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Meta-analysis of mobile applications and their impact on student outcomes: Enhancing interest and intellectual abilities in physics learning

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Abstract

This meta-analysis study examines the impact of mobile applications on students' affective outcomes in physics learning, evaluating their contribution to the development of interest and cognitive abilities. The study reviews experimental research from the *Web of Science* and *Scopus* databases, considering only controlled experimental studies. A key inclusion criterion was that the selected studies reported sample size, arithmetic mean, standard deviation, or statistical values such as t, F, and df. The latest inclusion period covers February 2025. For data analysis, a statistical package program for meta-analysis was used, and the random effects model was applied. To detect publication bias, funnel plot and "trim and fill" method test were utilized. Educational levels, publication year, main intellectual outcome, mobile learning technique, publication type, database, and cultural variables were tested as moderators. As a result, mobile applications were found to be widely effective in enhancing student interest and intellectual abilities in physics education. All hypotheses were confirmed regarding the tested moderator variables such as education level, publication year, technique, intellectual output, type of research and database and culture. In this context, recommendations were provided for researchers and practitioners.

Keywords: mobile learning, physics education, meta-analysis, learning outcomes, educational technology

INTRODUCTION

Educational technologies play an increasingly important role in all levels of education, including physics education. The use of technology in physics teaching can significantly improve student learning when it is designed in a way that aligns with teaching objectives and is fully integrated into a course module (Turney et al., 2009). Mobile devices have also become important tools for physics education, especially with the increase in ease of access (Tavares et al., 2021). Digital mobile devices, such as mobile phones, *personal digital assistants*, and tablets, are increasingly being used for educational purposes (Pimmer et al., 2016). These technologies have the potential to support learning anytime and anywhere, allowing students to make the most of learning opportunities (Bernacki et al., 2020).

Mobile learning (also known as m-learning) refers to an educational approach that allows learners to access learning content and engage in instructional activities through mobile devices such as smartphones, tablets, and laptops, regardless of time and location. This method supports flexibility, personalization, and real-time interaction in the learning process (Traxler, 2007). The COVID-19 process has made many institutions no longer limited to books and face-to-face teaching (Aulakh et al., 2023). Mobile learning refers to accessing learning materials and interacting with others in different contexts using individual mobile technologies (Chen et al., 2008; Crompton, 2013). This method enables learners to access information regardless of their location and offers an alternative to place-based learning (Liu & Hwang, 2010). Mobile learning enables seamless communication and interaction between students and

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Contribution to the literature

- This study offers a comprehensive meta-analysis on the impact of mobile applications in physics education, specifically focusing on enhancing students' interest and intellectual abilities.
- Unlike previous research that primarily emphasized academic achievement, this analysis incorporates a broader range of affective and cognitive outcomes—including problem-solving, reflective thinking, and creativity.
- It bridges a critical gap in the literature by expanding the understanding of mobile learning's educational potential beyond traditional performance measures.

teachers by ensuring that information is available to all learners without time and geographical constraints (Swan, 2020). Mobile learning, which adopts a student-centered learning approach, offers a learning environment that supports different student-teacher interactions (Bennett et al., 2009).

Physics education differs from other fields in that it includes abstract concepts, the need for laboratory equipment, and requires certain experimental conditions (Cai et al., 2016). Mobile learning tools can provide facilitating solutions to these challenges in physics education. Mobile devices and apps can provide innovative ways to enhance physics learning by providing students with access to information, making sense of it, and creating products with rich visual representations (Castek & Beach, 2013). This research aims to evaluate the effects of mobile applications on the development of students' mental output, interest and cognitive abilities in physics learning.

Mobile Learning and Physics Learning

According to Wijaya et al. (2021); Mobile learning tools supply interactive and flexible learning environments to address the challenges faced by traditional physics learning and teaching methods. Traditional classroom approaches are limited in terms of effectively addressing the abstract concepts inherent in learning physics. Mobile platforms such as simulations, virtual labs, augmented reality (AR) applications, and mobile information management systems provide interactive models that make these concepts more concrete and understandable (Susilawati et al., 2022). Mobile learning tools allow students to conduct virtual experiments, manipulate models, and revisit topics they struggle with, providing an environment suitable for individual learning pace and increasing the retention of information. It also makes it possible to exhibit phenomena that are difficult to demonstrate in physical classroom settings in a more accessible way (Bernacki et al., 2020).

However, mobile phones and applications increase student interaction in class (Swan, 2020). The convenience offered by mobile learning allows students to learn at their own pace, which is such a convenience in terms of learning otherwise difficult topics like physics (Khasawneh et al., 2023). Interactive simulations and apps allow one to visualize and mold abstract forces and electricity and provide more familiar and accessible learning of such abstract materials to students (Criollo & Luján-Mora, 2018). In addition to improving the level of understanding, they improve the engagement and motivation towards the subject by the students. Additionally, mobile apps help in the development of teamwork, analytical reasoning, reflective reasoning and problem-solving skills through the facilitation of students to work on common platforms. Instant feedback, however, helps them to complete knowledge gaps (Wijaya et al., 2021).

Students use mobile technologies in different ways. Some students are preparing for the learning process, some are active in the process, and some are only benefiting from mobile devices through dedicated apps (Epp & Phirangee, 2019). The use of mobile devices in the learning process is considered as an effective learning strategy (Jeng et al., 2010). Students also use their mobile devices for simulation (Reeves et al., 2017), virtual lab (Lu et al., 2019), and instant feedback (Criollo & Luján-Mora, 2018).

Enhancing Interest and Intellectual Abilities in Physics Learning

Physics education is often seen as a challenging field for students because it involves abstract concepts. Increasing students' interest in this field and developing their intellectual skills is possible with effective teaching methods and pedagogical approaches (Rizzo & Taylor, 2016). When physics courses are transformed into a structure that allows students to explore and develop their problem-solving skills, their quality increases in outputs such as academic achievement and motivation (Roman et al., 2017). Skills that can be developed in the physics learning process include skills such as problem-solving ability, analytical thinking, critical thinking, abstract reasoning, scientific inquiry skills, spatial thinking, creative thinking, numerical competence, data analysis skills, and designing experiments (Ankeli et al., 2020). One of the most effective ways to increase students' interest in physics subjects is to make their teaching process more meaningful by relating them to real-world problems. In this context, technology can be an effective way (Marušić & Sliško, 2012). The use of technology-supported learning environments helps students better understand abstract concepts and develop their scientific thinking skills (Kotsis, 2024).

The ability to reason abstractly is one of the essential components of physics education. Interactive simulations, virtual laboratories and AR applications are used for students to make sense of abstract concepts. For example, conducting experiments in a virtual environment to understand Newton's laws of motion helps students better grasp the topics. Such digital tools enable students to better understand the physical world, while also improving their scientific thinking skills (Aboagye & Avor, 2025; Roman et al., 2017).

Another important intellectual skill is to develop students' creativity. Physics is a branch of science that encourages not only the learning of certain rules and laws, but also the generation of new ideas (Ankeli et al., 2020). In particular, presenting open-ended questions and projects helps them to innovate scientifically and develop original solutions (Marušić & Sliško, 2012). Teamwork and communication skills are also important in terms of group projects in physics laboratory work. It helps students understand different perspectives, solve problems together, and increase their academic interactions. Collaborative learning environments allow students to learn physics subjects more in-depth while also strengthening their social skills (Kotsis, 2024). Focusing on skills such as problem solving, analytical thinking, abstract reasoning, creative thinking, and data analysis in physics teaching will both increase students' academic success and enable them to better adapt to future scientific and technological developments (Aboagye & Avor, 2025).

With the increase in access to mobile devices in recent years, studies on the effects of mobile learning on various student outcomes in different disciplines, especially physics, have been included in the literature. In the systematic review study by Anselmo et al. (2024), the impact of mobile learning tools on physics education was examined. The systematic literature review by Bakri et al. (2023) analyzed the impact of mobile learning on physics education by addressing its integration with STEM-based project-based learning. In their research, Zhai et al. (2019) examined the pedagogical characteristics of mobile technology in the context of science education and its relationship with student achievement. In their study, Prahani et al. (2022) examined research trends in mobile learning, web-based learning, and e-learning over the past two decades through bibliometric analysis. As can be seen, research on the subject is mostly in the form of bibliometric analysis and systematic survey. The only research found in the literature on this subject was conducted by Abdullah et al. (2024). In the study, they examined the effect of the use of mobile technology in physics education on student academic achievement with meta-analysis technique. The results show that mobile learning has a significant positive effect on physics achievement. Moderator analyses revealed that variables such as sample size, academic level, gender distribution, learning environment, learning model, learning outcome, and measurement tool led to differences in impact, but there was no significant difference in country status, year of publication, sampling method, and physics. This study was limited to the variable of academic achievement and did not include other educational outcomes. In this context, it is thought that this research, which aims at the effect of mobile learning applications in physics education on the development of mental output, interest and cognitive abilities, will fill the gap in the literature.

This meta-analysis study was conducted to evaluate the effects of mobile applications on the development of students' mental output, interest and cognitive abilities in physics learning. For this purpose,

(1) the intellectual output focused,

(2) the education level at which the research was conducted,

(3) the year of publication of the research,

(4) the techniques applied in the experimental groups,

(5) the type of research,

(6) the database, and

(7) the culture in which the research was carried out were determined as moderators. In connection with these variables, the following hypotheses were tested.

H1. Mobile applications positively affect students' interests and intellectual abilities in physics learning.

H2. *Education levels* are moderators in the effect of student interest and intellectual abilities in the physics learning of mobile applications.

H3. *The year of publication is* a moderator on the influence of student interest and intellectual abilities in the physics learning of mobile applications.

H4. In the physics learning of mobile applications, the *intellectual output focused on* the effect of student interest and intellectual abilities plays a moderating role.

H5. *The technique applied is* the moderator in the physics learning of mobile applications under the influence of student interest and intellectual abilities.

H6. *The type of research is* moderating the influence of student interest and intellectual abilities in the physics learning of mobile applications.

H7. *The database* is a moderator in the physics learning of mobile applications, under the influence of student interest and intellectual abilities.

Table 1. Profile of the studies included in the meta-analytic review

Variable	Category	n	%
Year of publication	2017-2018	18	40.91
	2019-2020	7	15.91
	2021-2022	8	18.18
	2023-	11	25.00
School level	High school	29	65.91
	University	15	34.09
Country	Indonesia	16	36.36
	Morocco	7	15.91
	Taiwan	7	15.91
	Malaysia	5	11.36
	Mexico	2	4.55
	Czech Republic	3	6.82
	USA	2	4.55
	England	1	2.27
	Finland	1	2.27
Database	Scopus	32	72.73
	Wos	12	27.27
Publication type	Article	27	61.36
	Statement	12	27.27
	Book Chapter	5	11.36
Total		44	100

H8. *Culture* is the moderator of the influence of student interest and intellectual abilities in the physics learning of mobile applications.

METHOD

Research Model

In this study, the meta-analysis technique, one of the quantitative research techniques, was used. A meta-analysis is an analysis used to synthesize and statistically analyze results from a large number of independent studies focused on a specified topic (Littel et al., 2008; Petitti, 2000).

Inclusion/Exclusion Criteria

In order to determine the studies suitable for inclusion in the meta-analysis, *a search was made from Web of Science* (*WoS*) and *Scopus* databases. At this stage, the search parameters were included to cover the *title and keyword fields, using the keywords related to* "Physics" AND "Mobile", "Physics" AND "m-learning", *"Physics" AND "Mobile application"*, *"Physics" AND "Mobile app."*, *"Physics" AND "Mobile" AND "Tool"*. The deadline for inclusion in this study was determined as March 2025, and *research articles, books* and *papers* formed the universe of this study.

In this research, a multi-pronged approach was used to identify studies suitable for inclusion in the follow-up meta-analysis. Initially, there was a comprehensive study that included all the work on the intersection of experimental research on physics and student outcomes. This initial research created a pool of a total of 274 studies with title and keywords fields. Subsequently, the research abstracts were subjected to rigorous scrutiny. This abstract-oriented review led to the exclusion of 186 studies that were not conducted experimentally from the scope of the research. In the next phase, the remaining 88 studies underwent an in-depth evaluation and concluded that 44 of these studies met the necessary criteria for inclusion, while the remaining studies were not eligible for the current analysis.

In the researches, experimental studies conducted to evaluate the effects of mobile applications on the development of mental output, interest and cognitive abilities of students in physics learning *Data, Journal of Physics: Conference Series, Journal of Baltic Science Education, International Journal of Interactive Mobile Technologies, International Journal of Science and Mathematics Education, International Journal of Instruction, Science Teacher Education, Journal of Education and e-Learning Research, 7th World Engineering Education Forum, 15th International Conference on Mobile Learning and AIP Conference Proceedings*. The combination of these 44 studies revealed an extensive sample size of 11,683 participants (see **Appendix A**). There was no year limit in the research. Descriptive statistical profiles of these 44 selected studies are presented in **Table 1**.

Looking at the distribution of the publication year of the studies, it is seen that the studies for the period covering the years 2017-2018 (40.91%) have a significant density compared to other periods. In the distribution according to school levels, it is seen that high school students (65.91%) and university students (34.09%) are represented.

When the distribution by country is examined, it is seen that the highest rate of research was carried out in Indonesia (36.36%). This is followed by Morocco and Taiwan (15.91%). In terms of databases, it was determined that 72.73% of the studies were based on Scopus and 27.27% were from *WoS*. In terms of publication type, article type research is represented at the highest rate (61.36%).

The criteria for inclusion of research studies in the meta-analysis are defined as follows:

1. Study designs were conducted with pre-test/post-test or post-test experimental or quasi-experimental or post-test experimental design without control group.
2. If more than one skill was focused on in the experimental groups, each skill was included as separate research.
3. Sufficient data were reported to be able to calculate the effect sizes (n values and standard deviation [SD] in each group or $\overline{X}$, t, F, or x^2 values in each group).

Furthermore, the research studies were excluded from the meta-analysis under the following conditions:

1. Absence of quantitative data, which is indicative of qualitative research orientation.
2. Inadequate data reporting hinders the calculation of impact sizes.
3. Lack of emphasis on student outcomes.
4. Moving away from the center of physics learning and mobile learning.

Coding Process

The coding process was used as a basic categorization method to determine the datasets to be included in the study. Accordingly, a comprehensive and rigorous coding framework was established before the statistical analysis and this framework was adhered to throughout the process. The main goal is to develop a coding system that comprehensively evaluates selected research studies and to record all important features specific to each study in full.

The coding process consists of the following sections:

1. references of studies,
2. details sample and population,
3. the mean and standard deviation of the groups,
4. output type,
5. educational level,
6. experimental methods,
7. the dimension, especially the year of publication of the study, is discussed,
8. the country in which the publication took place,
9. the name of the journal in which it was published, and
10. database information.

Statistical Processes

CMA software has been used as a tool to conduct meta-analytical procedures. During this research, the random effects model was applied as the methodological framework in conducting the meta-analysis. For studies that provided mean and SD metrics, in accordance with the formula described by Rosenthal (1979), the effect size was determined using the mean difference between the experimental and control groups, measured as both pretest and posttest, or only posttest. Furthermore, for studies that presented data in the form of mean, t, F, or $\chi 2$ values for each interested group, effect sizes were calculated using the formula methodologies described by Lipsey and Wilson (2001).

It is important that all studies included in this comprehensive review adhere equally to an experimental design that involves random selection of participants or a quasi-experimental design in which participants are not randomly selected. In each sample, a post-test experimental framework was maintained, with a pre- and post-test or only pre-test equalized, thus enabling the calculation of effect sizes for each study based on a comparative analysis of an experimental group. In studies with only the experimental group, pre-test and post-test data were considered to reveal the effect of mobile learning. This design allows for examining changes within the same group over time, making it useful in identifying potential effects of the intervention, especially when control groups are not feasible (Creswell, 2012). In the analysis of the data, each experimental-control comparison was duly included in the data set. In addition, in cases where different student outcomes were compared within the experimental and control groups in a particular study, each of these different abilities was categorically considered as a separate subgroup.

There are two main ways in meta-analysis studies: *the fixed effects model* and the *random effects model*. When deciding which model to use, the characteristics of the research included in the meta-analysis look at which model meets the prerequisites (Kulinskaya et al., 2008). *Fixed effect model*; it involves

(1) the assumption that the studies are functionally identical and

(2) the purpose of calculating the effect size for a defined population only.

If it is believed that the studies are functionally unequal and it is desired to generalize to larger populations with the calculated effect size, the model to be used is the *stochastic effects model*. When these conditions were evaluated together, the random effects model was used in the meta-analysis processes in this study.

Moderator Variables

To test the statistical significance of the moderator variables used in research, Qb statistics values (Littel et al., 2008). Test analysis for the variances across groups of moderators was performed with Hedges and Olkin's (1985) Q statistic method. According to this method, the combined Q value is broken down into two distinct pieces: Qbetween (Qb) and Qwithin (Qw), both being utilized to fulfill a unique role during analysis. Qw is utilized to test for consistency across one moderator category in effect sizes, while Qb is utilized to test whether or not there are significant differences between multiple moderator groups (Borenstein et al., 2009; Kulinskaya et al., 2008) (see **Appendix B**).

Seven moderator variables were used as having a high probability of potentially contributing to the average effect size, which is limits of the research. The first moderator examined is the intellectual output that is focused on. The second moderator in focus is the education level. In addition, the moderator was tested as a variable in terms of the year of publication of the study, the technique applied, the type of research, the database and the culture.

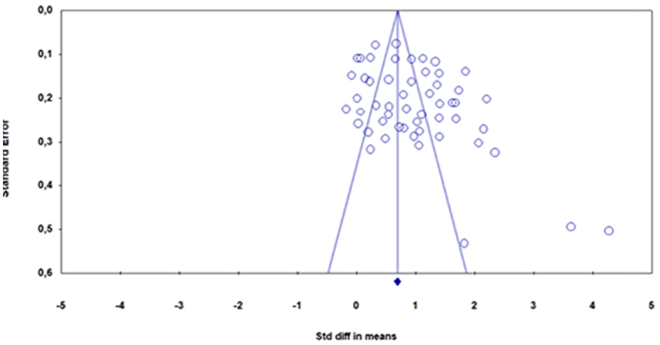

Figure 1. Funnel chart of impact size for delivery bias (Source: Authors' own elaboration)

Publication Bias

Publication bias is basically based on the assumption that all research on a topic may not have been published. In particular, studies in which statistically significant relationships are not detected or low levels of relationships are not considered worthy of publication, which negatively affects the total effect level and increases the average effect size biasedly (Hanrahan et al., 2008). This publication bias effect, which we can also call missing data, negatively affects the total impact of meta-analysis studies. In this sense, the possibility of publication bias is considered in meta-analysis studies. In this study, the following questions were answered to examine publication bias.

1. Is there evidence according to publication bias?
2. Is it possible that the overall effect size has been influenced by diffusion bias?
3. How much of the total amount of influence is due to publication bias?

In meta-analyses, a number of calculation methods are used to give a statistical answer to the questions involving the above probabilities. At the beginning of these *funnel plot* (*funnel drawing*) method. Although the form provided by this method is not exactly objective, it allows us to see whether the studies obtained are under the influence of publication bias (Littel et al., 2008). In this study, the funnel plot of the studies included in the meta-analysis is presented in **Figure 1**. In the studies included in the meta-analysis in **Figure 1**, there was no evidence of an effect due to publication bias. In publication bias, the funnel plot is expected to be seriously asymmetrical. It may suggest the possibility of the existence of the spread bias of scattering, especially in the right parts of the funnel. It is important to note, however, that the present research does not reveal any concrete or proven indication of publication bias in any of the 44 datasets that were rigorously examined, thus highlighting the integrity of the meta-analytic analysis.

Although no clear signs of publication bias were identified through visual inspection of the funnel plot, a comprehensive analysis was conducted using Duval and Tweedie's (2020) trim and fill method. This analysis, implemented within the framework of the *random effects model* and detailed in **Table 2**. This' mean to assess whether potential publication bias might have influenced the estimated effect size. According to the data presented in **Table 2**, the adjusted (imputed) effect size and the initially observed effect size were found to be identical. This result suggests that the distribution of studies is largely symmetrical around the central axis, with only two studies deviating from this symmetry, both positioned on the right side of the centerline, thus minimizing concerns regarding bias-induced distortion.

RESULTS

Table 3 presents the findings of the meta-analysis on the effects of mobile applications on students' interests and intellectual abilities in physics learning. The findings confirmed the **H1** hypothesis, which suggests that mobile apps *have a significant impact on students' interests and intellectual abilities in physics learning*. The overall calculated effect size was ($g = 1.72$), indicating *a high level of effect size* (Cohen, 1988). This shows that mobile applications *are an effective method to increase* students' interests and intellectual abilities in physics learning.

However, according to the moderator analysis, **H2** *hypothesis, which suggests that the school level* plays a moderating role on interests and intellectual abilities, was supported. Moderator analysis showed that the difference in effect sizes between the sampled groups was statistically significant ($Qb = 18.77$, $p < 0.05$). It was observed that there was a high level of effect at both the high school level [$g = 1.31$] and the university level [$g = 2.35$].

The **H3** hypothesis, which suggested that the year of publication played a moderating role on the impact of innovative poetry teaching methods, was supported ($Qb = 108.36$, $p < 0.05$). In particular, it was determined that the effect size of the studies conducted in 2019 and 2024 *was very high with* ($g = 2.75$) and ($g=2.50$), while the effect size was not statistically significant *in 2022* [g=.31].

Table 2. Duval and Tweedie's trim and fill test results

	Studies trimmed	Point estimate	95% confidence level		Q
			Lower Limit	Upper Limit	
Observed values		1.72	1.44	2.00	1990.02
Adjusted values	0	1.72	1.44	2.00	1990.02

Table 3. Findings on the effect of mobile applications positively affecting students' interests and intellectual abilities in physics learning: Meta-analysis results

Variable	k**	N	Effect size (*g*)	95% confidence interval		*Q*	*Qb*
				Lower limit	Upper limit		
Mobile applications	44	11,683	1.729*	1.448	2.010	1,990.029*	
Moderator [education level]							**18.77***
High school	29	2,953	1.31*	1.03	1.58		
University	15	8,730	2.35*	1.97	2.73		
Moderator [year of publication of the study]							**108.36***
2017	8	5,767	.71*	.30	1.12		
2018	10	852	1.95*	1.56	2.35		
2019	4	954	2.75*	2.15	3.35		
2020	3	180	1.47*	.76	2.17		
2021	1	908	1.25*	.16	2.33		
2022	7	1,876	.31	-.09	.73		
2023	1	64	4.43*	2.94	5.76		
2024	10	1,082	2.50*	2.12	2.88		
Moderator [interest and intellectual abilities]							**187.55***
Creative Thinking Skills	4	218	1.81*	1.22	2.41		
Reflective Thinking Ability	1	60	3.44*	2.17	4.72		
Critical Thinking Skills	1	50	1.92*	.72	3.12		
Diagrammatic and Argumentative Representation Competence	2	400	.98*	.24	1.71		
Divergent Thinking Skills	1	65	7.36*	5.68	9.04		
Grades for Laboratory Reports	4	452	3.01*	2.43	3.58		
Higher Order Thinking Skills	6	4,589	.74*	.31	1.18		
Technical Skills	8	580	.30	-.06	.66		
Learning Gains	3	910	3.19*	2.55	3.84		
Learning Independence	2	126	1.66*	.84	2.47		
Physics Perseverance	1	908	1.25*	.25	2.26		
Problem-Solving Ability	3	174	2.71*	1.85	3.58		
Representation Ability	2	94	.96*	.14	1.79		
Interest and Perception	5	2,990	2.35*	1.85	2.85		
Technology Self-Efficacy	1	67	.91	-0.20	2.03		
Moderator [mobile technique]							**401.42***
M-Learning Management Systems	3	384	.89*	.45	1.32		
Physics Mobile Learning Media	1	68	6.06*	4.76	7.37		
Android-Assisted Mobile Physics Learning	11	717	1.60*	1.28	1.93		
Android-Assisted with BatuHombo Theme	2	354	2.57*	1.86	3.27		
Android-Based Learning Media	1	54	1.10*	.22	1.97		
Augmented Reality (Mobile AR app)	2	94	.96*	.33	1.60		
Handheld Augmented Reality System (Android)	1	50	1.08*	.19	1.97		
Lab4Physics mobile laboratory	7	1,876	.32*	.05	.59		
Mobile AR system	1	64	4.34*	3.23	5.46		
Mobile Instructional Particle Image Velocimetry	2	846	2.85*	2.35	3.36		
Mobile Science Laboratory	5	5,570	.17	-.13	.47		
Pocket Mobile Learning	1	50	1.92*	.98	2.86		
R-assisted manual with QR codes	6	648	3.66*	3.29	4.04		
The Representational Triplet in Chemistry (RTC) Dictionary	1	908	1.25*	0.58	1.93		
Moderator [research type]							**15.06***
Article	27	3,625	1.42*	1.04	1.81		
Book chapter	5	1,546	3.35*	2.45	4.25		
Proceeding	12	6,512	1.81*	1.23	2.38		
Moderator [database]							**25.23***
Scopus	32	9,319	2.19*	1,86	2.53		
Wos	12	2,364	.58*	.05	1.11		
Moderator [culture]							**7.09***
Horizontal-Individualistic	9	2,337	2.34*	1.81	2.88		
Vertical-Collectivist	35	9,346	1.53*	1.25	1.80		

Note. *$p < .05$ & *k***Number of population

The **H4** hypothesis, which suggested that the variable interest and intellectual abilities played a moderating role, was supported. Moderator analysis *showed that there were positive differences in the effect sizes* of mobile applications for different interests and intellectual abilities *in physics education* ($Qb = 187.55$, $p < 0.05$). *The effect size calculated for* divergent thinking skills was found to be high with [*g*=*7.36*]. In addition, *creative thinking skills* [*g* = *1.81*], *reflective thinking ability* [*g* = *3.44*], *critical thinking skills* [*g* = 1.92], *grades for laboratory reports* [*g* = *3.01*], *learning gains* [*g*=*3.19*], *learning independence* [*g* = *1.66*]. The *effect size calculated for physics perseverance* [*g* = *1.25*], *problem-solving ability* [*g* = *2.71*], *interest and perception* [*g* = *2.35*] was similarly high. In addition, the impact values calculated for *higher order thinking skills* [*g* = *.74*] and *diagrammatic and argumentative representation competence* [*g* = *.98*] were moderate (Cohen, 1988). However, the impact values for technical skills [*g* = *.98*] and technology self-efficacy [*g* = *.98*] were not significant ($p < 0.05$).

In terms of the applied mobile learning technique, the moderator analysis supported the **H5** hypothesis that the applied technique is a moderator in the effect of student interest and intellectual abilities in the physics learning of mobile applications ($Qb = 401.42$, $p < 0.05$). In particular, *it was found to be very high* with effect size [*g* = *6.06*] for physics mobile learning media, *and highly effective with* [g = 4.43] for *mobile AR system*. In addition, *m-learning management systems, Lab4Physics mobile laboratory and augmented reality* applications were found to be moderately effective. On the other hand, *it was determined that the effect size of the mobile science laboratory* [*g* = *.32*] method did not make a significant difference.

In terms of the type of research, the **H6** hypothesis was accepted ($Qb = 15.06$, $p < 0.05$). Studies published in all three types of research show that mobile learning has a different effect on interest *and intellectual abilities in physics learning*. The highest effect belongs to *the book chapter* with [*g* = *3.35*]. In terms of databases, the **H7** hypothesis was accepted ($Qb = 25.23$, $p < 0.05$). Studies published in *Scopus* and *WoS* databases show that mobile learning has a different effect on interest *and intellectual abilities in physics learning*. The highest effect was *Scopus* with [*g* = *2.19*]. Finally, the **H8** *hypothesis, which suggests that the culture variable plays a moderating role, was supported. In vertical-collectivist cultures*, the effect size of mobile learning *was found to be moderate with* g = .83, while the *effect size was higher* in horizontal-individualist cultures *with g* = *2.34*. There is a statistically significant difference between these two cultures in terms of the effect of mobile applications on students' interests and intellectual abilities in physics learning ($Qb = 7.09$, $p < 0.05$).

The findings show that mobile applications have a positive and high level of effect *on students' interests and intellectual abilities in physics learning*. In addition; *It shows that the variables of education level, year of publication, intellectual skill based, mobile technic used, type of research, database* and *culture* serve as moderator variables.

DISCUSSION

This meta-analysis study was conducted to evaluate the effects of mobile applications on the development of students' mental output, interest and cognitive abilities in physics learning. Research findings show that mobile learning has a significant effect on increasing students' interest and intellectual skills in physics learning. The results of the meta-analysis reveal that these practices improve students' thinking skills, problem-solving skills and learning independence. This suggests that, given the abstract and complex nature of physics courses, mobile apps are effective tools that can help students' intellectual output (Agustihana, 2018; Ayaichi et al., 2024).

The results obtained from the study show that there are different effect sizes on high school and university students. The higher effect size in university students may be due to the fact that this age group is more prone to technology and has more developed independent learning skills (Menon et al., 2020). In contrast, high school-level students also benefit from mobile learning, but may be more reliant on traditional teaching methods (Astuti et al., 2018). Moderator analysis by year of publication reveals that the impact of mobile applications varies over time. Especially in 2019 and 2024, it was observed that the effect size of the studies was quite high. This is because mobile applications and interaction developed in recent years after the pandemic period are more interactive, personalized, and AI-powered (Prahani et al., 2022; Rizal et al., 2024). On the other hand, the low impact size of the studies conducted in 2022 can be explained by the limited number of studies with effective data collection methods due to the pandemic in this period (Amaaz et al., 2024).

Analyses of different intellectual skills show that creative and reflective thinking skills are highly supported by mobile learning. In particular, a strong effect was observed in variables such as problem-solving skills, reflective reporting to laboratory reports, and learning outcomes (Liliarti & Kuswanto, 2018). However, the low impact size in areas such as more technical skills and technology self-efficacy may be related to the inability to develop these skills directly with mobile applications (Carreño et al., 2022). Moderator analysis of mobile learning techniques shows that different mobile applications have different impact sizes. In particular, the high impact of *physics mobile learning media* and *mobile AR system* applications can be explained by the fact that these systems increase the active participation of students by making sense of experimental learning processes in physics education (Bakri et al., 2023). The low impact size of the mobile science laboratory method is due to the fact that these systems do not provide enough interaction to meet students' expectations (Robledo-Rella et al., 2019).

In terms of types of research, book chapters appear to highlight the impact of mobile learning more strongly (Anselmo et al., 2024). This can be attributed to the fact that there is more controlled research in order to include more sample mobile applications in book chapters and to provide detailed explanations of how they can be used in education (Adnan et al., 2018; Shabrina & Kuswanto, 2018). The high impact size of the studies published in the *Scopus* and *WoS* databases may be due to the fact that the research in these databases, which have a say in the field, is stronger methodologically (Rahmat et al., 2023). In terms of cultural differences, it has been found that the impact of mobile learning is higher in individualistic cultures. This can be explained by the fact that in individualistic cultures, students are more likely to learn independently (Husna & Kuswanto, 2018). On the other hand, the lower impact of mobile learning in collectivist cultures can be attributed to the greater emphasis on face-to-face and teacher-centered education in these cultures (Abdullah et al., 2024; Gebze et al., 2020).

This meta-analysis provides a substantial contribution to the literature on mobile learning in physics education by addressing gaps left by prior research and expanding the scope of inquiry beyond academic achievement. While earlier studies such as the bibliometric analyses by Prahani et al. (2022) and systematic reviews by Anselmo et al. (2024) and Bakri et al. (2023) these studies have mapped general trends in mobile-assisted learning, they did not empirically quantify the educational outcomes of such interventions. Notably, the only meta-analytical work found in the literature, conducted by Abdullah et al. (2024), focused exclusively on the impact of mobile applications on academic achievement. However, that study did not account for other cognitive and motivational outcomes, such as students' interest, reflective thinking, problem-solving abilities, and independent learning.

This study fills that critical gap by synthesizing empirical evidence on the effects of mobile applications on students' intellectual skills and engagement in physics learning. Furthermore, moderator variables such as academic level, year of publication, cultural context, and type of mobile application offer nuanced insights into how the effects of mobile learning vary across different educational and demographic contexts.

The findings reveal that mobile applications not only enhance learning outcomes but also foster critical thinking and engagement, particularly in higher education contexts where learners exhibit greater autonomy. The study also highlights the evolution of mobile learning tools over time, emphasizing the increased effectiveness of recent applications that incorporate artificial intelligence and interactivity. By focusing on both cognitive and affective learning domains, this research contributes a multidimensional understanding of how mobile technologies can be strategically integrated into science education, especially in conceptually abstract fields such as physics.

CONCLUSION & RECOMMENDATIONS

This meta-analysis indicates that mobile applications significantly affect students' interest and intellectual skills in physics education. Especially in areas such as problem-solving, reflective thinking, and independent learning, mobile tools provide meaningful support. The higher effectiveness observed in university students suggests that age-related digital competence plays a role. Additionally, the impact of mobile learning varies across years, cultures, and app types, with more interactive and recent tools showing stronger effects. Overall, mobile applications stand out as effective tools for promoting engagement and cognitive development in physics learning.

Although this research evaluates the effect of mobile applications on students' interest and intellectual skills in physics learning, it has some limitations. The meta-analysis data used in the study are based on studies published in specific databases. For this reason, research in different indexes can also be considered. In addition, considering the methodological differences of the studies evaluating the effect of mobile applications, correlational studies should also be examined, except for the control group or post-test single-subject design. Although cultural differences are an important factor that changes the effectiveness of mobile learning applications, the cultural variables examined in the research need to be considered from a broader perspective. Apart from collectivist and individualist cultures, the effects of regional and socio-economic factors on mobile learning processes can also be analyzed.

Future studies should include diverse databases and research designs, including correlational and mixed methods, to broaden generalizability. Application development should prioritize interactivity and cultural adaptability. Educators and policymakers are encouraged to integrate mobile tools into physics curricula, especially in ways that foster independent learning. Moreover, further research is needed to explore socio-economic and regional influences on mobile learning effectiveness.

Author contributions: DMZ: conceptualization, formal analysis, investigation, data curation, writing – original draft; **BZA:** conceptualization, formal analysis, writing – original draft, writing – review & editing, visualization; **BKK:** methodology, investigation, writing – original draft, visualization; **AAA:** methodology, data curation, writing – original draft, writing – review & editing; **BKK:** formal analysis, writing – review & editing; **APK:** data curation, writing – original draft, visualization. All authors agreed with the results and conclusions.

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Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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APPENDIX A

Articles Included in the Meta Analysis

Table A1.

Articles
Abdullah, W. D., Afikah, A., Apino, E., Supahar, S., & Jumadi, J. (2024). Moderator effect of mobile learning on students' achievement in physics: A meta-analysis. *Journal of Baltic Science Education, 23*(2), 187-207. Scopus. https://doi.org/10.33225/jbse/24.23.187
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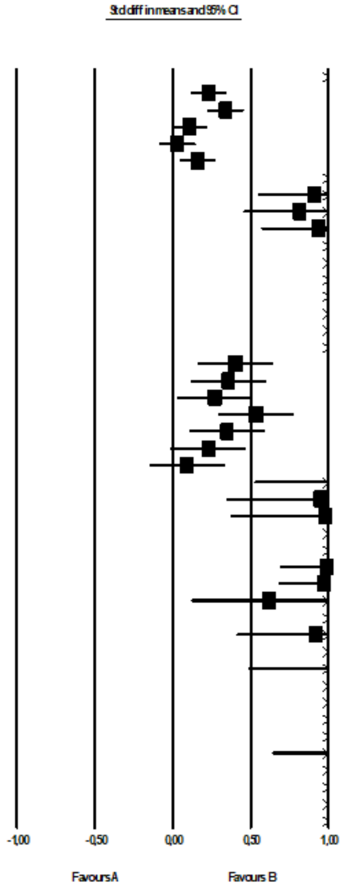
APPENDIX B

Summary of Study Characteristics Included in Analysis

Study name	Std diff in means	Standard error	Variance	Lower limit	Upper limit	Z-Value	p-Value
Agustihana, S. & Supamo	6,064	0,574	0,329	4,939	7,188	10,569	0,000
Adnan, et al. (a)	0,230	0,060	0,004	0,112	0,348	3,826	0,000
Adnan, et al. (b)	0,339	0,060	0,004	0,221	0,457	5,617	0,000
Adnan, et al. (c)	0,107	0,060	0,004	-0,011	0,224	1,781	0,075
Adnan, et al. (d)	0,030	0,060	0,004	-0,088	0,147	0,494	0,621
Adnan, et al. (e)	0,160	0,060	0,004	0,042	0,278	2,665	0,008
Almubarak, R.	1,252	0,073	0,005	1,110	1,395	17,254	0,000
Amaaz, A; Mouradi, A and Erradi, M (a)	0,912	0,186	0,034	0,548	1,276	4,909	0,000
Amaaz, A; Mouradi, A and Erradi, M (b)	0,814	0,184	0,034	0,454	1,175	4,426	0,000
Amaaz, A; Mouradi, A and Erradi, M (c)	0,934	0,186	0,035	0,569	1,299	5,016	0,000
Astuti et al.	1,920	0,342	0,117	1,250	2,590	5,613	0,000
Ayachi et al. (a)	3,154	0,288	0,083	2,589	3,719	10,941	0,000
Ayachi et al. (b)	2,775	0,270	0,073	2,247	3,304	10,294	0,000
Ayachi et al. (c)	2,741	0,268	0,072	2,215	3,266	10,227	0,000
Ayachi et al. (d)	4,279	0,349	0,122	3,595	4,963	12,261	0,000
Ayachi et al. (e)	5,107	0,397	0,158	4,328	5,885	12,857	0,000
Ayachi et al. (f)	4,783	0,378	0,143	4,042	5,524	12,650	0,000
Carreño et al. (a)	0,402	0,125	0,016	0,158	0,646	3,232	0,001
Carreño et al. (b)	0,358	0,124	0,015	0,114	0,601	2,877	0,004
Carreño et al. (c)	0,270	0,124	0,015	0,027	0,513	2,181	0,029
Carreño et al. (d)	0,534	0,125	0,016	0,288	0,780	4,258	0,000
Carreño et al. (e)	0,348	0,124	0,015	0,104	0,591	2,801	0,005
Carreño et al. (f)	0,227	0,124	0,015	-0,016	0,469	1,834	0,067
Carreño et al. (g)	0,092	0,123	0,015	-0,150	0,334	0,746	0,456
Gebze et al.	1,097	0,292	0,085	0,525	1,669	3,758	0,000
Husna, M. and Kuswanto, H. (a)	0,948	0,308	0,095	0,344	1,553	3,077	0,002
Husna, M. and Kuswanto, H. (b)	0,981	0,309	0,096	0,375	1,587	3,171	0,002
Shabrina & Kuswanto, H. (a)	2,084	0,321	0,103	1,455	2,712	6,497	0,000
Shabrina & Kuswanto, H. (b)	3,444	0,407	0,166	2,647	4,242	8,466	0,000
Liliani, N & Kuswanto, H. (a)	0,986	0,150	0,022	0,692	1,279	6,581	0,000
Liliani, N & Kuswanto, H. (b)	0,970	0,150	0,022	0,677	1,264	6,491	0,000
Nana, M & Heru, K. (a)	0,617	0,254	0,064	0,120	1,115	2,431	0,015
Nana, M & Heru, K. (b)	7,357	0,691	0,478	6,002	8,712	10,642	0,000
Meron et al.	0,914	0,257	0,066	0,411	1,418	3,561	0,000
Rahmat et al.	4,343	0,458	0,210	3,445	5,241	9,481	0,000
Rizal et al.	1,078	0,303	0,092	0,485	1,671	3,561	0,000
Robledo-Rella et al. (a)	2,697	0,136	0,018	2,431	2,963	19,866	0,000
Robledo-Rella et al. (b)	3,011	0,143	0,021	2,730	3,292	21,003	0,000
Saputra & Kuswanto (a)	3,588	0,443	0,196	2,720	4,455	8,106	0,000
Saputra & Kuswanto (b)	1,835	0,328	0,108	1,191	2,479	5,587	0,000
Shabrina & Kuswanto (a)	1,188	0,280	0,078	0,639	1,737	4,242	0,000
Shabrina & Kuswanto (b)	3,446	0,407	0,166	2,649	4,244	8,468	0,000
Kuswanto et al. (a)	1,739	0,296	0,088	1,158	2,319	5,873	0,000
Kuswanto et al. (b)	1,574	0,289	0,083	1,008	2,140	5,454	0,000
	1,729	0,143	0,020	1,448	2,010	12,079	0,000



(Borenstein, 2022)