



Research article

A meta-analysis of the effects of E-books on students' mathematics achievement

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ABSTRACT

The 21st century allows the use of e-books to substitute printed books in educational context, thereby adapt teaching and learning to the potentialities of our digital era. Several studies examined the effect of mathematics e-books compared to traditional printed books on students' mathematics achievement, however, the results are still inconclusive. Therefore, this research conducted a meta-analysis to determine the effects of mathematics e-books on students' mathematics achievement. This is a quantitative research with data collected from 17 studies with 26 effect sizes ($N = 3115$) published between 2010 and 2021. The collected data were used to analyze the moderating effects of publication year, sample size, level education, treatment duration and type of e-books on students' mathematics achievement. The result showed that overall using mathematics e-books has a high effect ($g = 0.82$) on students' mathematics achievement. Furthermore, using e-Books does not affect students' mathematics achievement in year publication and significantly affects the pre-school level, who are more proficient in using technology. Mathematics e-books are more effective when used for less than 4 weeks and also effective when the sample is less than 30 students. There is no significant difference between non-interactive and interactive mathematics e-books. Moreover, this research provided a detailed description of the findings and implications as well as highlighted some suggestions for future studies.

1. Introduction

Mathematics is the scientific study of numbers, measurements, space, quantities, magnitudes, and others [1]. It plays a vital role that is inseparable from daily life activities [2, 3]. Mathematical knowledge also plays an essential role in other subjects such as science, social studies, music and art [4, 5]. Therefore, this is a very important subject that needs to be learnt by students. Until now studies show that mathematics is not an easy subject to be mastered by students [6, 7, 8], with many teachers finding it difficult to teach it effectively [9]. This led to the evolution of technology-based learning media as an effective learning strategy to help students acquire adequate mathematical knowledge [10, 11, 12].

What is unique about enhancing mathematical learning processes through using technologies is that, on the one hand, purely mathematical objects can be represented in different ways. On the other hand, the real world is more easily connected to the mathematical world through

technologies in mathematical modeling. Through this, real-world problems can be processed fact- or evidence-based.

Multiple representations of mathematical objects mean that the same mathematical object can be represented as a function, equation, graph, table and other possible representations. The different representations can provide different perspectives on a mathematical problem, so it is vital that students are aware of different representations and are supported in their learning process to switch between them. Using technologies in mathematics learning should help facilitate students to switch between different representations or use different representations simultaneously [13, 14].

A specific mathematical learning process that relies on using different representations is mathematical modeling. The first step in mathematical modeling is transforming a real situation into a real model. This real model is then mathematized and developed into a mathematical model. This mathematical model is then treated with the help of mathematical tools, and a mathematical result is obtained [15]. Using technologies in

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developing a mathematical model and then in developing mathematical results could enhance students' learning processes, support students' creativity, and allow more complex mathematical concepts to be used than in technology-free approaches [16].

Among other things, using e-books in learning mathematics could enable students to benefit more easily from the technological advantages of learning mathematics over technology-free approaches, thus increasing students' learning and enjoyment as well as improving mathematics education as a whole.

Currently, the adoption of technology in the education sector has continued to develop with a significant impact on students' abilities [17, 18, 19, 20, 21]. Among these educational technologies are e-books that could improve the teaching and learning mathematics. The use of dynamic mathematical software, e-books, and web-based learning helps to convey new knowledge [22]. The National Council of Teachers of Mathematics [23] stated that technology helps students to master mathematical concepts. Many studies (e.g. [24, 25, 26]) indicated that its integration in the teaching and learning process improves learning outcomes, makes students active in class, changes the perspectives that mathematics is a tedious and challenging subject, and triggers their interest compared to traditional approaches.

Technology-based teaching approaches have led, among other things, to traditional printed books transformation into e-books. According to the Organization for Economic Co-operation and Development (OECD), the definition of an e-book is described as a book in the digital format displayed on a monitor or handheld device [27]. In other words, an e-book is read through a computer, tablet, or cellphone [28]. Hawkin [29] added that it includes all book contents available in electronic form that can be downloaded and printed on demand. E-books were developed in 2008 and adopted in the education sector in 2010 [30]. E-books are becoming common and more relevant in developed nations. In some countries, they are used to substitute printed books or Worksheets, while several educational institutions have started to adopt e-books [27, 31].

Radovic's [19] stated that mathematics e-books could trigger and motivate students to learn. Al-astal's [32] stated that the students in the experimental class with mathematics e-books developed better mathematical thinking skills than those in the control group. Shatat's [33] also reported that the adoption of mathematics e-books has a significant effect on the students and increases their learning motivation. Huang's research [34] shows the use of mathematics e-books can improved students' mathematics achievement. In addition, students do not have to sit for a long while in class because e-books make online learning more accessible [35]. These learning resources tend to be quickly downloaded, besides, students need not be afraid of running out of mathematics books. The pandemic and the associated distance learning, among other things, also boosted the use of mathematics e-books, and this needs to be maintained in the post-COVID-19 era [36]. This has become a concern in the 21st century and is bound to continue in the future.

In the past 10 years, several studies have been carried out on the use of mathematical e-books. It is reportedly effective in terms of boosting students' mathematics achievement, interest in learning, and motivation at various academic levels. Irrespective of the fact that mathematical e-books are familiar, there is a lack of information on what conditions the mathematics e-books is most effective. Interestingly, no research has been able to resolve this issue. Therefore, this research used a meta-analysis technique to determine the effect of mathematical e-books on students' mathematics achievement. The findings can be useful for instructors and teachers to realize the maximum effect of mathematics e-books.

1.1. Previous research about e-book

In recent years, several researches have already been carried out on the use of e-books in an educational context. Huang, et al. [37] stated that elementary students find it more attractive and easier to use than traditional printed books. Another research [38] reported that mathematics,

science, literature, and social studies e-books, have a significant effect on students' learning motivation.

The use of these e-books in the education sector is still debated because its effects are uncertain. Based on systematically reviewed results [39], 11 studies reported that students prefer using e-books because it is effective, however, 4 of them stated that it was similar to printed books. On the contrary, 13 studies stated that printed books are better than digital ones. Meta-analysis results [40] show that reading from a printed book is better than a digital one. According to Tang, some preliminary study of e-books from 2010 to 2014 focused on the importance of pre-school students' literacy skills and the effect of e-books on their reading abilities [30]. A previous study has been carried out on the risks of using e-books in pre-schools. In the past few years (from 2015 to present), several studies have been conducted to ascertain its impact on various education levels.

Investigation to determine the impact of e-books on students' mathematics achievement still show uncertain results. Limited studies also have been carried out to determine the effect of mathematical e-books. This means there is little or no information about the effect size and moderators that affect e-books on students' mathematics achievement. Furthermore, no previous research has been carried out on the meta-analysis of e-book on students' mathematics achievement in the field of mathematics. This background carries out a further review on the effect of e-books on mathematics achievement, and it also contributes to covering the gap between these 2 attributes. Therefore, the meta-analysis method was used to examine the overall effect and moderator's impact of e-book on students' mathematics achievement.

1.2. Purpose of the study and research questions

The purpose of our study comes from the circumstance that using different technological tools in mathematics education is increasing, that enhancing the learning process through technologies could be of particular importance especially in mathematics, and that thus using technological tools is essential in learning mathematics [41]. One technological tool that could facilitate mathematics learning is the e-book, which has been the subject of research since the beginning of the 21st century [42] and could be an effective form of teaching and learning mathematics [43].

Despite this long history from a digital perspective and its potentially high effectiveness, we found few studies that use the meta-analysis method to determine the effect of e-books on students' mathematics achievement. The research on factors that affect the effects of mathematics e-books on students' mathematics achievement are limited. Unfortunately, no systematic investigation syntheses have been made regarding the effect of e-books on students' mathematics achievement. To fill this gap, the meta-analysis method was adopted to analyze the quantitative data obtained from empirical research, the effects of e-books on students' mathematics achievement, and relevant factors that influence the effects of e-books on students' mathematics achievement. Furthermore, this study analyzes the overall effect and moderator's impact on mathematics achievement. Specific questions in accordance with the research objectives are as follows:

- (1) What is the overall effect of e-books on students' mathematics achievement?
- (2) Does publication year, sample size, level education, treatment duration or type of e-books moderate the effect of e-books on students' mathematics achievement?

1.3. Moderator analysis

This approach not only analyzes the overall effect of e-books on students' mathematics achievement, but also takes into account several precise conditions. This specifically involves 5 aspects, namely publication year, sample size, level of education, treatment duration, and types

of e-books. These contextual factors are concerned as potential moderators that affect the overall effect further described in the following paragraphs.

In 2010, there was an increase in the preliminary research carried out to ascertain the impact of e-books in the education sector [30], and in 2021, it witnessed a peak in the publication of mathematics e-books. Based on this background, we take data on the study effect of mathematics e-books on students' mathematics achievement from 2010-2021. In addition, the year of publication was divided into 2 parts, from 2010 to 2015 and 2016 to 2021. Based on published data on Scopus, research on digital mathematics textbooks in mathematics education increased in 2010 (e.g. 3 publications in 2010) and 12 publications in 2013. Meanwhile, on the Scopus database, it was reported that between 1996 and 2010, a maximum of 2 e-book was published per year.

Another potential moderator is the education level, besides, previous research proved that digital tools are more attractive for beginners [44]. The meta-analysis method was used by Güler et al [45] to divide this attribute into pre-school, elementary (K1–K6), secondary (K7–K12), and university levels.

Empirically, research with smaller sample sizes reported significant effects [46, 47, 48]. This research was divided into 2 groups, comprising of samples that are more and less than 30 students. It is similar to the meta-analysis research carried out by [49].

According to preliminary research, learning media for a shorter duration treatment has a better effect than when used for a long time [49]. In this research, the duration treatment of using mathematics e-books was divided more and less than 4 weeks because previous research reported that the adoption of technology in the learning process had a significant effect [32, 33, 50, 51].

The final potential moderator is the mathematics e-books type, which is divided into non-interactive and interactive mathematics e-books. The non-interactive mathematics e-books are in PDF format. Besides, the interactive type is in the form of attractive multimedia files, animations and hyperlinks. Therefore, it was further assumed that its effect of interactive mathematics e-books is more significant.

2. Method

The meta-analysis technique aims to statistically combine and evaluate the findings of independent research that examined the effects of e-books on mathematics achievement. The following steps were adopted, first, determining the research objectives, second, searching for similar literature, and third, all research are coded based on certain criteria. Finally, statistical analysis was performed, and the findings were interpreted.

2.1. Research protocol

This study utilized comprehensive search literature based on recommendations from Cooper [52]. The acquired databases are Web of Sciences, Scopus, Google Scholar, CNKI, Sciences Direct, Springer, ACM, Proquest dissertation and Theses, JSTOR, and ERIC. The sequential kind of Boolean search strings was used to create the query ((e-book OR "digital book" OR "interactive book" OR "electronic book" OR "e-textbook" OR "electronic textbook" OR "multimedia book") AND mathematics AND (achievement OR outcomes OR performance)).

Every paper in this research is in accordance with the following criteria.

- Published between 2010 and 2021.
- Published articles, proceedings, doctoral dissertation, and master thesis.
- Research focused on any interactive mathematics e-books (example, storybooks, iBooks, and various e-books)
- Article written in English language
- The research measured mathematics outcomes or achievement

- These research are valid and reliable
- Research using quantitative methods with sufficient data to calculate size effect (mean, standard deviation, and student sample)
- The sample comprises not less than 15 students in both control and experimental classes
- Research design control (without E-books) and experimental groups (Using E-books)
- Published in full-text
- The research participants represented all education levels from kindergarten to university.

2.2. Data collection

This meta-analysis research used the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flowchart [53] to explain various processes. Based on the initial search from the databases, 1942 studies were recorded. The screening process started by analyzing the title, abstract, and keywords with the assistance of Zotero. After eliminating the duplicated materials, 1088 studies were left. In addition, after the screening process, 234 potential studies were also recorded. In the following stage, the full text was analyzed, and the research that had incomplete data in terms of calculating the effect sizes (mean, std. dev sample) and one pretest-posttest analysis as well as the research that adopted a quasi-experimental approach were all excluded. The final result constitutes 17 studies (26 side effects) and 3115 students that fulfilled all the criteria. The identification, screening, eligibility, and inclusion processes are evident in the PRISMA flowchart, as shown in Figure 1. These were coded based on the goal scheme used to describe the acquired data. Meanwhile, 6 aspects, namely year and resource, sample size, education level, and nation, were coded as shown in appendix 1.

2.3. Research reliability

This research was coded by 2 different authors. Information such as year of publication, sample size, education level, treatment duration, nation, and type of e-books was coded using Microsoft Excel. Afterward, the effect size was calculated in these 2 studies, and the Cohen's Kappa ($k(7)$) coefficient was used to ascertain its reliability. According to Viera and Garrett' [54], the agreement level is acceptable, supposing the kappa value is greater than 0.61. However, it is a perfect agreement when the value of Kappa is greater than 0.81. The agreement level in this research is 0.88, therefore, it was concluded that there is a nearly perfect substantial match between the 2 authors.

2.4. Data analysis and interpretation

The Comprehensive Meta-Analysis (CMA) 3.0 was used to determine the effect sizes reported in 17 studies. A heterogeneity test was carried out to select fixed or random models. A fixed model is used, assuming there is no heterogeneity. Conversely, a random model is used in the case of heterogeneity. This proves that each research was carried out using a different population.

The moderators were divided into publication year, sample size, education level, treatment duration, and type of mathematics e-books. Then, effect sizes were calculated using Hedges' g coefficient, and the confidence level was set at 95%. According to this equation, an effect size of 0.2, 0.5, and 0.8 is considered to be small, medium, and large, respectively [55].

2.5. Findings

This research aims to determine the overall effect of e-books on students' mathematics achievement and analyze each moderator's effect. The research objectives were achieved by analyzing the acquired data. In this section, findings of publication bias, the overall effects of the

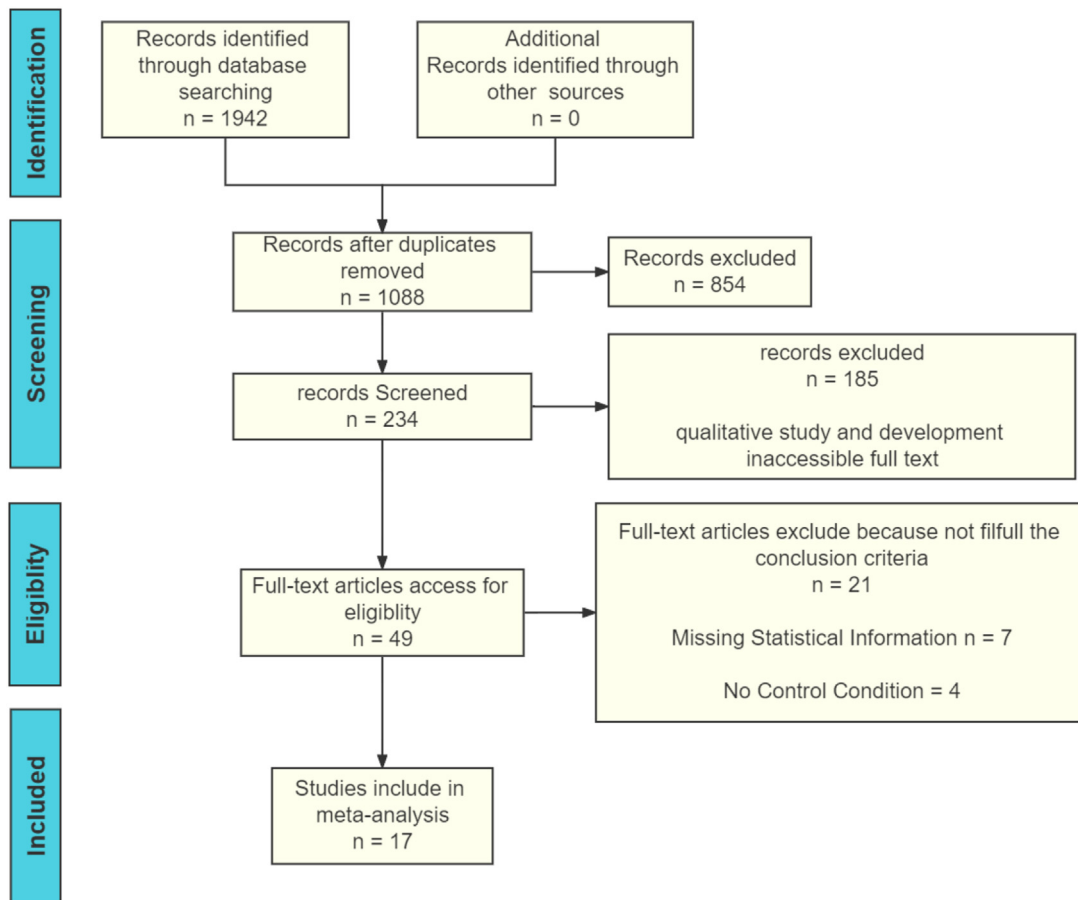


Figure 1. PRISMA flowchart describes the process of data collection.

mathematical e-book, and the impact of moderator variables were reported.

2.6. Publication bias

The funnel plot (Figure 2) shows that the vertical and horizontal lines are the standard error and effect size with a 95% confidence interval. As the bubble goes up, the standard error decreases. A circle represents each

research, while a diamond depicts the overall size effect. Therefore, it is evident that all research are symmetrically distributed on both sides and clustered in the middle of the graph, indicating no publication bias [55]. As additional evidence to ensure that there is no subjective interpretation, the Rosenthal safe N. data [55] was used as supportive evidence. The CMA software analysis in Table 1 shows that its value is 1881. In accordance with the Mullen formula, assuming $N/(5K + 10)$ is greater than 1, it is ascertained that there is low publication bias [49, 56]. Based

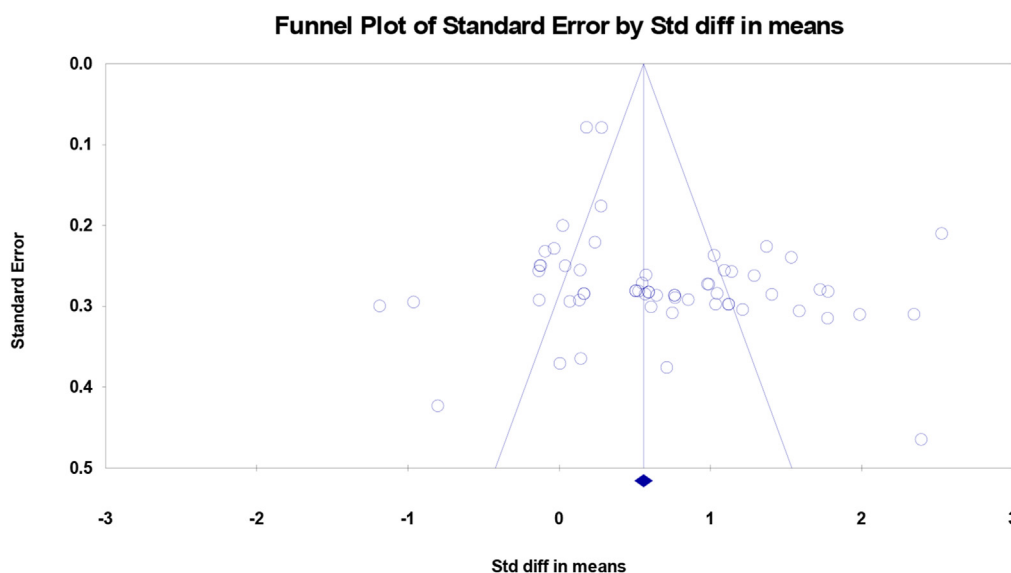


Figure 2. Funnel Plot shows the effect size, standard error, and the impact of e-books on students' mathematics achievement.

Table 1. Classic fail-safe N for meta-analysis effect mathematics e-books on students' mathematics achievement.

Bias Condition	
The z value for observed studies	16.78205
The p-value for observed studies	0.000
alpha	0.050
Tails	2.000
The z value for Alpha	1.960
Number of Observed Studies	26
p>the number of missing studies for the alpha result	1881.00

on this research $[1881/(26*5 + 10) = 13.44]$, the realized result is greater than 1, therefore, it has a relatively low meta-analysis publication bias.

2.7. Overall effects of the mathematics e-books on mathematics achievement

Table 2 shows the overall mean weighted effect size, which ranges from -0.12 to 2.52, and the standard errors of each research. Interestingly, 7 studies have a high effect, while 8 have a medium impact, and 4 others have a small effect. Some studies (7 effect sizes) proved that e-books do not affect students' mathematics achievement.

The test results show that the data is not homogeneous ($p < 0.05$). Therefore, the overall effect size is calculated using a random model (Table 3). The overall effect size of the mathematics e-books on students' learning scores is 0.82, which is also classified as having a high impact. The I-square score and radiance value of 90.98% and 9.02%, respectively, indicate a high heterogeneity and random error level.

2.8. Effects of sample-related characteristics (moderator analysis)

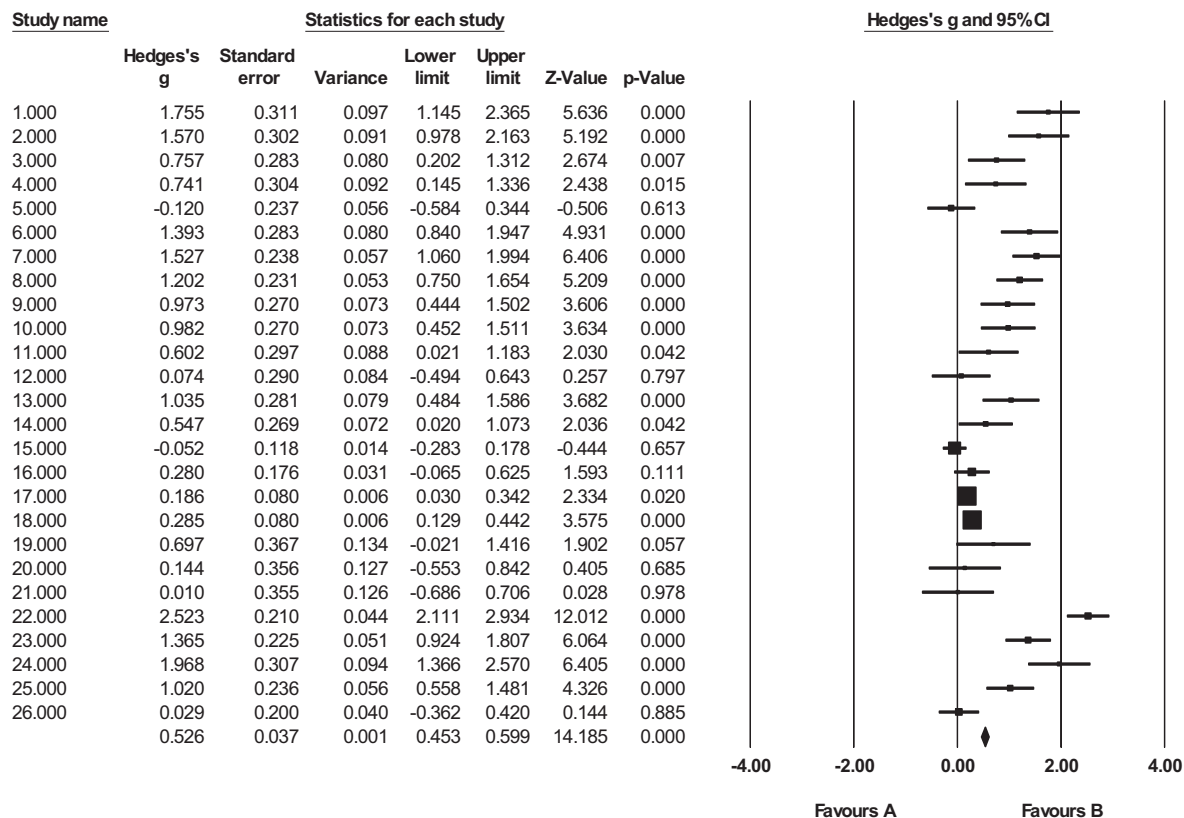
The samples were collected from 2010 to 14 November 2021, and the year of publication was divided into 2 subgroups (see Table 4). From 2010 to 2015, it was realized that e-books had a moderate effect ($g = 0.47, p < 0.05$) on students' mathematics achievement. Meanwhile, those published from 2016 to 2021 shows that mathematics e-books have a higher effect ($g = 0.55, p < 0.05$). In recent years, there has been an increase in effect sizes, which has proven to be statistically significant, however, the between-level variance was insignificant.

Referring to sample sizes, those less than 30 had a high effect ($g = 0.92, p < 0.05$), while those greater than 30 had a moderate impact ($g = 0.42, p < 0.05$). However, there is a significant difference among these categories.

In the aspect of education level, the use of e-books has the highest effect ($g = 1.13, p < 0.05$) when adopted in the Pre-school, following by

Table 2. Forest Plot of E-books effect on students' mathematics achievement.

Meta Analysis



Meta Analysis

Table 3. Overall effect size of e-books on students' mathematics achievement.

	K	ES	SE	95% confidence interval		Test of mean		Test of heterogeneity in effect sizes			I-Squared
				lower	upper	z-value	p-value	Q-value	Df (Q)	p-value	
								Q-value			
1.Random	26	0.82	0.13	0.56	1.07	6.16	0.00	277.020	25	0.00	90.98

Table 4. Effect size data on e-book on students' mathematics achievement.

Study characteristic	Sub-Group	K	ES	SE	95% confidence interval		Test of mean		Test of heterogeneity in effect sizes		
					lower	upper	z-value	p-value	Q-value	Df (Q)	p-value
									Q-value		
year	2010–2015	11	0.47	0.07	0.34	0.61	6.96	0.00			
	2016–2021	15	0.55	0.04	0.46	0.64	12.39	0.00			
Total between									0.86	1	0.35
sample	Less 30	13	0.92	0.08	0.75	1.08	11.13	0.00			
	More 30	13	0.42	0.04	0.35	0.51	10.27	0.00			
Total between									28.09	1	0.00
Grade level	Pre-school	3	1.33	0.17	0.99	1.66	7.70	0.00			
	Elementary	14	0.36	0.06	0.24	0.48	5.88	0.00			
	Secondary	6	0.51	0.05	0.42	0.62	10.05	0.00			
	University	3	0.16	0.16	0.80	1.42	7.00	0.00			
Total between									42.66	3	0.00
Duration	less than 4 weeks	11	0.92	0.08	0.76	1.08	11.19	0.00			
	More than 4 weeks	7	0.68	0.09	0.50	0.85	7.60	0.00			
	none	8	0.36	0.04	0.26	0.45	7.56	0.00			
Total between									38.95	2	0.00
Type of e-books	Non-interactive mathematics e-book	6	0.41	0.09	0.25	0.58	4.82	0.00			
	Interactive mathematics e-book	20	0.55	0.04	0.47	0.63	13.42	0.00			
Total between									2.17	1	0.14

the secondary ($g = 0.51, p < 0.05$), elementary ($g = 0.36, p < 0.05$), and university levels ($g = 0.16, p < 0.05$). Interestingly, there is a significant difference among these categories.

The subsequent finding is based on treatment duration, the use of e-books for less than 4 weeks has a high effect ($g = 0.92, p < 0.05$), while it had a lesser impact on students' mathematics achievement ($g = 0.68, p < 0.05$) when utilized for more than 4 weeks. Some studies failed to state that the treatment duration has a low effect on students' mathematics achievement ($g = 0.32, p < 0.05$). However, the between-levels variance was significant.

By type of mathematics e-books, the use of interactive mathematics e-books has a medium effect ($g = 0.55, p < 0.05$) while the traditional ones are smaller ($g = 0.41, p < 0.05$). Meanwhile, the between-levels variance was an insignificant difference.

3. Discussion

This meta-analysis research aims better to understand the effect of e-books on students' mathematics achievement. Mathematics e-books have been adopted at the pre-school [57], elementary [32], secondary [58], and university levels [33]. In addition, they also trigger and motivate students to learn mathematics [19, 38].

The mean overall effect size of e-books on students' mathematics achievement ($g = 0.82$) needs to be interpreted with caution. Although the overall effect size of mathematics e-books on students' mathematics achievement was reported to have high effect, we must consider that the effect of individual studies depends on several factors such as control treatment, learning environment, their way and manner in using mathematics e-books, their perceptions, teaching method adopted by the teacher and student [59]. Mathematics e-books are likely to be more effective when designed to meet the numerical abilities of students [60].

Software such as Simmagic, Geogebra and Canva, can be easily used to develop digital textbooks.

The results obtained demonstrated that the use of mathematics e-books positively impacts students' mathematics achievement. This finding is in line with previous research that stated mathematics e-books also has a positive effect on students' mathematical skills [29, 33, 60]. One of the advantages of mathematics e-books is its ability to enhance students' numerical ability and provide an interactive learning environment. Additionally, the Covid-19 pandemic triggered the adoption of mathematics e-books to assist teaching activities during online learning [35, 61]. This digital tool also aids students in learning inside and outside the classroom.

This research found that the effect of e-books on students' mathematics achievement is different from its impact on reading ability. Previous meta-analysis studies stated that e-books have an insignificant impact on students' reading ability [40, 62].

The effect of e-books on students' mathematics achievement is 0.82, and it is more significant than online education, which is relatively 0.39 [63]. Furthermore, the e-book effect is 0.82 greater than the impact of mobile learning on mathematics achievement of relatively 0.47 [45]. Its effect is also greater than the impact of augmented reality on students' mathematics achievement of 0.68 [64]. The effect of the e-book on students' mathematics achievement is more significant than its impact on the general technological use of 0.28 [65]. This is because mathematics e-books trigger students' interest to learn mathematics [33, 59] by making it easier and motivating them to be willing to learn both at school and home [19].

One important contribution of this meta-analysis research is evaluating the purposes or learning roles of e-books in teaching mathematics. It filled the current literature gap that no preliminary research has systematically explored such a critical issue. Mathematics e-books had a

positive effect on students' mathematics achievement (a) when they were used for less than 4 weeks, (b) tested on a sample of less than 30 students, and (c) more effective when used at the pre-school level.

The e-book effect on students' mathematics achievement is influenced by educational level, treatment duration, and the number of samples. Its content also influences the implementer, approach, and method of usage as well as the options of device, such as a tablet, computer, laptop, or cellphone [45].

In 2010, several studies were carried out on the effect of e-books on students' mathematics achievement, and there was an increase in the number of publications from 2016 to 2021 compared to from 2010 to 2015. Interestingly, statistical data shows an insignificant difference between these years of publication. The E-book is used as a new learning medium to increase students' mathematics achievement, students' interest and ensure they enjoy new experiences. In addition, it was discovered that non-interactive mathematics e-books had been converted to interactive ones in recent years, thereby making them more attractive and useful [51, 60].

The meta-analysis approach found that the effect of mathematics e-books on students' mathematics achievement was highest at the pre-school and lowest at the university level. This is in line with the research carried out by Leung [66], which stated that the adoption of technology in lower-level schools highly motivates students.

In accordance with this research, the mathematics e-book effect on students' mathematics achievement is higher when the treatment duration is less than 4 weeks. This finding is similar to [48, 49], which shows a shorter treatment duration has a more significant effect. Teachers need to think about this attribute to get the best results. In other words, the traditionally employed textbook format is less engaging for students than technological tools. The introduction of a e-books is perceived as a novelty that increases and motivates the students, which directly impacts learning achievement. Therefore, the students' engagement and motivational process were considered using mathematics e-books with different instructional tools. Moreover, the implementation duration needs to be extensive enough to eliminate the novelty effect.

Although many studies proved the effect of mathematics e-books on students' mathematics achievement, the research by [62] seriously emphasized its impact when used for a long term to teach young children. For instance, tablets, cellphones, and computers endanger the students' eyes and health for too long.

4. Conclusion and implications

This research analyzes the effect of the e-book on students' mathematics achievement and several conditions that moderate this impact. The findings of this meta-analysis proved that e-book has an overall effect size of 0.82 (high effect) on students' mathematics achievement. This depicts that e-books could facilitate teaching and learning mathematics better than traditional printed books. High effectiveness of using e-books in teaching and learning mathematics should lead to more integration of its usage in classrooms and lecture halls, specifically while doing homework. These activities tend to achieve 21st century and digital era goals simultaneously.

The main conclusion of our study is that using e-books can be highly effective in learning mathematics, especially at the beginning of the school career. The high effectiveness of e-books at the beginning of the school career could be related to the fact that already young children have developed a high level of technological competencies in recent years, that these technological competencies are now used in school learning processes and that students still enjoy learning at the beginning of their school career. The decline in the effectiveness of e-book use over the school career could be related to a decrease in students' general motivation or that mathematical concepts, especially proof-based university mathematics, are less supported by the use of technologies than secondary mathematics.

Furthermore, there has been an increase in the quantity of research on mathematics e-books in the last 5 years. However the difference between years of publications was not statistically significant. The increase in study carried out on the use of e-books to teach and learn mathematics is related to the fact that, among other things, students' competencies in terms of using digital tools in learning contexts have also improved. Therefore, a key aspect of future research needs to identify the factors contributing to the increased effectiveness of e-book and its usage to further develop teaching and learning mathematics. Additionally, mathematics e-books have a higher effect on lower education levels (e.g., teaching and learning mathematics at pre-schools) than on university level.

The result of this study has two practical implications. First, the high effectiveness of using e-books in teaching and learning mathematics at an early stage contributes to monitoring it scientifically. Second, the relatively low effectiveness of using e-books in tertiary mathematics education needs to contribute to the scientific investigation of both the learners' and the teachers' perspectives in this context. Finally, using e-books less than 4 weeks has a greater effect on mathematics achievement.

The decline in using e-books to teach mathematics depicts two things. First, every learning approach and tool loses its appeal after a certain time. This means that these methods and instruments need to be varied at regular intervals. This variation means that teachers must possess a profound knowledge of teaching and learning approaches and tools. Secondly, aspects involving e-books were highly effective in the first 4 weeks. After a certain time, the specific causes for a decline need to be scientifically investigated. Teachers need to consider these variables while implementing mathematics e-books. In conclusion, the findings of this research will promote education practitioners to use e-books for teaching mathematics.

The development of e-books or digital books in mathematics education sector is still new, and its effect will continue to grow. However, research on its advantages and disadvantages compared to traditional books, how teachers use it and students' attitudes, are still rare. This meta-analysis research shows that the effect of mathematics e-books differs depending on each condition, such as usage, getting the best effect, thereby providing information, consideration, and inspiration for further development.

4.1. Limitations and future research

Although this research contributes to understanding the effect of mathematics e-books on students' mathematics achievement, some limitations need to be considered. Firstly, it was limited to research that used quantitative data to examine the effect of e-books on students' mathematics achievement. Secondly, Some studies do not have complete data for calculating the size effect of mathematics e-books on students' mathematics achievement. We support other researchers further to investigate the effect of mathematics e-books on students' mathematics achievement. In addition, future studies may consider adding additional sources, databases, or studies; For papers written not in English, they are not included in this study. Perhaps many important factors affect the effect of mathematics e-books on students' mathematics achievement outside this study. Furthermore, future studies can analyze the moderator effect more deeply about the effect of mathematics e-books on students' mathematics achievement. Discusses the reasons for the differences and similarities in effect sizes on various moderator effects. Adding moderator variables such as the gender of the teacher, how the teacher uses the mathematics e-book, might affect the effect of the mathematics e-book on students' mathematics achievement. Moreover, 17 studies were carried out on traditional, interactive, hypermedia, and game-based e-books, while studies say there is no additional approach. The information gaps are potential opportunities and suggestions for further research.

Attachment

Author	Experiment Sample Student	Control Sample Student	Sample	Publication year	Education Level	Nation	Type of E-book
Segal-drori et al. [67]	28	28	Less 30	2016–2021	Pre-School	Israel	E-book
Segal-drori et al. [67]	28	28	Less 30	2016–2021	Pre-School	Israel	E-book
Shamir & Lifshitz [57]	26	26	Less 30	2010–2015	Pre-School	Israel	E-book
Hwang & Lai [68]	24	21	Less 30	2016–2021	Elementary	Taiwan	Interactive E-book
Al-astal et al. [32]	3	34	More 30	2010–2015	Elementary	Gaza	E-book
Shatat et al. [33]	31	30	More 30	2016–2021	University	Jordan	E-book
Zhao, et al. 2021 [44]	42	48	More 30	2016–2021	Elementary	China	Interactive e-book
Zhao, et al. 2021 [44]	40	48	More 30	2016–2021	Elementary	China	Interactive e-book
Lim et al., 2020 [60]	30	30	More 30	2016–2021	University	Malaysia	Interactive e-book
Lim et al., 2020 [60]	30	30	More 30	2016–2021	University	Malaysia	Interactive e-book
Hung et al [69]	23	23	Less 30	2010–2015	Elementary	Taiwan	Interactive e-book
Hung et al [69]	23	23	Less 30	2010–2015	Elementary	Taiwan	Interactive e-book
Y. Huang et al. [59]	28	28	Less 30	2016–2021	Elementary	Taiwan	Interactive e-book
Y. Huang et al. [59]	28	28	Less 30	2016–2021	Elementary	Taiwan	Interactive e-book
Kim et al. [70]	144	144	More 30	2010–2015	Elementary	Korea	E-book
J. Li et al. [71]	71	59	More 30	2016–2021	Elementary	China	interactive e-book
Radović et al. [19]	320	313	More 30	2016–2021	Junior High School	Serbia	Interactive e-book
Radović et al. [19]	320	313	More 30	2016–2021	Junior High School	Serbia	Interactive e-book
Zakrzewski [72]	15	15	Less 30	2010–2015	Elementary	USA	Interactive e-book
Zakrzewski [72]	15	15	Less 30	2010–2015	Elementary	USA	Interactive e-book
Zakrzewski [72]	15	15	Less 30	2010–2015	Elementary	USA	Interactive e-book
Guo [73]	81	81	More 30	2010–2015	Junior High School	China	Interactive e-book
Guo [73]	48	48	Less 30	2010–2015	Junior High School	China	Interactive e-book
Chen [74]	29	33	Less 30	2016–2021	Junior High School	China	Interactive e-book
Zhang [75]	40	40	More 30	2016–2021	Junior High School	China	Interactive e-book
Ge [76]	51	48	More 30	2010–2015	Elementary	China	Interactive e-book

Declarations

Author contribution statement

Tommy Tanu Wijaya: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Yiming Cao: Conceived and designed the experiments; Analyzed and interpreted the data.

Robert Weinhandl: Analyzed and interpreted the data; Wrote the paper.

Maximus Tamur: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data.

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Data availability statement

Data will be made available on request.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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