-order thinking, including critical thinking, creative thinking, reasoning, and problem-solving. Study designs; quantitative research with experimental and quasi-experimental methods. In addition to these PICOS elements, several additional inclusion criteria are added as limitations in this research;

- Primary studies in the form of documents, such as journal articles, conference proceedings, theses, and dissertations. Grey literature and conference proceedings in systematic reviews and meta-analyses are useful to minimize research bias [27].
- Primary studies providing comprehensive information related to statistical data, such as means, standard deviations, sample sizes, t-values, or p-values in the experimental class (flipped classroom model) and the control class (conventional model).
- Primary studies published in journals and proceedings that have undergone a peer-reviewed process to enhance the quality of the selected data.

The data search was conducted on several databases, including Google Scholar, Scopus, Semantic Scholar, Education Resources Information Center (ERIC), DOAJ and Portal Garuda. The keywords used were [("flipped classroom" ATAU "flipping classroom" ATAU "inverting classroom" ATAU "inverted classroom") DAN ("berpikir tingkat tinggi" ATAU "berpikir kritis" ATAU "berpikir kreatif" ATAU "penalaran" ATAU "pemecahan masalah")] and [("flipped classroom" OR "flipping classroom" OR "inverting classroom" OR "inverted classroom") AND ("higher-order thinking" OR "critical thinking" OR "reasoning" OR "problem solving" OR "creative thinking")]. These keywords were entered into the search bar simultaneously or interchangeably, adapting to the search system of each database as they have different search systems. Data collection was facilitated using the preferred reporting items for systematic reviews and meta-analyses (PRISMA) protocol, as the general concept of PRISMA is relevant to literature reviews and meta-analyses. Based on the carefully conducted data search process, with each study issued having clear exclusion reasons, a total of 30 primary studies with 34 statistical data obtained. The thirty primary studies consisted of 18 journal articles, five proceedings articles, and seven theses.

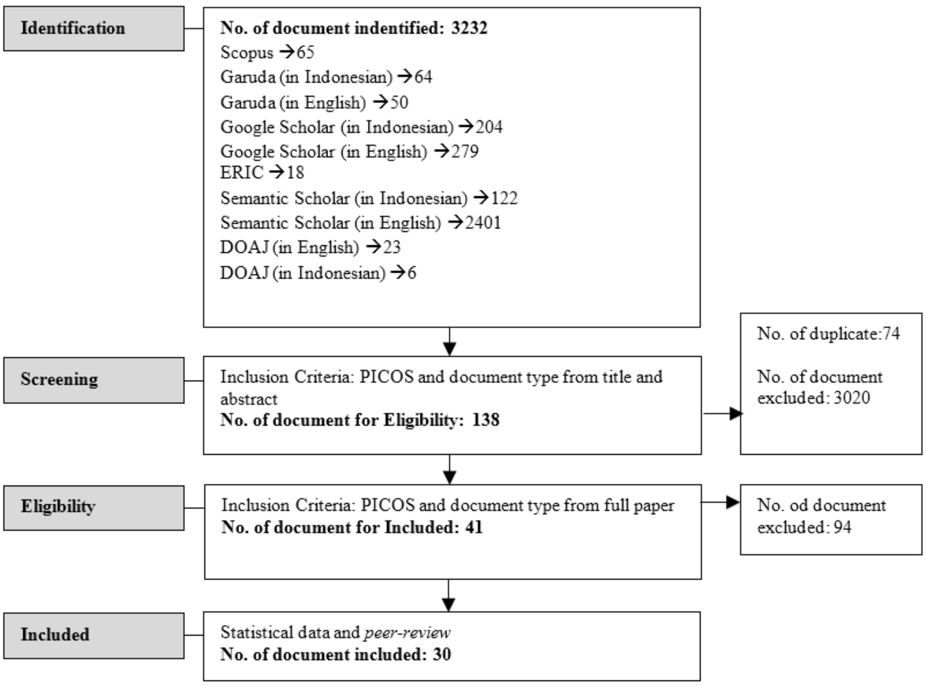

Figure 1. PRISMA flow diagram

3. RESULTS AND DISCUSSION

Many meta-analyses have explored the impact of the flipped classroom model, focusing on student attitudes, such as student satisfaction [28] and attitudes toward learning and learning resilience [29]; as well as learning outcomes, including interpersonal and affective outcomes [22], cognitive learning outcomes [22], [30]; and academic achievement [29], [31]–[33]. Positive effects have been highlighted in these aspects. While some studies have investigated the effectiveness of the flipped classroom model, there is a need to understand its effectiveness across various educational levels and settings. This study specifically focuses on its effectiveness in promoting mathematical higher-order thinking, exploring potential moderating factors, such as the educational levels, learning media, sample size, and year of study. This involved analyzing studies that have investigated the impact of flipped classroom instruction on students' mathematical problem solving, critical thinking, reasoning, and creative skills.

In the meta-analysis, there is a threat of publication bias, where researchers tend to involve more published studies than unpublished ones. Hence, performing sensitivity tests and assessing publication bias from the involved studies is crucial. Sensitivity analysis ensures that the obtained results are robust, the conclusion of the calculations is not dependent on specific studies, such as the effect of outliers. Publication bias tests examine whether the utilized data show a tendency toward bias and assess its effect if bias is present. The sensitivity analysis in this research includes funnel plots and the Rosenthal fail-safe N (FSN) test, while the publication bias test involves the trim-and-fill method. The distribution of effect size data from each observed primary study is shown in Figure 2.

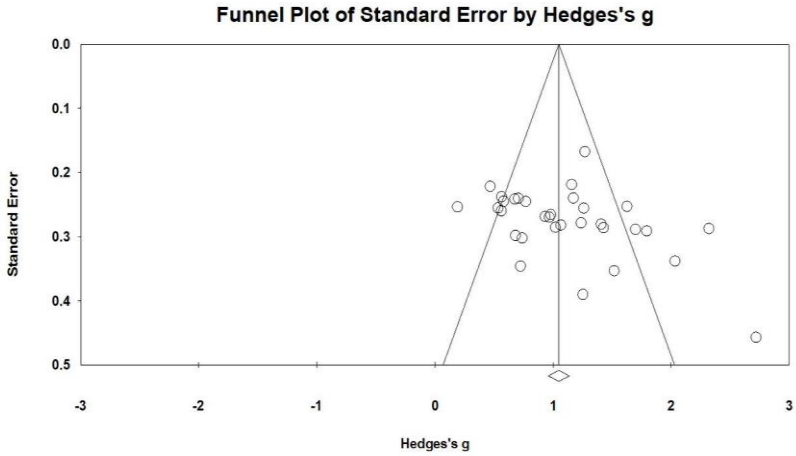

Figure 2. Funnel plot of effect size of all observed studies

Figure 2 indicates that many circles clustered in the middle of the funnel, with fewer circles in the lower part, especially on the left side. Moreover, circles at the bottom tend to be numerous on the right side. This suggests the possibility of unpublished or undiscovered studies on the left side, despite efforts to include research from grey literature. Access limitations to grey literature sources may have influenced these findings, indicating an asymmetric funnel plot [34]. However, it is essential to note that asymmetry in the funnel plot does not automatically imply publication bias, as studies with small sample sizes may genuinely have higher effect sizes.

The FSN test is employed to determine the potential presence of publication bias. The FSN value represents the number of missing studies needed to yield a p-value larger than alpha, intending to render the overall effect statistically nonsignificant. In this study, the FSN value is calculated as 4,887. This implies that at least 4,887 missing studies with a zero-effect size is required to make the overall effect statistically nonsignificant. This value is then substituted into the formula, $N/((5k+10))=4,887/((5\times34+10))=27.15$. The calculation results indicate that the value is greater than 1, suggesting that all studies included in this research are not susceptible to publication bias [35], [36].

To estimate the extent of bias and the effect size in the absence of bias, the trim-and-fill test is employed [34]. Based on the trim-and-fill results, no studies were excluded in the procedure, indicating that all studies in the analysis can be used to calculate the combined effect size. If the asymmetry in the funnel plot is indeed caused by bias, the adjusted effect will be in the range of 0.92099 to 1.26613, with a point estimate of 1.09356 (equal to the observed effect size). Based on sensitivity analysis and publication bias tests, the study's finding suggests indications of bias, but with no significant impact.

Addressing the research question, the effect size Hedges's g (effect size based on the mean difference between flipped classroom and conventional class) was calculated using Comprehensive Meta-Analysis (CMA) Software Version 4. The results and visualization of the forest plot is presented in Figure 3. The p-values for each study are less than 0.05 (except for study B01), indicating that Hedges's g effect size is significantly different from zero, suggesting an effect of the flipped classroom model on higher-order thinking. However, study B01 lacks sufficient evidence to reject the null hypothesis, suggesting no significant difference between the flipped classroom model and the conventional model. The combined effect size has a p-value of 0.000<α=0.05, indicating a significant difference between the flipped classroom model and the conventional model on higher-order thinking. The obtained combined effect size is 1.094, with 95% confidence interval ranging from 0.921 to 1.266 (this interval indicates the precision of the combined effect in a comparable population).

Study name	Statistics for each study				
	Hedges's g	Lower limit	Upper limit	Z-Value	p-Value
B01	0.192	-0.305	0.690	0.758	0.448
B02	0.971	0.442	1.500	3.599	0.000
B03	1.240	0.693	1.786	4.445	0.000
B04	1.022	0.462	1.582	3.578	0.000
B05	0.567	0.100	1.033	2.381	0.017
C01	0.469	0.034	0.904	2.115	0.034
C02	1.628	1.132	2.124	6.433	0.000
C03	1.700	1.133	2.267	5.881	0.000
C04	2.322	1.758	2.885	8.072	0.000
C05	1.271	0.942	1.600	7.579	0.000
C06	0.564	0.054	1.073	2.168	0.030
D01	0.469	0.034	0.904	2.115	0.034
D02	1.628	1.132	2.124	6.433	0.000
D03	0.935	0.408	1.461	3.478	0.001
D04	0.740	0.148	1.333	2.449	0.014
D05	1.409	0.858	1.959	5.015	0.000
D06	0.982	0.461	1.503	3.695	0.000
D07	0.771	0.290	1.251	3.142	0.002
D08	1.519	0.827	2.212	4.299	0.000
D09	1.068	0.515	1.621	3.783	0.000
D10	0.536	0.035	1.037	2.098	0.036
D11	1.159	0.730	1.588	5.290	0.000
D12	0.684	0.099	1.269	2.291	0.022
D13	1.429	0.868	1.990	4.992	0.000
D14	1.255	0.489	2.020	3.213	0.001
D15	0.583	0.103	1.063	2.380	0.017
D16	0.708	0.237	1.180	2.945	0.003
D17	1.174	0.704	1.645	4.890	0.000
E01	1.795	1.224	2.366	6.162	0.000
E02	0.677	0.204	1.151	2.803	0.005
E03	1.262	0.760	1.763	4.932	0.000
E04	2.035	1.372	2.698	6.016	0.000
E05	0.726	0.048	1.405	2.097	0.036
E06	2.721	1.825	3.618	5.952	0.000
Pooled	1.094	0.921	1.266	12.420	0.000
Prediction Interval	1.094	0.192	1.995		

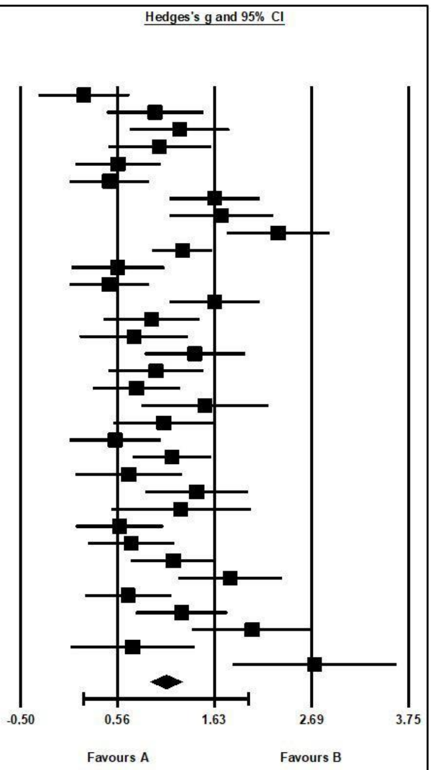

Figure 3. Forest plot of Hedges's g for all primary studies

However, neither the combined effect size nor its confidence interval provides information about how the true effect size is distributed around the combined effect size in the population. Moreover, in a random-effects model, it is essential to consider not only the combined effect size but also the distribution of true effects around this combined effect [34], which is addressed by prediction interval presented in Figure 4. The prediction interval depicted by the curve surpassing 0.19. Consequently, there is 95% confidence that the true effect size in a comparable population will fall within the interval of 0.19 to 1.99. If a researcher or practitioner intends to implement the flipped classroom model and considers the effect of its implementation, the effect size is expected to fall within this interval. However, this prediction interval is considered too wide and may not be very informative. Additionally, investigating the asymmetry in the funnel plot trend is necessary to uncover potential specific patterns [37]. Therefore, identifying factors contributing to such variability is essential.

The Q test aims to answer the question of whether there is evidence that the true effect size varies across all studies. The CMA output indicates a Q-value of 122.159, exceeding the Q-table value of 47.400, leading to the rejection of the null hypothesis. This suggests that the actual effect size differs across all studies, indicating heterogeneity. Additionally, the I^2 value, which assesses heterogeneity and is less sensitive to sample size, is 72.986. An I^2 value exceeding 50% is considered moderate heterogeneity, while an I^2 value exceeding 75% is considered high heterogeneity [38]. The I^2 value obtained in this meta-analysis is 73%, indicating moderate to almost high heterogeneity, suggesting the variance identified in the primary studies is not solely due to sampling but may be influenced by one or more moderator variables [39]. Subgroup analysis (heterogeneity test) for each potential moderating factors is presented in Table 1. The results show no significant difference in the application of the flipped classroom model on higher-order thinking skills across educational levels, class/sample sizes, types of learning media, year of study, and higher-order thinking indicators.

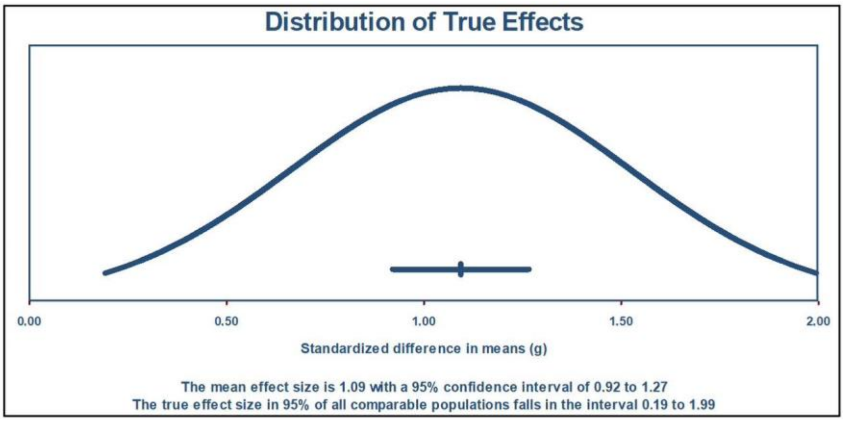

Figure 4. Distribution of true effects in prediction interval

Table 1. Subgroup analysis of study characteristics

Moderator variable	No. of study	Effect size	Lower limit	Upper limit	P-value for heterogeneity (α=0.05)
1. Education level					
Junior high school	15	0.935	0.673	1.196	0.142 (not significant)
Senior high school	13	1.327	1.039	1.616	
University	5	1.076	0.655	1.539	
2. Sample size in the flipped classroom					
>32	14	1.038	0.775	1.302	0.578 (not significant)
<=32	20	1.139	0.904	1.373	
3. Year of study					
2018/2019	3	1.623	1.055	2.191	0.274 (not significant)
2019/2020	4	0.905	0.396	1.414	
2020/2021	10	1.009	0.700	1.318	
2021/2022	6	1.137	0.719	1.555	
2022/2023	4	0.838	0.341	1.335	
4. Learning media					
More than 1 media	14	1.021	0.746	1.295	0.741 (not significant)
Education platform	3	1.028	0.395	1.661	
Learning video	7	1.275	0.881	1.668	
Others	9	1.168	0.829	1.508	
5. Higher-order thinking indicators					
Critical thinking (B)	5	0.788	0.353	1.222	0.088 (not significant)
Creative thinking (C)	6	1.300	0.911	1.689	
Problem solving (D)	17	0.990	0.753	1.228	
Reasoning (E)	6	1.455	1.035	1.876	

The effect size obtained in this meta-analysis is higher than Tutal and Yazar's [29], suggesting a stronger effect of the flipped classroom model on learning outcomes. The Hedges's g effect size for the effect of flipped classrooms on mathematics learning reported is 0.524, with a 95% confidence interval of 0.310 to 0.738. This effect size falls into the low to moderate range [40]. Similarly, Strelan *et al.* [41] found Hedges's g effect size for the effect of the flipped classroom model on learning outcomes in mathematics to be 0.35. Similarly, Cheng *et al.* [31] reported Hedges's g effect size for the effect of the flipped classroom model on learning outcomes in mathematics, science, social studies, engineering, arts, business, and health as 0.193, which is considered a negligible effect.

The flipped classroom fundamentally expects students to engage in higher-order thinking inside the classroom, focusing on activities requiring complex skills, while low-order thinking is encouraged outside the classroom [42], [43]. Learning time is utilized for higher-order thinking by solving problems and engaging in discussions, making it more effective than the conventional model. When students learn materials before the lesson, they have the opportunity to prepare questions for the teacher and their peers, and these questions help them understand and assess their comprehension. By reading materials before class, students mentally and intellectually prepare themselves for the activities and applications. This preparation represents a form of student engagement in learning, which in the conventional model is still dominated by the teacher.

While this study includes primary studies with samples from the elementary school level, the limited number restricts further analysis. Research on flipped classroom at the elementary level is scarce, limiting conclusions about its effect on higher-order thinking [44]. However, the subgroup analysis aligns with the discovery [28] that the flipped classroom model is associated with good learning outcomes across all educational levels. The learning barriers during the COVID-19 pandemic make the flipped classroom model an important and promising alternative. Additionally, there is a common assumption that more recent research on the flipped classroom model typically utilizes more advanced technology and more complex designs than earlier studies. However, based on the results of the Q test, it can be concluded that the effect size does not differ, whether before, during, or after a pandemic or in the development of more "luxurious and sophisticated" technology and designs.

Although flexible learning has become the norm for students, especially in urban areas, merely providing online materials does not guarantee a good learning experience. Even though students respond positively to the use of technology, particularly instructional videos, they still require direct learning experiences where they can engage in discussions and assess their knowledge [45]. Furthermore, learning effectiveness should not be solely assessed based on technology use because this model has a strong pedagogical foundation derived from several existing theoretical learning principles, such as scaffolding theory, zone of proximal development theory, and active learning theory. The challenges of the flipped classroom learning model still apply to both students and teachers, but strategies that can overcome some of these challenges can be implemented through simple design frameworks and technology that motivate students and enhance student engagement in all phases of learning [46]. A good strategy for implementing the flipped classroom: keeping things related to the lower-level knowledge and cognitive dimensions in Bloom's taxonomy in videos and things related to the higher-level knowledge and cognitive dimensions in the classroom [47].

Most of the studies included in this research focus on the immediate effects of the flipped classroom model on students' higher-order thinking skills. It is difficult to know if there are differences in how long the model was used because researchers have limited access. The flipped classroom model requires teachers to have a strong understanding of the model and the ability to effectively implement it in their classrooms. There are no one-size fits all approach to implementing the flipped classroom model and different teachers may have different methods for designing and delivering pre-class activities. This can lead to inconsistencies in the quality and effectiveness of the flipped classroom model across different educational settings.

4. CONCLUSION

The research indicates that the flipped classroom model significantly enhances students' higher-order thinking skills, including creative thinking, critical thinking, reasoning, and problem-solving, falling within the high to very high categories, with an overall effect of high. Furthermore, there is no significant difference in the effect of the flipped classroom model on higher-order mathematical thinking skills when considering educational levels, sample size, year of study, types of learning media, and higher-order thinking indicators (creative thinking, critical thinking, reasoning, and problem-solving). These findings offer valuable insights for educators, policymakers, and researchers considering the implementation of the flipped classroom model in mathematics education, particularly regarding its impact on higher-order thinking. The model proves effective in fostering creative thinking, critical thinking, reasoning, and problem-solving across various educational levels, especially in high school and tertiary institutions, irrespective of class size, with the assistance of various types of learning media.

Future research endeavors are encouraged to refine the inclusion criteria and expand databases to acquire a more comprehensive dataset, thereby enhancing generalizability. It is advisable for subsequent meta-analyses to explore the effect of the flipped classroom model on higher-order thinking with additional study characteristics, such as the elementary school education level, which were limited in this research. Other aspects for moderator variables could encompass research locations (rural and urban categories), learning materials (algebra, geometry, and statistics), the presence of pre-class quizzes, and intervention duration. These endeavors will contribute to a deeper understanding of the flipped classroom model's impact and its nuances across diverse educational contexts.

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AUTHOR CONTRIBUTIONS STATEMENT

This journal uses the Contributor Roles Taxonomy (CRediT) to recognize individual author contributions, reduce authorship disputes, and facilitate collaboration.

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study were obtained from publicly available databases (Google Scholar, Scopus, Semantic Scholar, ERIC, DOAJ, and Portal Garuda). The processed and synthesized data generated during the meta-analysis are available from the corresponding author, [NF], upon reasonable request.

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