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MODERATOR EFFECT OF MOBILE LEARNING ON STUDENTS' ACHIEVEMENT IN PHYSICS: A META-ANALYSIS

Abstract. *The use of mobile technology in physics education has become more prevalent, but more data about its effect on student academic performance needs to be collected. This meta-analysis examines the effects of mobile learning on student achievement in physics and any moderating factors. The study collected 36 primary studies from various scientific databases (Scopus, ERIC, DOAJ, Google Scholar) that met the inclusion criteria. The findings indicate that using mobile technology has a significant effect on student performance in physics compared to without mobile learning. Moderator analysis revealed differences in the effects of mobile learning on physics learning outcomes based on sample size, academic level, gender composition, learning media type, learning model type, learning outcome type, and measurement instrument type. However, no effect difference was observed in country status, publication year, sampling technique, and physics content. No publication bias was found in this study. Overall, the study suggests that mobile learning has a strong positive effect on student achievement in physics.*

Keywords: *learning achievement, meta-analysis, mobile learning, physics learning*

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Introduction

Mobile devices have become important tools for science education (Tavares et al., 2021). In recent years, the use of mobile technology in education has increased significantly. Digital mobile devices such as mobile phones, Personal Digital Assistants (PDAs), and smartphones are increasingly used for educational purposes (Pimmer et al., 2016). Mobile technology in learning has a great potential to support learning anytime and anywhere, enabling students to take advantage of every opportunity to learn (Bernacki et al., 2020). This type of learning, also known as mobile learning, adapts to the rapidly advancing technological world of education, especially after the COVID-19 pandemic. This pandemic has changed the teaching and learning process, which is no longer limited to books and face-to-face learning (Aulakh et al., 2023).

Mobile learning refers to using personal mobile technology to access learning material and interact with others across different contexts (Chen et al., 2008; Crompton, 2013). This allows learners to access information regardless of location and provides an alternative to location-based learning (Liu & Hwang, 2010). Mobile learning makes knowledge available to all learners without time or geographical constraints (Sun et al., 2008) ensuring uninterrupted communication and interaction between students and teachers (Katz, 2002). It focuses on student-centered learning (Swan, 2020), providing an environment supporting various student-teacher interactions. Therefore, teachers must play an essential role in designing an environment that caters to the needs of students and promotes effective learning (Bennett et al., 2009).

Students vary in their use of mobile technology. Some use it at the beginning of learning, others at the end, and some only use it when requested (Epp & Phirangee, 2019). Using mobile devices is one of the strategies for learning (Jeng et al., 2010). Students use mobile devices to seek help (Reeves et al., 2017), obtain information based on their real-life experiences (Lu et al., 2019), and get real-time feedback (Criollo & Luján-Mora, 2018). Using mobile devices in learning offers many benefits to students, such as promot-

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ing seamless learning in formal and informal environments and enhancing their ability to transfer knowledge to others (Bernacki et al., 2020).

Research Problem

The success of mobile learning is based on its unique characteristics, which include portability, individuality, availability, connectivity, and social interactivity. These features make mobile learning suitable for active learning in all situations, providing increased mobility and timely interactions that enhance learners' motivation to learn (Sung et al., 2019). It is essential to consider the factors that influence learning achievement in mobile learning classes. These factors can be used to evaluate the results and achieve optimal outcomes. The factors influencing mobile learning achievement are classified based on organizational, personal, general environmental, pedagogical, and contextual differences, closely linked to technology integration (Panigrahi et al., 2018).

Mobile learning has significant challenges, including device ownership, internet access, and app access. Although the number of people owning smartphones is increasing, technical issues can influence users' ability to learn using mobile phones. This limits mobile phone learning to being merely an assistance tool (Alghazi et al., 2020). For example, learners often need help with the small size of the phone's keyboard and screen, making it difficult to type long responses and access resources when the phone is turned off during learning (Kim et al., 2014). Another challenge is detecting inappropriate actions, such as cheating, which is more likely to occur in mobile learning (Tang & Hew, 2017). Students also find mobile learning time-consuming since information can become irrelevant (Hazaea & Alzubi, 2016) or overwhelming with difficult access (Bouhnik & Deshen, 2014). Furthermore, students' self-regulation using mobile phones during learning could be better as they get easily distracted by the slightest disturbance (Ravizza et al., 2017), This often leads to multitasking activities (Sana et al., 2013), influencing memory and performance (Mueller & Oppenheimer, 2014). Finally, using mobile phones in learning can increase students' concerns about interpersonal relationships (Flanigan & Kiewra, 2018).

Research Focus

Numerous studies have explored the effectiveness of mobile learning, and its importance has been further amplified amid the COVID-19 pandemic as it is being widely used for remote learning. To answer many of the questions related to mobile learning, researchers have used the meta-analysis method to summarize the research. According to several meta-analysis studies, digital technology has proven to enhance learning achievement compared to learning methods without technology (Chauhan, 2017; Merchant et al., 2014). Furthermore, according to the meta-analysis conducted by Sung et al. (2016), learner motivation has been found to increase significantly through mobile learning.

However, a review of the analyses of the effects of mobile technology on learning by Crompton et al. (2016) and Wu et al. (2012) against the theoretical framework of mobile learning, as pointed out by Sharpies et al., (2007), has highlighted that while mobile learning has inspiring potential, it also runs the risk of not achieving meaningful learning. The potential opportunity is that mobile learning can provide many benefits to learners. However, the conceptualization of how mobile learning can span environments with multiple users with different interaction methods is yet to be operational. Therefore, many systematic empirical studies on theoretical assumptions contradict the expected results. In this case, research aims to provide a broader picture of the effect of mobile learning on cognitive, psychomotor, and affective learning achievement.

A study conducted by Hwang and Tsai (2011) found that the most common research on mobile learning pertains to the effect of mobile learning, design aspects of mobile learning, and analysis of learner characteristics in the context of language and language materials. Additionally, research conducted by Zheng et al. (2016) found that mobile learning is applied in English, writing, mathematics, and science materials. To add to the existing studies, this research aims to conduct a literature study to analyze the effect of mobile technology on learning achievement in physics learning. A meta-analysis study conducted by Sung and Mayer (2013) found that the effect of using mobile devices is moderated by variables such as teaching time, hardware used, and learning methods. This study focused on the effect of mobile learning on learning achievement in physics learning. Another purpose is to describe the use of learning models, media, and academic levels commonly used in learning. It is important to integrate different methods and types of teaching-learning strategies to create more learning scenarios in different situations, as suggested by Sung et al. (2019).

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Research Aim and Research Questions

This study aimed to systematically analyze and measure the effect of mobile learning on students' learning achievement in physics. Thus, the research questions: (1) What is the effect of mobile learning on students' learning achievement in physics? (2) What are the potential moderator variables that may influence the effect of mobile learning on students' learning achievement in physics? (3) Do these moderator variables influence the effect of mobile learning on students' learning achievement in physics?

Research Methodology

General Background

This study used the meta-analysis method. Meta-analysis involves analyzing and synthesizing multiple primary research findings to form a conclusive outcome. The search for relevant articles was conducted based on the characteristics of meta-analysis (Borenstein et al., 2009; Manaf et al., 2022; Retnawati et al., 2018; Schroeder et al., 2007). This technique allowed for an aggregate effect of each study's effect size on the topic of interest to be determined. The study also explored potential moderator effects to identify factors that contributed to differences in effect size between studies on the topic of interest from 2012 to August 2023.

Procedures

The steps involved in conducting a meta-analysis are formulating the problem, collecting data, coding the data, analyzing the data, and then interpreting the data (Cooper & Hedges, 1994). Meta-analysis is research that uses a screening method in the scientific process. This method synthesizes studies with a specific hypothesis (Jupp, 2006). This research requires the effect size of previous research results on using mobile learning on students' physics learning achievement.

The coding sheet used in the meta-analysis tool played a crucial role in helping researchers collect and analyze data. The variables used in the coding provided the necessary information to calculate the effect of mobile learning on students' physics learning achievement. The following steps were taken during the meta-analysis process (DeCoster et al., 2009): (1) identifying and examining the research topic to be studied; (2) searching and collecting relevant studies from reliable sources; (3) using the meta-analysis method to calculate the size of the effect; (4) determining whether the effect size was heterogeneous and how it related to the topic; and (5) drawing conclusions and interpreting the results of the meta-analysis research.

Moderator Variable

Moderators were independent variables hypothesized to influence the effect size of observations. The moderators in this study were: (1) country status (developing vs. developed); (2) publication year (in the pandemic, before the pandemic, or after the pandemic); (3) sample size (small vs. large); (4) level academic (bachelor's degree, college, secondary school, or primary school); (5) sampling technique (probability or random, non-probability, or no information); (6) gender composition (female majority, male majority, equal or nearly, only female, only male, or no information); (7) type of learning media (apps, e-module, e-book, website, virtual reality (VR), augmented reality (AR), or other); (8) physics content (electricity and electromagnetism, wave and vibration, mechanics, thermodynamics, or others); (9) learning model (inquiry, STEAM or STEM, cooperative, PJBL, PBL, others, or no information); (10) type of students' achievement (cognitive, affective, psychomotor, or no information); and (11) type of measurement instrument (develop by author, standardized, adaptation, or no information).

Literature Search Procedure

The collection of databases based on predefined inclusion and exclusion criteria was the first approach to address the research question. The 'ERIC (EBSCO)', 'DOAJ', 'Scopus' and 'Google Scholar' databases were used for the current study. The search aimed to retrieve relevant research from different databases by using keywords covering the following areas: mobile learning (including blended learning, mobile, mobile phone, smartphones, tablets, iPad, handheld, mobile application, mobile technology, m-learning, physics mobile learning media), learning achieve-

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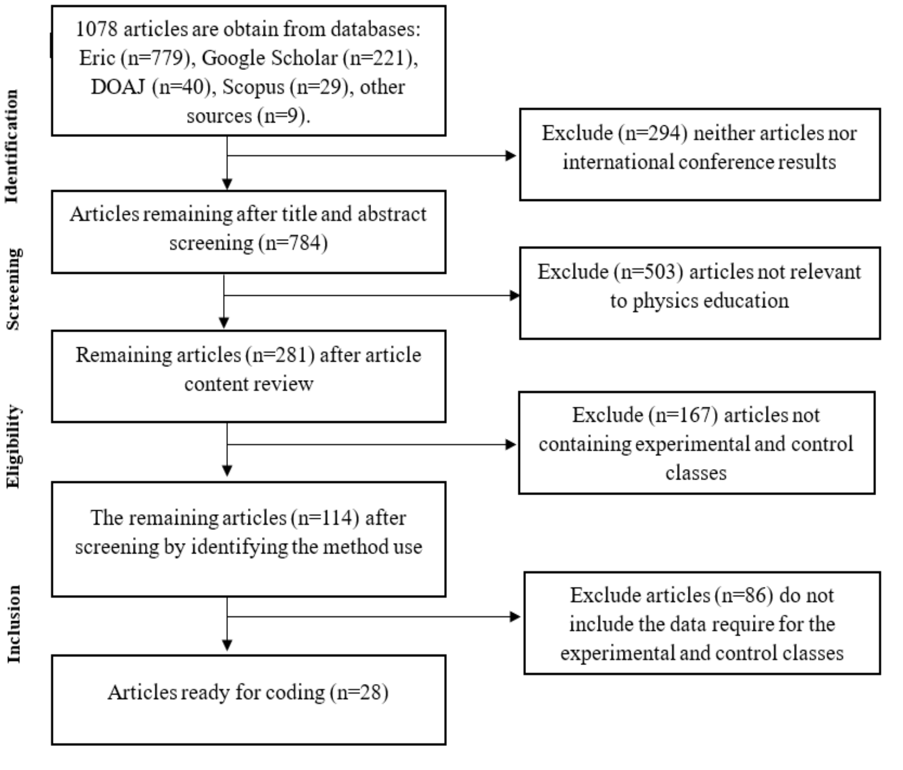
ment (including achievement, cognitive ability, affective ability, psychomotor ability, and learning performance), and physics education (including STEM education, physics book, and all aspects of physics content). In this search, articles written in both Indonesian and English were selected.

Inclusion and Exclusion Criteria

The studies relevant to this meta-analysis were chosen based on specific inclusion criteria. Firstly, the selected time frame covered the period from 2012 to August 2023. Secondly, the sources of the studies were restricted to academic journals. Thirdly, the research method used was quasi-experimental with experimental and control groups. The study focused on the independent variable of mobile learning in physics education, and the dependent variable to be measured was learning achievement. Fourthly, the articles needed to contain complete numerical data such as sample size (*n*), mean (*M*), and standard deviation (*SD*) in experimental and control groups in order to calculate the effect size later on. Studies that did not meet these criteria were excluded from this meta-analysis. Specifically, the exclusion criteria were: (1) scientific documents including dissertations, (2) non-open access scientific articles, (3) research using qualitative methods, and (4) studies with insufficient quantitative data for effect size calculation. If studies from multiple databases were identified during the screening process, only one database was used for analysis. Additionally, nonparametric studies were excluded from the meta-analysis. Experimental studies that did not include a control group were also excluded from the analysis.

Figure 1
PRISMA Flow Diagram



The following steps were taken to identify the relevant studies for this research: Firstly, the titles and abstracts of all studies were identified based on pre-defined inclusion or exclusion criteria. The content of the relevant research was then assessed. The PRISMA flow diagram in Figure 1 shows the process followed in this study. The search from several databases yielded 1078 articles related to the effect of mobile learning on physics learning. These articles were reviewed, and 294 titles were excluded because they either were not scientific articles or were not from international conferences. After reviewing the articles based on the inclusion criteria, 784 articles remained. Out of these, 503 articles were excluded because they were found to be irrelevant to physics learning. The remaining 281 articles were then re-

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evaluated to identify the presence or absence of experimental and control groups. Out of the 281 articles, 167 articles were excluded because they did not need to meet the criteria. The remaining 114 articles were reviewed to confirm that their numerical data was complete, which is critical to calculating effect size. As a result, 86 articles were excluded because of incomplete data, leaving 28 articles that met all the inclusion criteria for meta-analysis.

Coding Method

To ensure that the research objectives could be met, the scope of the study was defined through coding. This helped in comparing the characteristics of the articles included in the meta-analysis and converting the quantitative data for effect size calculation. The coding method applied is shown in Table 1.

Table 1
Overview of Coding Aspect in Meta-Analysis

The identity of the study	Characteristics of the study	Quantitative data of the study
The first author of the study	Country status	Sample size (*n*)
Publication year	Gender composition	Mean (*M*)
The title of the study	Sampling technique	Standard deviation (*SD*)
Publication database	Level academic	
	Type of learning model	
	Type of learning media	
	Type of physics content	
	Type of measurement instrument	
	Sample size	
	Type of students' achievement	

Data Analysis

The analysis of data began after it was collected and coded. Microsoft Excel was used for calculating frequencies and percentages. In this meta-analysis, RStudio (Posit Team, 2023) was used for data analysis with the help of 'meta' (Balduzzi et al., 2019) and 'metaphor' (Viechtbauer, 2010) packages. RStudio provided analyses for effect size, heterogeneity testing, and publication bias. Table 2 shows the most common effect size classification.

Table 2
Effect Size Classification

Cohen (1997)	Lipsey et al. (2001)	Thalheimer and Cook (2002)
d = 0.20 – 0.50, small	d = 0.15, small	$-0.15 < d < 0.15$, negligible
d = 0.50 – 0.80, medium	d = 0.45, medium	$0.15 < d < 0.40$, small
$d \geq 0.80$, large	d = 0.90, large	$0.40 < d < 0.75$, medium $0.75 < d < 1.10$, large $1.10 < d < 1.45$, very large $1.45 < d$, excellent

This study utilized standardized mean differences to determine the effect size (Borenstein et al., 2009; Card, 2011; Retnawati et al., 2018). The Thalheimer and Cook (2002) classification was used to interpret the effect size in this study. After obtaining the effect sizes for the relevant studies, a homogeneity test was conducted (Borenstein et al., 2009; Retnawati et al., 2018). The fixed-effects model was recommended if the test results indicated homogeneity in the effect size. However, a random effects model was suggested if the effect size between studies was heterogeneous. The heterogeneity between effect sizes also prompted the moderators to explore the variation in effect sizes.

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Research Results

Detailed information about the moderator of the subject was presented in the appendix, along with summaries of the type of measurement instrument and sampling technique used. A total of 36 independent samples were obtained from 28 primary studies based on inclusion criteria.

Descriptive Statistic of the Included Studies

A meta-analysis was conducted to identify the essential characteristics of eligible studies. The study characteristics were described based on moderator variables such as country status, gender composition, sampling technique, academic level, learning model type, learning media type, physics content type, measurement instrument type, sample size, learning outcome, and publication year. The descriptive statistics of the eligible studies based on these variables are shown in Table 3.

Table 3
Descriptive Statistics of Included Studies

Variables	*n*	%
Country status		
Developing	29	80.6
Developed	7	19.4
Publication year		
In the pandemic	19	52.8
Before the pandemic	6	16.7
After the pandemic	11	30.6
Sample size		
Small (n ≤ 30)	15	41.7
Large (n > 30)	21	58.3
Level academic		
Bachelor's degree	14	38.9
College	20	55.6
Secondary school	1	2.8
Primary school	1	2.8
Sampling technique		
Probability or random	16	44.4
Nonprobability	4	11.1
No information	16	44.4
Gender composition		
Female majority	3	8.3
Male majority	1	2.8
Equal or nearly	3	8.3
Exclusively female	1	2.8
Exclusively male	1	2.8
No information	27	75.0
Learning media type		
Apps	11	30.6
E-module	5	13.9

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Variables	*n*	%
E-book	2	5.6
Website	7	19.4
Virtual Reality	1	2.8
Augmented Reality	1	2.8
Others	9	25.0
Physics content type		
Electricity & electromagnetism	11	30.6
Wave and vibration	2	5.6
Mechanics	12	33.3
Thermodynamics	1	2.8
Others	10	27.8
Learning model type		
Inquiry	2	5.6
STEAM or STEM	1	2.8
Cooperative	2	5.6
PJBL	6	16.7
PBL	1	2.8
Others	18	50.0
No information	6	16.7
Achievement type		
Cognitive	21	58.3
Affective	9	25.0
Psychomotor	5	13.9
No information	1	2.8
Measurement instrument type		
Develop by author	12	33.3
Standardized	11	30.6
Adaptation	4	11.1
No information	9	25.0

According to Table 3, more studies are conducted in developing countries than in developed countries that aim to improve physics learning achievement through mobile learning. The number of studies conducted during the pandemic has significantly increased compared to before the pandemic period. Upon review, most of the 21 studies used a large sample size, whereas only 15 used a small sample size. In addition, 20 studies used samples from college. Most of the studies used random or probability sampling techniques, but most lacked information on the participants' gender. Using apps as tools for learning physics was a popular topic, with mechanics being the most explored topic in this meta-analysis. However, the learning models used were not consistently reported in most studies. Many studies used measurement tools developed by researchers in mobile learning in physics education. The meta-analysis included 1,113 participants in experimental and control groups.

The Overall Effect of Using Mobile Learning on Students' Learning Achievement in Physics

Figure 2 shows the forest plot of the 36 studies in the random-effects model analysis. A gray square dot represents each study's effect size, while the estimated confidence interval is shown by horizontal lines on either side of the square dot. The forest plot showed that the effect size of the 36 studies was quite diverse, with the lowest effect size being –1.90 and the highest being 2.48. It is important to note that the scientific literature presents varied findings regarding the effectiveness of mobile learning in physics education.

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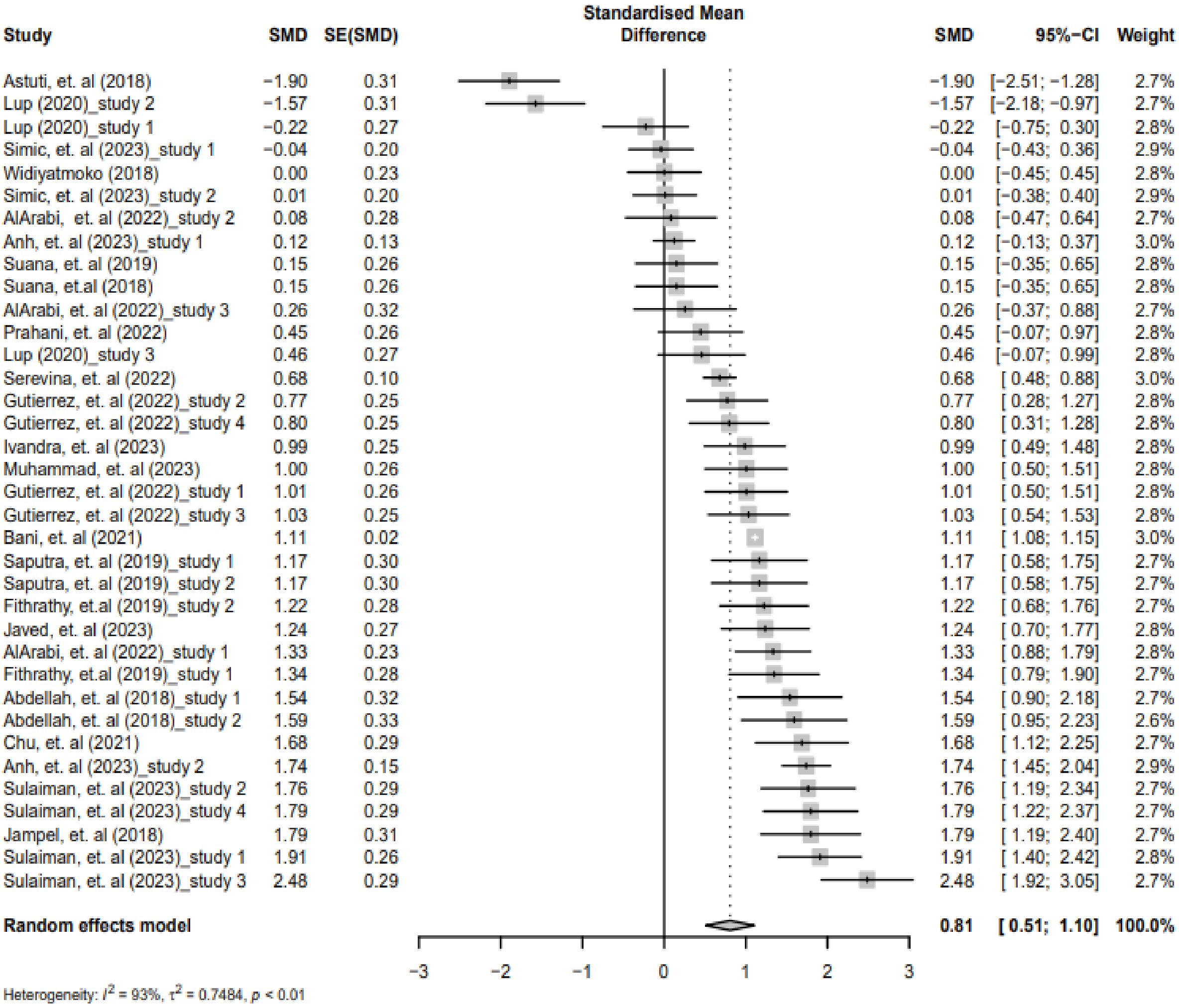
Various studies have been conducted to evaluate the effectiveness of mobile learning in physics education. While some studies, such as those conducted by Astuti et al. (2018) and Hamza-Lup and Goldbach (2021) in study 1 and study 2, along with Simić et al. (2023) in study 1, reported negative effect size, indicating that mobile learning might not consistently outperform learning without mobile devices approaches in physics education. However, several significant studies, including Anh and Truong (2023) in study 1, Billah and Widiyatmoko (2018), and Simić et al. (2023) in study 2, proved the effectiveness of mobile learning in physics education. These studies suggested using mobile learning for physics was more effective than learning without mobile devices. The results of these studies are represented in the forest plot, which shows a high and statistically significant effect size.

Figure 2
Forest Plot



An overall analysis was conducted to determine the effect of the use of technology in statistics courses on learning achievement, including all studies (aggregate effect). The effect size of 36 studies ranged from −1.90 to 2.48. There were 32 studies (88.89%) with a positive effect size. This meant that the learning outcome of the experimental group (using mobile learning) was higher than the control group. However, four studies (11.11%) showed a negative effect size, meaning that the learning outcome of the experimental group was not better than the control group. Overall, the results indicated that using mobile learning in physics had varying effects on learning outcomes.

This study used a random effects model to show that mobile learning has a significant effect on students' achievement in physics ($d = 0.81$, 95% confidence interval [0.513; 1.103], $p < .001$). The overall effect is considered

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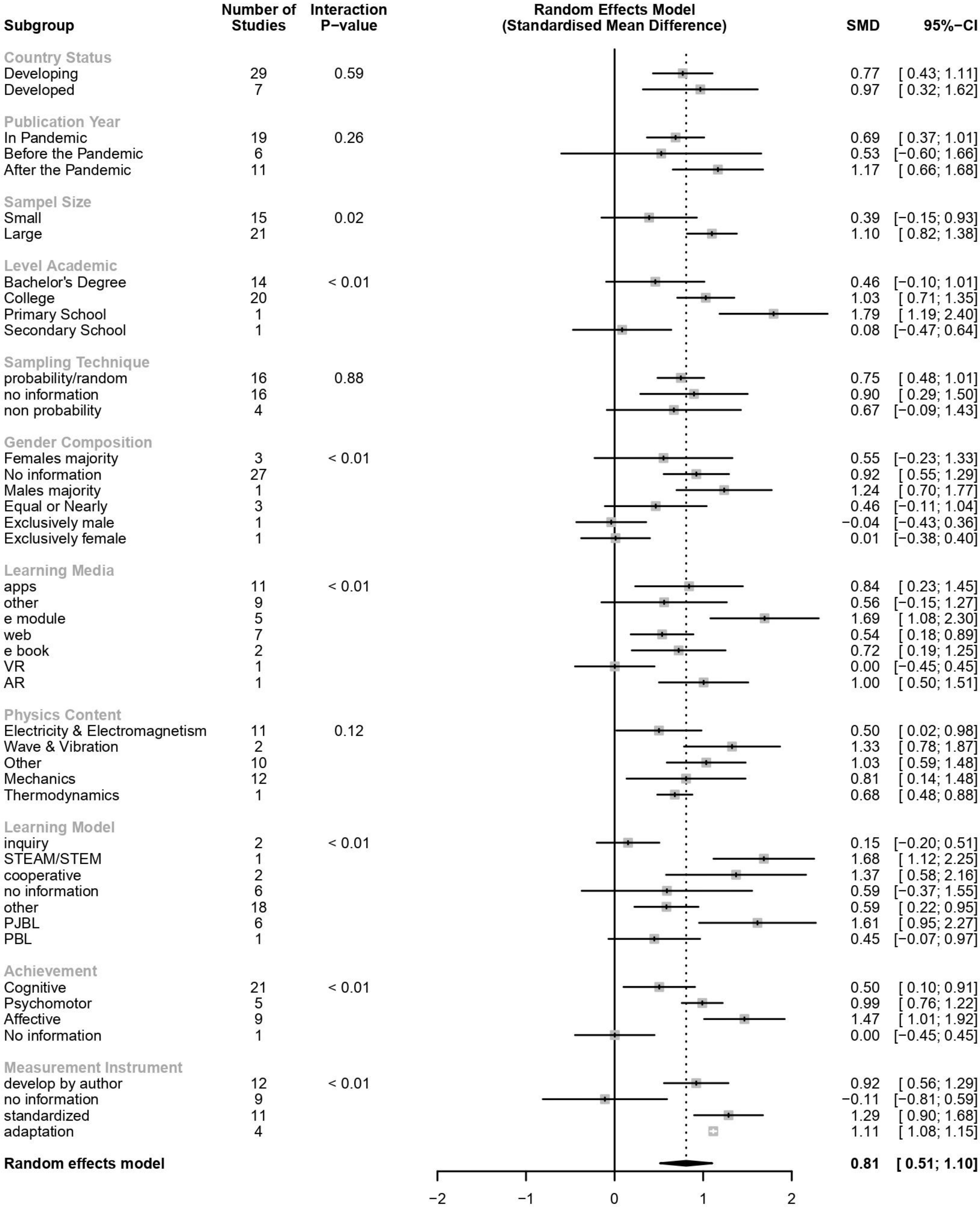
"large". However, the study found significant heterogeneity of effect sizes across 36 studies (Q = 483.87, df = 35, p < .0001), indicating that the effect sizes varied. This suggests the need for a moderator variable analysis to determine the contribution of each variable to the difference in variance between effect sizes (I^2 = 92.8%).

Figure 3

Forest Plot of Moderator Effect



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Moderating Effect of Using Mobile Learning on Students' Learning Achievement in Physics

A meta-analysis study was conducted to test the effects of mobile learning on physics learning achievement. Eleven moderator variables were examined: country status, pandemic year, sample size, academic level, sampling technique, gender composition, learning media type, physics content type, learning model type, and measurement instrument type. The analysis of the moderator variable effects is summarized in Figure 3. The results showed that there was no significant difference in the effect of mobile learning on physics learning achievement in terms of country status ($p = .59$) or publication year ($p = .26$). However, sample size ($p = .02$) and academic level ($p < .01$) had a significant effect of mobile learning on physics learning achievement. Studies with sample sizes greater than 30 had better aggregate effects. Additionally, studies of primary school students had the highest aggregate effect compared to other academic levels.

There was no significant difference in the effect of mobile learning on students' physics learning achievement when considering the sampling technique ($p = .88$). However, the results showed that there was a difference in the effect of mobile learning based on the gender composition of the sample ($p < .01$). Studies with a majority of male students had the highest effect. In contrast, studies that only included males or females had the lowest effect.

This study found mobile learning had a significant effect on students' physics learning achievement. The effect of mobile learning differed based on the type of learning media used. However, there was no difference in the effect of mobile learning on students' physics learning achievement in terms of the type of physics content. The study also revealed that learning using an e-module was the most effective method while learning using virtual reality was the least effective for learning physics.

The research findings indicate a significant difference in the effect of mobile learning on students' physics learning achievement based on the learning media used ($p < .01$). The study shows that e-modules are the most effective learning media, while virtual reality is the least effective for learning physics. However, no difference was observed in the effect of mobile learning on students' physics learning achievement based on the type of physics content. The effect of mobile learning on physics learning achievement is also influenced by the type of learning model used ($p < .01$). STEAM/STEM and Project-Based Learning (PJBL) models are the most effective while learning with inquiry models is the least effective for physics learning.

This meta-analysis also explored the different effects of mobile learning on students' physics learning achievement in terms of learning outcome type and measurement instrument type. The findings indicate that there are differences in the effects of mobile learning based on learning outcome type ($p < .01$) and measurement instrument type ($p < .01$). In terms of learning outcome type, studies that focused on measuring students' cognitive aspects had the highest effect. On the other hand, studies that employed standardized instruments had the highest effect on learning outcome measurement instrument type.

Evaluation of Publication Bias

The symmetrical patterns of the effect size plot in all 36 studies' funnel plot (Figure 4) indicate no publication bias issue in this study's data analysis. The results of Egger's test, with a $t = -1.99$ and $p = .055$, further confirm the symmetry of the funnel plot. According to Rothstein (2008) standards, if the fail-safe N value is more than $5K + 100$ (where K is the number of individual studies), it can be concluded that there was no publication bias within the meta-analysis. In this study, $K = 36$, so $5(36) + 10 = 190$. With a target significance level of .05 and $p < .0001$, this study's obtained fail-safe N value was 11541. These results confirmed that no problems of publication bias existed within this meta-analysis study. Therefore, it could be concluded that this meta-analysis did not suffer from any problems of publication bias.

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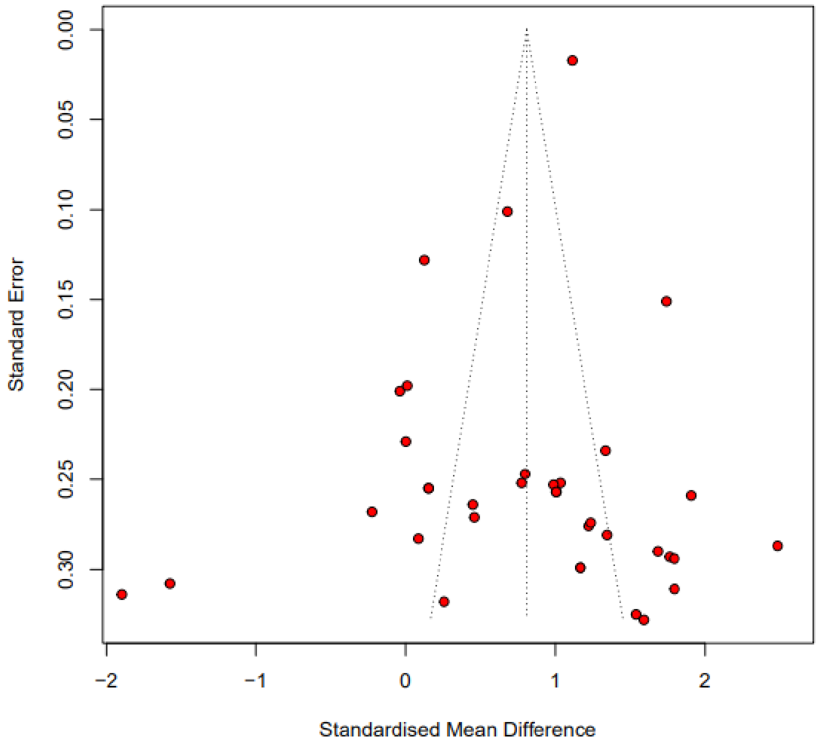
Figure 4
Funnel Plot



Discussion

Overall Effect

The study aimed to explore whether mobile learning is more effective than traditional classroom learning (without mobile devices) in improving students' physics achievement. The results showed a significant difference ($d = 0.81$, $p < .001$), indicating that mobile learning leads to significantly higher physics learning achievement than learning without mobile devices. Therefore, the use of mobile learning in improving students' physics learning achievement is highly satisfactory. This finding is consistent with previous studies (e.g., Anh & Truong, 2023; Chu et al., 2023; Elfeky & Masadeh, 2016; Fithrathy & Ariswan, 2019; Sulaiman et al., 2023). Although some studies have claimed mobile learning is ineffective (e.g., Astuti et al., 2018; Hamza-Lup & Goldbach, 2021), mobile learning is strongly recommended as an alternative to improve students' physics learning achievement.

Moderator Effect

It is important to analyze the moderator variables to explore each variable's effect on the difference in the variance between the effect sizes. The exploration focuses on studying the research characteristics such as country status, publication year, sample size, academic level, sampling technique, gender composition, learning media type, physics content type, learning model type, learning outcome type, and measurement instrument type. This study aims to identify which of these eleven moderators have moderated the effect. The study found that only seven variables (i.e., sample size, academic level, gender composition, learning media type, learning model type, learning outcome type, and measurement instrument type) show significant differences in effect size variation.

This finding indicates no difference in the effectiveness of mobile learning on students' physics learning achievement in terms of country status. It indicates that the effectiveness of mobile learning is not influenced by a country's social or economic status. Suana et al. (2019) showed that mobile learning use in developing countries,

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particularly Indonesia, led to cognitive improvements compared to developed countries, so there were no discernible differences in mobile learning use across countries. AlArabi (2022) reported that mobile learning in physics education leads to cognitive improvements compared to non-use in developed countries, especially the United Arab Emirates (UAE). However, it is essential to be cautious about generalizing and categorizing developed and developing countries based on these findings. This is because most of the studies were from developing countries.

Research on mobile learning has shown a growing trend in recent years. In particular, there has been a significant increase in the use of mobile learning during the pandemic period (2020-2022). This is due to several factors. For one, educational institutions were compelled to adopt mobile learning as a means of ensuring educational continuity during the pandemic. This trend was expected as face-to-face learning was limited under these circumstances. As a result, there have been many advancements in the implementation of mobile learning to achieve learning objectives. The education technology industry has been continuously improving the effectiveness and efficiency of mobile learning. In particular, advancements in the field of mobile learning have been made. According to a recent study by Festiyed et al. (2022), using information and communication technology (ICT) can lead to improved learning achievement compared to teaching without mobile device methods. These recent developments could enhance the performance of physics students. However, despite the increasing trend of using mobile learning, there is no significant evidence to suggest that its implementation differed significantly before and after the pandemic.

The size of a study's sample significantly influences the variation in effect size. The sample size is connected to the statistical power of a study regarding effect size (Peterson & Foley, 2021). These findings are crucial for guiding future studies, particularly those that are empirical. If researchers are interested in further exploring the effect of mobile learning on physics learning, they should consider sample adequacy. It is also intriguing why studies with larger sample sizes produce better effects than those with smaller ones. Therefore, future empirical studies must test this hypothesis to gain a deeper understanding.

The research indicates that mobile learning has greatly benefited physics education at all levels. However, the results suggest that mobile learning is particularly effective at the primary level. It should be noted that only one study has been conducted at this level (Jampel et al., 2018). Hence, further research is needed to prove that mobile learning is the best option for primary school. Nonetheless, this finding presents a new avenue for future research. Many areas can be explored through empirical studies to substantiate the claims of this research.

All the studies included in the meta-analysis were conducted using different sampling techniques. Sampling techniques are considered the most crucial aspect of research (Singh & Masuku, 2011). The meta-analysis identified various sampling techniques, including probability, non-probability, and convenience. Despite using different sampling techniques, no significant difference in the study findings was observed. This indicates the consistency of the results obtained from the studies. For future studies, random sampling techniques should be used to achieve a greater level of generalizability in uncovering the effects of mobile learning. Additionally, it has been found that the effect of mobile learning on physics learning achievement varies depending on the gender composition of the group. A significant variation in effect was observed when most males used mobile learning. However, it is important to note that only one study has addressed this issue. Therefore, further studies are required to confirm these findings.

The type of learning media used can significantly influence the effectiveness of learning. Research shows that using e-modules can greatly enhance learning outcomes in physics, especially when mobile learning is involved. This finding is consistent with previous studies, such as those conducted by Serevina et al. (2022) and Sulaiman et al. (2023). Many studies have explored the potential of mobile learning to make e-modules more accessible and easier to deliver to students. E-modules are designed to help students develop their independent learning skills and can significantly improve the overall learning experience, which may lead to higher academic achievement.

This meta-analysis aimed to identify studies that explained physics concepts in different ways. The study found no significant difference in the effectiveness of the different physics materials used in the studies. This suggests that, within each category of physics content, one material is less effective than another. However, some articles should have covered physics-related topics, concepts, or content. Based on findings, mobile learning is an effective way to teach physics.

Different types of learning models show differences in the effects of mobile learning on physics learning achievement. This research indicates that the STEAM or STEM model is more effective than others. However, it is important to note that only one study has examined this issue, so further research is required to validate these findings. Additionally, the effect of mobile learning differs significantly depending on the learning outcome measured. Mobile learning has the most significant effect on students' affective aspects. This finding is in line with the

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results of previous studies, which have shown that mobile learning in physics education increases personal interest (Sulaiman et al., 2023), student attitudes (Simić et al., 2023), and motivation (Anh & Truong, 2023).

It has been observed that the effect of mobile learning on the learning achievement of students in physics varies depending on the instrument used in the study. Studies that use measurement instruments developed by researchers have a more significant effect than other measurement instruments. This meta-analysis identified 12 studies that utilized researcher-developed measurement instruments (e.g., Elfeky & Masadeh, 2016; Jampel et al., 2018). The measurement instruments developed by researchers are more relevant to the content and learning processes experienced by students. Therefore, studies using measurement instruments developed by researchers report more substantial effects than other instruments. Future researchers in this field should consider these findings when conducting empirical studies.

Conclusions and Implications

This study is a meta-analysis that systematically examines the effect of mobile learning on learning achievement in physics. The findings reveal that mobile learning strongly influences student learning achievement in physics. This suggests that mobile learning can be highly recommended as an alternative method to improve student learning achievement in physics. The study also indicates that several factors, including sample size, academic level, gender composition, type of learning media, type of learning model, type of learning outcome, and type of research instrument, influence the effectiveness of mobile learning on students' physics learning achievement. However, the effectiveness of mobile learning is not influenced by country status, sampling technique, and physics content type. The study found that mobile learning is more potent for studies with large sample sizes and mostly male samples. Additionally, mobile learning is effective at the primary school level. However, the study also found that mobile learning could have been more effective when implemented at the bachelor's degree and secondary school levels. Other important findings include that the physics learning achievement of male students using mobile learning is better than that of females, learning facilitated using e-modules is most effective compared to other learning media, and PJBL and STEAM/STEM are the best models to facilitate mobile learning. Effective aspects of students are most optimal when mobile learning is applied. These crucial findings can be a valuable reference for researchers and practitioners interested in implementing mobile learning to strengthen literature and best practices in physics learning.

It is important to conduct future meta-analysis research on mobile learning in physics education to understand how it helps students acquire physics skills and concepts. Analyzing how mobile learning enhances different skills can help improve the selection of optimal mobile learning to improve students' physics learning achievement. Therefore, future research should determine whether physics learning tasks can explain the relationship between mobile learning and student achievement. Future studies should also explore how mobile learning characteristics influence specific learning achievements in different physics domains. However, the current literature review suggests that this exploration can be challenging. Thus, studies on this topic are essential for future research.

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Declaration of Interest

The authors declare no competing interest.

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Appendix A. Literature characteristics of studies included in meta-analysis

No	Study	Country status	Publication year
1.	Astuti et al. (2018)	Developing	Before the Pandemic
2.	Hamza-Lup & Goldbach (2021) Study 2	Developing	In Pandemic
3.	Hamza-Lup & Goldbach (2021) Study 1	Developing	In Pandemic
4.	Simić et al. (2023) Study 1	Developed	After the Pandemic
5.	Billah & Widiyatmoko (2018)	Developing	Before the Pandemic
6.	Simić et al. (2023) Study 2	Developed	After the Pandemic
7.	AlArabi et al. (2022) Study 2	Developing	In Pandemic
8.	Anh & Truong (2023) Study 1	Developing	After the Pandemic
9.	Suana et al. (2019) Study 1	Developing	In Pandemic
10.	Suana et al. (2019) Study 2	Developing	Before the Pandemic
11.	AlArabi et al. (2022) Study 3	Developed	In Pandemic
12.	Prahani et al. (2022)	Developing	In Pandemic
13.	Hamza-Lup & Goldbach (2021) Study 3	Developing	In Pandemic
14.	Serevina et al. (2022)	Developing	In Pandemic
15.	Gutiérrez et al. (2022) Study 2	Developing	In Pandemic
16.	Gutiérrez et al. (2022) Study 4	Developing	In Pandemic
17.	Latumakulita et al. (2023)	Developing	After the Pandemic
18.	Nasir & Fakhruddin Z (2023)	Developing	After the Pandemic
19.	Gutiérrez et al. (2022) Study 1	Developing	In Pandemic
20.	Gutiérrez et al. (2022) Study 3	Developing	In Pandemic
21.	Bani & Masruddin (2021)	Developing	In Pandemic
22.	Saputra & Kuswanto (2019) Study 1	Developing	In Pandemic
23.	Saputra & Kuswanto (2019) Study 2	Developing	In Pandemic
24.	Fithrathy & Ariswan (2019) Study 2	Developing	In Pandemic
25.	Javed et al. (2023)	Developing	After the Pandemic
26.	AlArabi et al. (2022) Study 1	Developing	In Pandemic
27.	Fithrathy & Ariswan (2019) Study 1	Developing	In Pandemic
28.	Elfeky & Masadeh (2016) Study 1	Developed	Before the Pandemic
29.	Elfeky & Masadeh (2016) Study 2	Developed	Before the Pandemic
30.	Chu et al. (2023)	Developing	In Pandemic
31.	Anh & Truong (2023) Study 2	Developing	After the Pandemic
32.	Sulaiman et al. (2023) Study 2	Developing	After the Pandemic
33.	Sulaiman et al. (2023) Study 4	Developing	After the Pandemic
34.	Jampel et al. (2018)	Developing	Before the Pandemic
35.	Sulaiman et al. (2023) Study 1	Developing	After the Pandemic
36.	Sulaiman et al. (2023) Study 3	Developing	After the Pandemic

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Appendix B. Sample or student characteristics of studies included in meta-analysis

No	Study	Gender composition	Sample size	Level academic
1.	Astuti et al. (2018)	No information	Small	Bachelor's Degree
2.	Hamza-Lup & Goldbach (2021) Study 2	No information	Small	Bachelor's Degree
3.	Hamza-Lup & Goldbach (2021) Study 1	No information	Small	Bachelor's Degree
4.	Simić et al. (2023) Study 1	Exclusively male	Small	College
5.	Billah & Widiyatmoko (2018)	No information	Large	College
6.	Simić et al. (2023) Study 2	Exclusively male	Small	College
7.	AlArabi et al. (2022) Study 2	Equal or Nearly	Large	Secondary School
8.	Anh & Truong (2023) Study 1	No information	Large	College
9.	Suana et al. (2019) Study 1	Females majority	Small	Bachelor's Degree
10.	Suana et al. (2019) Study 2	Females majority	Small	Bachelor's Degree
11.	AlArabi et al. (2022) Study 3	Equal or Nearly	Large	College
12.	Prahani et al. (2022)	No information	Small	College
13.	Hamza-Lup & Goldbach (2021) Study 3	No information	Small	Bachelor's Degree
14.	Serevina et al. (2022)	No information	Large	College
15.	Gutiérrez et al. (2022) Study 2	No information	Large	Bachelor's Degree
16.	Gutiérrez et al. (2022) Study 4	No information	Large	Bachelor's Degree
17.	Latumakulita et al. (2023)	No information	Large	College
18.	Nasir & Fakhruddin Z (2023)	Equal or Nearly	Large	College
19.	Gutiérrez et al. (2022) Study 1	No information	Large	Bachelor's Degree
20.	Gutiérrez et al. (2022) Study 3	No information	Large	Bachelor's Degree
21.	Bani & Masruddin (2021)	No information	Small	College
22.	Saputra & Kuswanto (2019) Study 1	No information	Small	College
23.	Saputra & Kuswanto (2019) Study 2	No information	Small	College
24.	Fithrathy & Ariswan (2019) Study 2	No information	Large	College
25.	Javed et al. (2023)	Males majority	Large	Bachelor's Degree
26.	AlArabi et al. (2022) Study 1	Females majority	Large	Bachelor's Degree
27.	Fithrathy & Ariswan (2019) Study 1	No information	Large	College
28.	Elfeky & Masadeh (2016) Study 1	No information	Small	Bachelor's Degree
29.	Elfeky & Masadeh (2016) Study 2	No information	Small	Bachelor's Degree
30.	Chu et al. (2023)	No information	Large	College
31.	Anh & Truong (2023) Study 2	No information	Large	College
32.	Sulaiman et al. (2023) Study 2	No information	Large	College
33.	Sulaiman et al. (2023) Study 4	No information	Large	College
34.	Jampel et al. (2018)	No information	Small	Primary School
35.	Sulaiman et al. (2023) Study 1	No information	Large	College
36.	Sulaiman et al. (2023) Study 3	No information	Large	College

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Appendix C. Instructional design characteristics of studies included in meta-analysis (Part A)

No	Study	Learning model	Learning media	Physics content	Achievement
1.	Astuti et al. (2018)	No information	apps	Mechanics	Cognitive
2.	Hamza-Lup & Goldbach (2021) Study 2	Other	other	Electricity & Electromagnetism	Cognitive
3.	Hamza-Lup & Goldbach (2021) Study 1	Other	other	Electricity & Electromagnetism	Cognitive
4.	Simić et al. (2023) Study 1	Other	web	Mechanics	Cognitive
5.	Billah & Widiyatmoko (2018)	Other	VR	Other	No information
6.	Simić et al. (2023) Study 2	Other	web	Mechanics	Cognitive
7.	AlArabi et al. (2022) Study 2	Other	other	Mechanics	Cognitive
8.	Anh & Truong (2023) Study 1	PJBL	other	Other	Affective
9.	Suana et al. (2019) Study 1	Inquiry	apps	Electricity & Electromagnetism	Cognitive
10.	Suana et al. (2019) Study 2	Inquiry	apps	Other	Cognitive
11.	AlArabi et al. (2022) Study 3	Other	web	Mechanics	Cognitive
12.	Prahani et al. (2022)	PBL	e book	Electricity & Electromagnetism	Cognitive
13.	Hamza-Lup & Goldbach (2021) Study 3	Other	other	Electricity & Electromagnetism	Cognitive
14.	Serevina et al. (2022)	No information	e module	Thermodynamics	Cognitive
15.	Gutiérrez et al. (2022) Study 2	Other	web	Electricity & Electromagnetism	Psychomotor
16.	Gutiérrez et al. (2022) Study 4	Other	web	Electricity & Electromagnetism	Psychomotor
17.	Latumakulita et al. (2023)	Cooperative	e book	Mechanics	Affective
18.	Nasir & Fakhruddin Z (2023)	No information	AR	Other	Cognitive
19.	Gutiérrez et al. (2022) Study 1	Other	web	Electricity & Electromagnetism	Psychomotor
20.	Gutiérrez et al. (2022) Study 3	Other	web	Electricity & Electromagnetism	Psychomotor
21.	Bani & Masruddin (2021)	No information	apps	Wave & Vibration	Cognitive
22.	Saputra & Kuswanto (2019) Study 1	Other	apps	Mechanics	Cognitive
23.	Saputra & Kuswanto (2019) Study 2	Other	apps	Mechanics	Cognitive
24.	Fithrathy & Ariswan (2019) Study 2	No information	apps	Electricity & Electromagnetism	Cognitive
25.	Javed et al. (2023)	Other	other	Other	Affective
26.	AlArabi et al. (2022) Study 1	Other	other	Other	Affective
27.	Fithrathy & Ariswan (2019) Study 1	No information	apps	Electricity & Electromagnetism	Cognitive
28.	Elfeky & Masadeh (2016) Study 1	Other	apps	Other	Cognitive
29.	Elfeky & Masadeh (2016) Study 2	Other	apps	Other	Psychomotor
30.	Chu et al. (2023)	STEAM/STEM	apps	Wave & Vibration	Cognitive
31.	Anh & Truong (2023) Study 2	PJBL	other	Other	Affective
32.	Sulaiman et al. (2023) Study 2	PJBL	e module	Mechanics	Affective
33.	Sulaiman et al. (2023) Study 4	PJBL	e module	Mechanics	Affective
34.	Jampel et al. (2018)	Cooperative	other	Other	Cognitive
35.	Sulaiman et al. (2023) Study 1	PJBL	e module	Mechanics	Affective
36.	Sulaiman et al. (2023) Study 3	PJBL	e module	Mechanics	Affective

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Appendix D. Instructional design characteristics of studies included in meta-analysis (Part B)

No	Study	Measurement instrument	Sampling technique
1.	Astuti et al. (2018)	Cognitive	No information
2.	Hamza-Lup & Goldbach (2021) Study 2	No information	No information
3.	Hamza-Lup & Goldbach (2021) Study 1	No information	No information
4.	Simić et al. (2023) Study 1	No information	Probability/random
5.	Billah & Widiyatmoko (2018)	Develop by author	No information
6.	Simić et al. (2023) Study 2	No information	Probability/random
7.	AlArabi et al. (2022) Study 2	Standardized	Nonprobability
8.	Anh & Truong (2023) Study 1	No information	Nonprobability
9.	Suana et al. (2019) Study 1	Develop by author	Probability/random
10.	Suana et al. (2019) Study 2	Develop by author	Probability/random
11.	AlArabi et al. (2022) Study 3	No information	Probability/random
12.	Prahani et al. (2022)	Develop by author	Probability/random
13.	Hamza-Lup & Goldbach (2021) Study 3	No information	No information
14.	Serevina et al. (2022)	Develop by author	Pon probability
15.	Gutiérrez et al. (2022) Study 2	Standardized	Probability/random
16.	Gutiérrez et al. (2022) Study 4	Standardized	Probability/random
17.	Latumakulita et al. (2023)	Develop by author	Probability/random
18.	Nasir & Fakhruddin Z (2023)	Adaptation	No information
19.	Gutiérrez et al. (2022) Study 1	Standardized	Probability/random
20.	Gutiérrez et al. (2022) Study 3	Standardized	Probability/random
21.	Bani & Masruddin (2021)	Adaptation	No information
22.	Saputra & Kuswanto (2019) Study 1	Develop by author	Probability/random
23.	Saputra & Kuswanto (2019) Study 2	Develop by author	Probability/random
24.	Fithrathy & Ariswan (2019) Study 2	Standardized	No information
25.	Javed et al. (2023)	Adaptation	Probability/random
26.	AlArabi et al. (2022) Study 1	Adaptation	Probability/random
27.	Fithrathy & Ariswan (2019) Study 1	Standardized	No information
28.	Elfeky & Masadeh (2016) Study 1	Develop by author	No information
29.	Elfeky & Masadeh (2016) Study 2	Develop by author	No information
30.	Chu et al. (2023)	Develop by author	Probability/random
31.	Anh & Truong (2023) Study 2	No information	Nonprobability
32.	Sulaiman et al. (2023) Study 2	Standardized	No information
33.	Sulaiman et al. (2023) Study 4	Standardized	No information
34.	Jampel et al. (2018)	Develop by author	No information
35.	Sulaiman et al. (2023) Study 1	Standardized	No information
36.	Sulaiman et al. (2023) Study 3	Standardized	No information

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