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The effectiveness of virtual reality media on student learning outcomes: A meta-analysis

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ABSTRAK

This study aims to analyze the effect of virtual reality media on student learning outcomes seen from the value of the effect size of published studies. This study used the meta-analysis method, with a group contrast design from experimental research and quasi-experiments that had experimental groups and control groups. The database used is the SCOPUS database. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method determines articles. Data collection is carried out by collecting article metadata with specific keywords that have been determined. The article metadata obtained is then sorted based on inclusion and exclusion criteria. The next step is to download a PDF of the article that matches the criteria. The downloaded PDF is tabulated to obtain statistical data in effect size calculations. Calculation of the effect size of each study and data analysis to prove research hypotheses using the R application version 4.2.0 and assisted by the RStudio. The results showed a Q value of 163.54 with a p-value of 0.0001 < α (0.05), so it can be concluded that there is heterogeneity from the observed data regarding the effectiveness of virtual reality media research on learning outcomes. An I2 value of 90.8% indicates substantial heterogeneity categories. For this reason, a random effect size model is used; The results showed a random effect size of 0.6285 with a p-value of 0.0001 < α (0.05). A value of 0.6285 indicates the influence is in the medium category; The results showed that there were differences in the effectiveness of the given continental differences (Q value = 8.24 and p-value 0.02 > α (0.05)). There was no significant difference in the effectiveness of virtual reality media on learning outcomes in terms of education level (Q = 7.39 and p-value 0.02 < α (0.05)); The results showed that the distribution of data showed symmetric, indicating that none of the studies were distorted or article bias occurred.

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INTRODUCTION

his rapid change makes education require enormous adaptation. Through technological developments, humans are not separated by the distance of space and time, which will undoubtedly impact people's lives, including in the world of education (Andriyani et al., 2021). The Covid-19 pandemic has triggered considerable change. Implementing teaching and learning activities, meeting activities from the central level (ministry of education, provincial, district, and city regional education offices), meetings at the school level, and education personnel must immediately adapt. Teachers and other education personnel are encouraged to understand the use of digital technology. Students must also explore technology and information and channel their creativity through innovations in the tasks given (Alfatih, 2021).

These changes also affect the learning environment used in contact with digital technology. With the support of digital technology, this learning model impacts learning resources, including school libraries and school information technology facility resources, including internet facilities. This digital-based learning environment changes learning patterns to be more differentiated in each individual. Students who previously tended to interact directly in learning will need various learning adaptations and understand learning modeled in the network (Luthfi & Hamdi, 2020). Students' independence is a new challenge in a digital technology-based learning environment. Students are encouraged to be aware of independent learning based on problem-solving (Msila, 2020). However, the change to Online learning indirectly affects students' absorption (Anam & Hanik, 2020; Kristanto & Padmi, 2020). The problem concerns changing the learning environment from offline to online (Rudyanto et al., 2019; Suhariyono & Retnawati, 2022; Syafii & Retnawati, 2022).

The development of 21st-century technology encourages the learning environment, advancing new strategies for the learning environment's effectiveness (Aviory et al., 2022; Freina & Ott, 2015). Virtual reality is one field that offers opportunities to enrich the learning and teaching environment (Akgün & Atıcı, 2022). The virtual learning environment is here to be one of the answers to these problems (Freeman et al., 2017; Taranilla et al., 2022). Wilson defines the learning environment as a condition, place, or space where the learning process occurs, or students learn, use devices, collect and interpret information, and interact with other students (Geiger, 2019; Setiawan et al., 2015). According to Wilson (1996), there are three categories of learning environments: first, computer-based learning environments. Students enter the learning environment with the help of computers. Some computer-based learning environments are open systems, and there is interaction between users. Both learning environments are classroom-based. This learning environment prioritizes classroom settings as its primary environment. This classroom-based learning environment setting can be supported by various elements related to tools, environments, space, and time. This learning environment uses Internet facilities. Students interact with other participants in a virtual learning environment through information devices in-network facilities. This technology is open and has good potential for the learning process (Zulkardi, 2002).

A virtual learning environment is a system created through the internet, combining some of the same virtual models for exams, assignments, teaching, classrooms, and other academic components (Arslan & Kaysi, 2013). Several components shape the virtual learning environment, including using computers, teacher support, student interaction and collaboration, personal relevance, authentic learning, student autonomy, fairness, and synchronicity (Trinidad et al., 2005).

Virtual learning environments offer an increased ability to solve current educational problems (Phungsuk et al., 2017). Various educational institutions around the world have used the use of virtual learning environments. Teachers can use this virtual learning environment because it is seen as an innovative approach to be used as a good delivery media design, user-centered, interactive, and flexible. Communication between teachers and students can still be well established, even though not in classical and formal situations. This virtual learning environment can be used as a solution to the problem of learning time. Teachers can still provide lesson materials even though the lesson time is up. Teachers can create another learning environment without meeting face-to-face with their students because learning can be done anywhere (Indraswari, 2016).

Previous research has shed light on how academic institutions, private training, and education companies have recently begun exploring the potential of commercially available multiplayer computer games to develop virtual environments. Most of the developments are still in their infancy and are focused on investigating the suitability of interactive games for remote user interaction, content distribution, and collaborative activities. Some ongoing projects have additional research objectives, such as analysing human behaviours patterns and studying collaboration between users and their interactions with virtual environments. Several other developments aim to utilize computer game technology as a personnel training platform and educational laboratory simulation (Aziz et al., 2009). Tenorio revealed significant advantages gained from adopting gamification in VLE in line with this explanation. However, the advantage is not unanimous and depends on how the element is applied (Tenório et al., 2018).

Another study revealed an adaptive 3D virtual learning environment. The study of 3D virtual learning environments includes factors in defining learner models, instructional strategies and content, and adaptation mechanisms (Scott et al., 2017). The study of 3D virtual learning environments is carried out in different fields of knowledge and at different stages of education. The study of 3D virtual learning environments continues to grow continuously. The 3D virtual learning environment is designed to support learning, simulation, and play. Language and science learning has become the most studied topic. Collaborative, exploration-based learning strategies are often used in 3D virtual learning environments. Virtual learning environments are closely related to student learning success. Learning success is characterized by changes in students. The flow of change starts from understanding, then being able to do evaluations, until finally getting good grades (Basri, 2014). In addition, learning success can also encourage students to be able to exchange ideas. This ability is an important part of capital in lifelong learning (Andiyanto, 2018).

The virtual learning environment certainly affects student learning success. The virtual learning environment encourages a high level of cognitive improvement in Norway. The improvement is especially in team-based learning (Hovlid et al., 2022). Virtual learning environments also encourage understanding in health education, especially dementia studies (Jones et al., 2021). Moodle's application-based virtual learning encourages a better understanding of mathematics teachers (Marfuah et al., 2022).

It is important to conduct a meta-analysis study of the influence of virtual reality learning on student learning outcomes because it can show an overview of trends in research topics that are developing today. Researchers observed a knowledge gap (Miles, 2017) because no studies conducted meta-analysis research on virtual reality learning, especially student learning outcomes. For this reason, it is important to research the study of meta-analysis of the influence of the learning environment on learning success in social sciences. This field of social sciences becomes more interesting, considering that studies in social sciences tend to be slower than studies in the sciences (Jaffe, 2014). This research was conducted as an attempt at a theoretical contribution to the study of meta-analysis of virtual learning environments.

Factors Influencing Student Learning Outcomes

Education and Factors Influencing Learning Outcomes Education is an essential framework in life. As a system, educational activities consist of the following components: educators, learners, educational objectives, educational devices, and educational environment. All parts of the education system are interconnected and interdependent. Each component has its own educational goals. Educational activities will run effectively if these elements are present (Saat, 2015). The success of education will greatly affect the progress of society as a whole. High-quality education that conforms to society's ideals is not given or happens automatically without effort. The community and all its members sociologically strive to develop an education system with ideal results (Wijayanti, 2018).

Education aims to create the necessary institutional and structural conditions for successfully implementing educational tasks. Structurally, creating an organizational framework that controls how the educational process is carried out is necessary. This ensures that the education process runs consistently and follows human needs and development, which tend to the ideal ability level. This ability is illustrated in the success of learning (Arifin, 2000). Bandura's social cognitive theory says that two types of factors influence how well a student learns: inside the student and outside the student (Bandura, 1977). Internal factors have to do with how students think, what they know, or their skills. Some examples of internal factors of students are self-confidence, self-study ability, motivation, creative and critical thinking ability, and so on. Students' External factors include the school environment, community environment, parental attention, etc.

The study delves into the external factors of the student, particularly within the context of the student's learning environment. The 21st century, often dubbed the 'Information Age', is witnessing a rapid technological evolution that is revolutionizing the way we access information and communicate. This is evident in the pervasive use of technology across various fields (Hutama, 2017). The rapid proliferation of technology has made it an integral part of our daily lives, bringing with it a wave of potential and excitement for the future of education.

The presence of increasingly massive information technology in the world of education is a breath of fresh air for future education development. All levels of Indonesian society need access to education services so that the development of Indonesian society can be evenly distributed. In line with the goals of the Indonesian government, citizens should strive to provide more people with better access to education. Indonesia needs to improve its access to education. One way to do this is to use information technology in the classroom (Maruhawa, 2019).

Virtual Reality Learning

The virtual learning environment is the latest development in information technology implementation in the classroom (Herlambang & Aryoseto, 2016). Virtual learning environments combine the mainstream learning process with the development of virtual reality technology that is increasingly used in many fields. Wilson defines a learning environment as a condition, place, or space where the learning process occurs or students learn, use devices, collect and interpret information, and interact with other students (Wilson, 1996). Gillespie defines virtual learning as a term used in schools and education in general to describe applications that allow teachers and students to share files, download information, email, use discussion boards, conduct tests and surveys, share information, manage time and resources, and connect applications and teaching and learning activities with management information systems (Gillespie et al., 2007).

Zulkardi added that there are three categories of learning environments, namely: (1) Computer-based learning environments. Students enter the learning environment with the help of computers. Some computer-based learning environments are open systems, and there is interaction between users; and (2) Classroom-based learning environment. This learning environment prioritizes classroom settings as its main environment. This classroom-based learning environment setting can be supported by various elements related to tools, environments, space, and time. Virtual learning environment. This learning environment uses Internet facilities. In a virtual learning environment, students interact with other participants through information devices in-network facilities. This technology is open and has good potential for the learning process (Zulkardi, 2002).

To facilitate effective learning for teachers and students, creating a learning environment in the classroom is essential (Oonk et al., 2022). It takes a theoretical and practical approach to prepare learning materials, apply them, and organize students and classes to create a virtual learning environment (Huang et al., 2022). The virtual learning environment offered in this study is considered to help teachers and students carry out learning practices. The principle of this approach in learning refers to five principles (Fauzan, 2002): the use of real-life contexts, the use of models, students' free products, interaction, and intertwining. These five principles are used in developing classroom-based learning environments and aided by developing virtual or web-based learning environments.

Learning Effectiveness

Effectiveness or effectiveness means a state of influence and memorable success with an effort or action (Hidayah et al., 2020). Effectiveness is the relationship between the output of a responsibility center and the target that must be achieved. The more significant the contribution of the output produced to the value of achieving the target, the more it can be said to be effective (Supriyono, 2000). According to Gibson in Putri (2019), effectiveness is an assessment concerning the achievements of individuals, groups, and organizations. The closer their achievements are to the expected achievements, the more effective they are.

Learning effectiveness is a learning process by teachers to change students' abilities and perceptions from being challenging to learning something too easy to learn. The effectiveness of learning programs is not only reviewed in terms of the level of learning achievement but must also be reviewed in terms of processes and supporting facilities. The effectiveness of learning methods is a measure related to the success rate of a learning process. Effectiveness can be measured by looking at students' interest in learning activities, underscoring the crucial role of student engagement in the learning process. Effectiveness means the extent to which the goals that have been set can be achieved as expected. The characteristics of the effectiveness of learning programs are successful in delivering students to achieve predetermined instructional goals, providing attractive learning experiences, involving students actively to support the achievement of instructional goals, and having facilities that support the teaching-learning process (Rohmawati, 2017).

Learning indicators can be effective if they achieve the desired goals regarding learning objectives and maximum student achievement. Some indicators of learning effectiveness are the achievement of learning completeness, the achievement of the effectiveness of student activities, the achievement of the ideal time used by students to carry out each activity contained in the lesson plan, the achievement of the effectiveness of the teacher's ability to manage learning and student responses to positive learning, which refers to the student's enthusiasm, engagement, and enjoyment in the learning process (Khasanah & Khoiriah, 2017). In this context, learning effectiveness is a measure of the success of the interaction process in educational situations to achieve learning objectives.

METHOD

Types of Studies

The research methodology used in this study is meta-analysis, chosen for its robustness in summarizing the effect size of the virtual learning environment's impact on learning success in the social sciences. This method is particularly powerful as it provides substantial statistical evidence by synthesizing data from multiple studies. Data collection was conducted from July 15, 2023, to September 30, 2023, with significant preparation required for data retrieval, including accessing the Scopus database, facilitated by resources from Yogyakarta State University. The meta-analysis draws on studies on virtual learning environment-based experiments related to learning success in the social sciences.

The population for this meta-analysis consists of all research indexed in the Scopus database under the keyword 'ALL ('virtual reality') ', a broad term that encompasses various aspects of virtual reality in education. At the time of this study, the search yielded metadata for 18,348 documents. The sample includes studies that meet predetermined inclusion and exclusion criteria from the population. Based on the researchers' analysis, 80 studies met these criteria, from which 220 data points were used as samples. Detailed explanations of the PRISMA flow diagram can be found in the appendix.

The data collected includes research findings grouped according to experimental and control groups, with recorded statistical data used to calculate effect sizes from each scientific publication. The Scopus database, a reputable international indexing platform recognized by the Ministry of Education and Culture (Herlambang & Aryoseto, 2016), was chosen for its comprehensive index of up-to-date research. Its accessibility also made it a suitable choice for this study.

The process of locating studies was meticulous and comprehensive, beginning with entering the keyword "ALL ('virtual Learning Environment')" into the Scopus database. Researchers filtered metadata for the last five years, then downloaded articles accessible via their DOI numbers. The downloading process was automated using Python applications through the sci-hub.se platform. These criteria guided the selection of articles for inclusion in the meta-analysis. Articles not meeting the criteria were excluded. The analysis database only includes experimental and quasi-experimental studies using pre- and post-designs. Inclusion and exclusion criteria for the meta-analysis are as follows: (1) Studies must use a quantitative research design; (2) Studies must employ experimental or quasi-experimental methods with a control group; (3) Studies must have been conducted in the last five years (2017–2022); (4) The study type must be published articles in

Scopus-indexed journals or proceedings; (5) Studies must include the sample sizes for experimental and control groups; and (6) Studies must report the mean and standard deviation values.

Research instruments are tools or resources used by our team of experienced researchers to collect data systematically, ensuring better accuracy, completeness, and organization. This study employed a coding sheet for data collection. Coding plays a critical role in data analysis by determining the quality of abstraction from the research data. The process involved identifying studies, verifying their eligibility based on explicit criteria, and recording essential information in screening forms or databases.

The coding procedure for the meta-analysis involved defining coding rules that specify the information to extract from each eligible study. Like survey research, coding involves a coder reading the study report and completing the coding protocol based on the study's details. The variables coded to determine the effect size of virtual reality meta-analysis studies include: (1) Researcher Name; (2) Year of Research; (3) Research Title; (4) Educational Subject; (5) Treatment Duration; (6) Education Level; (7) Type of Virtual Reality (VR) Used; (8) Mean and Standard Deviation for Treatment and Control Groups; and (9) Sample Size for Treatment and Control Groups.

The validity and reliability of the instrument were ensured through expert consultation on inclusion and exclusion criteria, maintaining the integrity of the research. Additionally, data validity was reinforced by including Digital Object Identifiers (DOIs) in the data table, ensuring transparency and facilitating verification of the articles' publication and indexing status. Transparency was further enhanced through a detailed explanation of the data analysis process based on the meta-analysis methodology.

The data analysis process was transparent and open, beginning by calculating the effect size for each study. A heterogeneity test was performed to determine if variance heterogeneity existed among the studies. A random effect model was used to calculate the summary effect size if heterogeneity was observed. Subgroup analyses were conducted to identify moderator variables contributing to heterogeneity. Publication bias was tested to assess any potential biases in the observed studies. All analyses were conducted using the RStudio Desktop 2023 software.

Effect Size Analysis

Various formulas for calculating effect size depend on the data collection type. The effect size formula used in this study is the estimate of the standardized mean difference δ () of the two contrast groups (Equation 1). The formula is as follows:

$$d = \frac{\overline{X}_1 - \overline{X}_2}{S_{within}}$$

X1 and X2 are the sample averages of the two groups, while S within is the combined standard deviation (Equation 2).

$$S_{within} = \sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}}$$

The standardized mean difference is used as a summary statistic in a meta-analysis when all studies assess the same results but measure them in multiple ways. The standardized mean difference was chosen because, in this study, the observed studies have different scales in measuring the effectiveness of the learning environment on learning success in the social field. The difference is calculated in the Standardized mean difference using the weight formula (equation 3). Standardizing study results to a uniform scale is necessary before they can be combined. This method assumes that the difference in standard deviation between studies reflects differences in measurement scales and not real differences in variability between study populations.

$$W_i = \frac{1}{V_{\gamma_i}}$$

Data Analysis

The fixed-effect model assumes that the modeled research is homogeneous. That is, there are no differences in the study population, no differences in patient selection criteria that might affect the outcome of therapy, and therapy is carried out in the same way. In this model, the between-study variance component is ignored, only variance. The random-effect model assumes that the studies observed in the meta-analysis are random samples of the population. This model allows the involvement of a component of inter-study variance and a within-study component of variance in effect size and statistical significance. The random-effect model is usually used if the homogeneity test has indicated more between-studies variance than expected due to sampling error. The measure in the heterogeneity test of this study is Cochran's Q, which is calculated as the sum of the weighted squared differences between individual study effects and combined effects across studies, with weights used in the collection method. Q is distributed as a Chi-squared statistic with k (number of studies) minus 1 degree V of freedom. Q has low power as a comprehensive heterogeneity test (Gavaghan et al., 2000), especially when the number of studies is small, i.e., mostly meta-analysis.

Conversely, Q has too much power as a heterogeneity test if the number of studies is large (Higgins, 2003). Statistics describe the percentage of variation across studies caused by heterogeneity rather than chance (Higgins & Thompson, 2002). From the results of the heterogeneity test analysis, if there is a heterogeneity variant from the observed study, the summary effect size model used is a random effect. However, if, from the results of the heterogeneity test analysis, there is no heterogeneity variance from the observed study, then the model used is a fixed effect model. This study also used the Baujat Plot and GOSH (Graphic Display of Heterogeneity) plots to see heterogeneity with more precision. The sub-group analysis was carried out with meticulous attention to detail, dividing the study into four groups: the treatment time, type of device, subject, and level of education.

Treatment time was chosen as a moderator variable because the time variable is an aspect that affects the results of experimental research. The type of device is chosen to be a moderator variable because, in practice, the virtual learning environment does not only use one type of device but various types of devices. The type of subject is chosen to be a moderator variable because, in social sciences, the subjects taught have various types. The level of education was chosen to be the moderator variable because, in practice, the virtual learning environment is implemented from early childhood learning to adult learning. Four publication bias tests were used in this meta-analysis study.

The first is to test the funnel plot. This test is carried out to observe whether a publication bias is seen from the shape of the funnel graph formed after calculation. The second is Egger's regression test. This test is used to determine whether or not the funnel plot graph formed is symmetrical. The third is the Duval & Tweedie Trim and Fill method test. This test is carried out by considering the effect of "loss" so the forest plot can be symmetrical. The fourth test is Fail-Safe N using Rosenthal's model. This test estimates the number of additional studies needed to change the effect size of the included studies and the additional studies combined to be insignificant, providing a comprehensive assessment of publication bias.

RESULTS AND DISCUSSION

Heterogeneity test

Our heterogeneity analysis is a comprehensive process involving several tests commonly used in meta-analysis. In this study, we applied five main tests to examine the presence of heterogeneity thoroughly: Cochran's Q test, I^2 test, H^2 test, Baujat Plot, and GOSH Plot Analysis. Cochran's Q test is used to identify whether significant variation exists between studies that cannot be attributed to random error. The I^2 and H^2 tests complement this analysis by providing quantitative measures of the proportion of total variability caused by inter-study heterogeneity. The Baujat Plot serves as a visual tool to identify individual studies that significantly influence the overall meta-analysis results.

Meanwhile, the GOSH Plot Analysis offers a deeper visualization of the overall effect distribution based on the data subsets considered. Using RStudio Syntax to conduct Cochran's Q test, I², and H² tests, as shown in Figure 1, enhances our analysis with systematic and structured results. Additionally, this combination of tools allows for a more precise measurement of heterogeneity and provides deeper insights into the impact of individual studies on the overall results. For a more detailed view of the analysis output using RStudio, readers are encouraged to refer to Figure 1.

```
                        SMD            95%-CI     z  p-value
Random effects model 0.6285 [0.3253; 0.9317] 4.06 < 0.0001

Quantifying heterogeneity:
 tau^2 = 0.3370 [0.1627; 0.8437]; tau = 0.5805 [0.4034; 0.9186]
 I^2 = 90.8% [86.7%; 93.7%]; H = 3.30 [2.75; 3.97]

Test of heterogeneity:
      Q d.f.  p-value
 163.54   15 < 0.0001
```

Figure 1. Test of Heterogeneity

Cochran's Q

Generally, two causes exist for the heterogeneity of effects observed in studies. First, heterogeneity is caused by sampling error. Second, heterogeneity is caused by the heterogeneity of the effect sizes of the studies observed. When measuring between-study heterogeneity, the difficulty is identifying how much of the variation can be attributed to sampling error and how much difference the effect sizes have. The meta-analysis test uses Cochran's Q to distinguish study sampling error from true between-study heterogeneity.

Cochran's Q is defined as the weight of the sum of squares. The Q test uses the deviation of each study's observed effect θ from the summary effect θ, weighted by the inverse of the study variance. The calculation results (Figure 1) show that the Q value is 163.54 with a p-value of 0.0001. Based on this test, it can be interpreted that the p-value of the Q test is 0.0001, which is smaller than the α value (0.05). Based on these comparative values, the heterogeneity hypothesis H0 is rejected so that it can be concluded that there is heterogeneity in the observed data regarding the influence of the effectiveness of virtual reality media on learning outcomes.

I^2 and H^2 Tests

The I^2 value is another method to determine heterogeneity between studies. The I^2 test is an extension of the Q test and is interpreted as a percentage—the variability in effect size not caused by sampling error. The I^2 test assumes that the Q value follows a χ^2 distribution with $K - 1$ degrees of freedom under the null hypothesis of no heterogeneity. The I^2 value quantifies the percentage by which the observed Q value exceeds the expected Q value without heterogeneity (i.e., $K - 1$).

K represents the number of studies. The I^2 value cannot be less than 0%, so if the Q value is smaller than $K-1$, zero is used instead of a negative value. Practically, Higgins and Thompson provided rules for evaluating the heterogeneity characteristics of the observed study effect sizes (Higgins & Thompson, 2002) in more detail as follows: $I^2 = 25\%$: Low Heterogeneity; $I^2 = 50\%$: Moderate Heterogeneity; and $I^2 = 75\%$: Substantial Heterogeneity.

Based on RStudio application calculations, shows that the I^2 value is 90.8%. Referring to Higgins and Thompson's rules, it can be concluded that the heterogeneity in the effect sizes of the studies observed regarding the influence of the effectiveness of virtual reality media on learning outcomes falls into the category of substantial heterogeneity.

Calculations using H² are considered more elegant than I² because they do not require artificial correction of values when Q is smaller than K−1. When there is no between-study heterogeneity, the H² value is equal to or smaller than one. A value greater than one indicates heterogeneity between studies. The RStudio application calculations show that the H² value is 3.3 (Figure 1). A H² value of 3.3, which is greater than 1, indicates heterogeneity in the studies observed regarding the influence of the effectiveness of virtual reality media on achievement.

Effect Size

Meta-analysis research is inseparable from the combined effect size model used. Two models are employed to determine the combined effect size of the observed studies: the fixed effects model and the random effects model. The fixed effects model assumes that the effect size of each study is a function of two components: the single population effect size and the deviation of the study from the population effect size. The random deviation of each study's effect size can be inferred from the study's standard error, where the variability in deviation exceeds expected due to sampling fluctuations alone (homogeneity).

Simply put, the random effects model is applied if the effect size data from the observed studies are heterogeneous. Based on the earlier discussion of heterogeneity tests, it can be concluded that the observed effect size data are heterogeneous, with a Q value of 163.54, a p-value of 0.0001 < α (0.05), an I² value of 89.8% (substantial heterogeneity), and a H² value of 3.30. Therefore, the combined effect size analysis uses the random effects model. As previously explained, the random effects model assumes that the true effect size of each study is not identical due to sampling error. Consequently, sampling error becomes a crucial concern in the random effects model. The random effects model analysis in RStudio uses the meta package.

The analysis results show that the random effect size value is 0.6285 with a p-value of 0.0001. Since the p-value of 0.0001 is smaller than the α value (0.05), H0 is rejected. Thus, it can be concluded that virtual reality media significantly influences learning outcomes. Based on Cohen's (1988) value intervals, an effect size of 0.20–0.49 indicates a small effect, 0.50–0.79 indicates a moderate effect, and an effect size of 0.80 or higher indicates a large effect. The calculation results show that the combined effect size value is 0.6285, which falls into the category of a moderate effect. The impact of virtual learning media on achievement is classified as having a moderate effect.

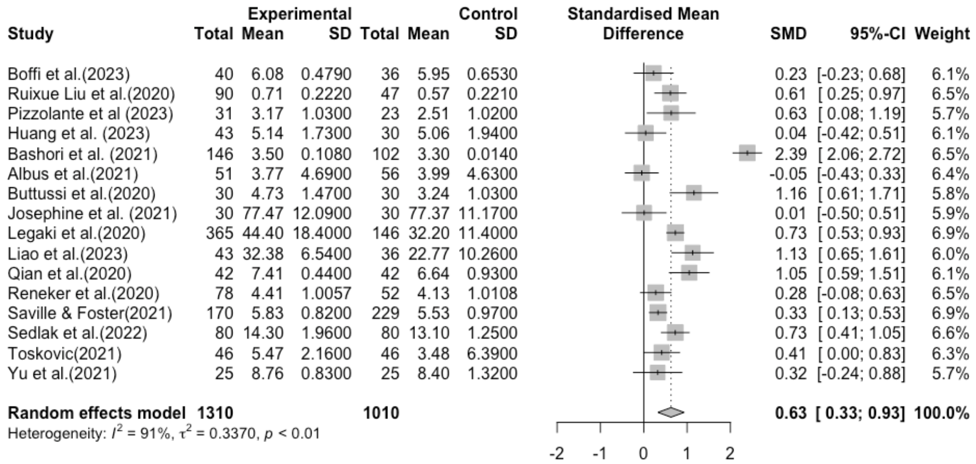

Figure 2. Forest Plot

The next step is to create a forest plot. The forest plot represents the effect size of each study and its contribution to the combined effect size (weight). The forest plot illustrates the effect size by visualizing it as a line in the center of the plot. This visualization shows the study's point estimates along the x-axis and lines representing the confidence intervals for the observed effect size. A square surrounds each point estimate. The size of the square corresponds to the weight of the effect size: studies with greater weights have larger squares, while those with smaller weights have smaller squares. The forest plot also includes effect size data used for the meta-analysis.

Figure 2 shows the syntax for creating a forest plot using the RStudio application. The forest plot is an essential component as it illustrates the influence of the virtual learning environment on success in social science studies. The output of the forest plot calculations from the RStudio application is displayed in Figure 2. The forest plot demonstrates that studies are ordered from the smallest to the largest effect sizes. The study with the largest effect size was conducted by Bashori et al. (2021), with an effect size value of 2.39, while the study with the smallest effect size was conducted by Albus et al. (2021), with an effect size value of 0.05. A closer look at the forest plot reveals that most studies cluster around the central axis of the combined effect size values. However, none of the studies extend to the left, and four intersect the standardized mean difference line. This indicates that most studies are more successful and exceed the combined effect size value.

Sub Group Analysis

The study of heterogeneity in meta-analysis is an important aspect in addition to identifying the appropriate combined effect size model and determining whether the variance aspect influences the combined effect size results. From the previous explanation, it has been explained that the results of meta-analysis research heterogeneity tests on the studies observed showed high/substantial heterogeneity values. For this reason, it is important to carry out a post-hoc test based on the high heterogeneity test results. The post-hoc test in meta-analysis is conducting subgroup analysis or what is usually called a moderator variable. These subgroup analyses use different approaches to identify why specific patterns of heterogeneity may be found in the observed study data. Subgroup analysis assumes that the heterogeneity of study effect sizes is not a nuisance but an interesting variation that scientific hypotheses can explain. In this research, four moderator variables are used to find out in more detail what aspects cause heterogeneity in the study's effect size.

Article Distribution Type Variable

Based on the distribution of articles by continent, it can be seen that studies conducted in Europe in terms of quantity have the most significant number of studies. Still, the articles have the lowest weight in terms of weight and influence on distribution.

Table 1. Number of Continental Group Studies

No.	Continental	N
1	Europe	9
2	Asian	4
3	America	3

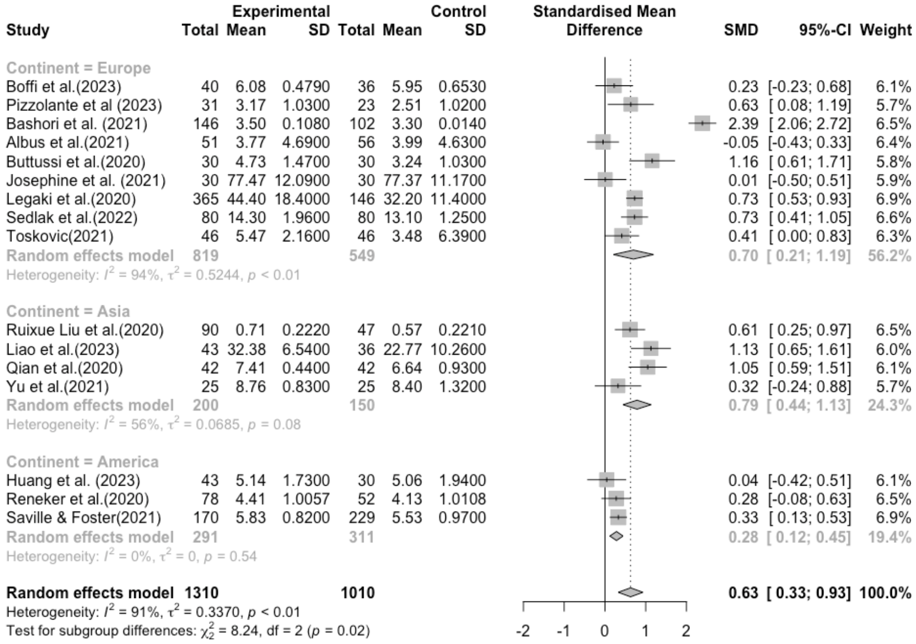

Figure 3. Analysis by Continent

This follows the theory of data distribution; the more data, the more data the results achieved will also be more heterogeneous. Meanwhile, articles from Asia and America have a high weight because they previously excluded articles with significant results. The results of the subgroup analysis are presented in Figure 3. It can be concluded that grouping by continent produces a significant distribution of articles and has a high level of heterogeneity.

Grade Type Variable

The media type variable "Grade" is a variable that can be used for subgroup analysis. The results of screening and coding in the research collected by observing the type of media used as treatment can be seen in Table 2.

Table 2. Number of Grade Group Studies

No.	Level of education	N
1	College	11
2	Elementary School	2
3	High School	3

Based on the distribution of articles based on subject grade, it is known that studies conducted at the College level in quantity have the highest number of studies. However, in terms of weight and influence on the distribution of articles, they have the lowest weight. Meanwhile, research conducted at elementary and high school grades is small in quantity. The following is a forest plot based on the grade presented in Figure 4.

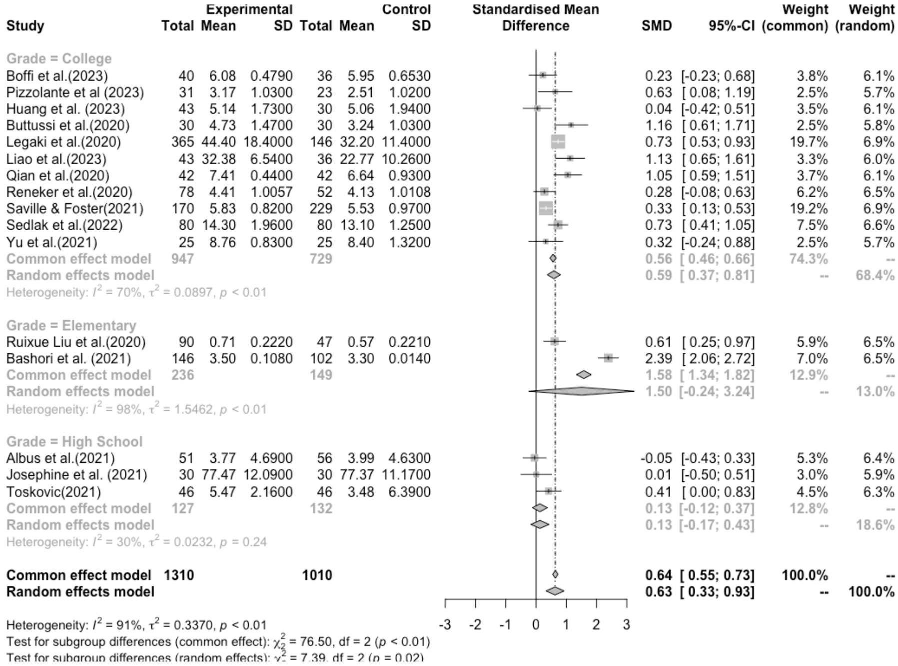

Figure 4. Distribution by Grade

A subgroup analysis was then carried out from the two study groups to determine the combined effect size of each treatment time group and whether there was heterogeneity in each treatment time group. To perform subgroup analysis in RStudio, the update. Meta function is used, which is part of the meta for package. Figure 4 shows the syntax used to create a sub-group analysis of treatment time. Based on the grouping effect size results, it can be concluded that the level of heterogeneity of all articles based on continental distribution is 91% with χ^2 0.337 with significant data, namely p value 0.02 (>0.05). It can be concluded that grouping based on grade and continental distribution produces a significant distribution of articles and has a high level of heterogeneity.

Bias Publication

Publication bias arises when the possibility of a study being published is influenced by the results (Rothstein, 2008). Many findings suggest that a study is more likely to be published if its findings are statistically significant or confirm the initial hypothesis (Chan et al., 2014; Scherer et al., 2021). For this reason, a publication bias test is needed to determine whether the observed study data is publication-biased. The publication bias test in this meta-analysis study used four publication bias tests. The four publication bias tests are the Funnel Plot test, Egger's Regression Test, Duval & Tweedie Trim and Fill method test, and Rosenthal's Fail-Safe N model test.

Funnel Plot

In this type of treatment research, the sample size and standard error are closely related. The larger the standard error of the effect size, the wider the confidence interval and the higher the likelihood that the effect is not statistically significant. Therefore, it is reasonable to assume that the effects of small-scale studies will significantly influence studies with larger standard errors. The funnel plot is the most commonly used tool for publication bias analysis. The publication bias test analysis was conducted based on a funnel plot—calculations were performed using the RStudio application with the funnel in meta function, a practical and widely accessible tool. The syntax for creating a funnel plot in the RStudio application is explained in Figure 5.

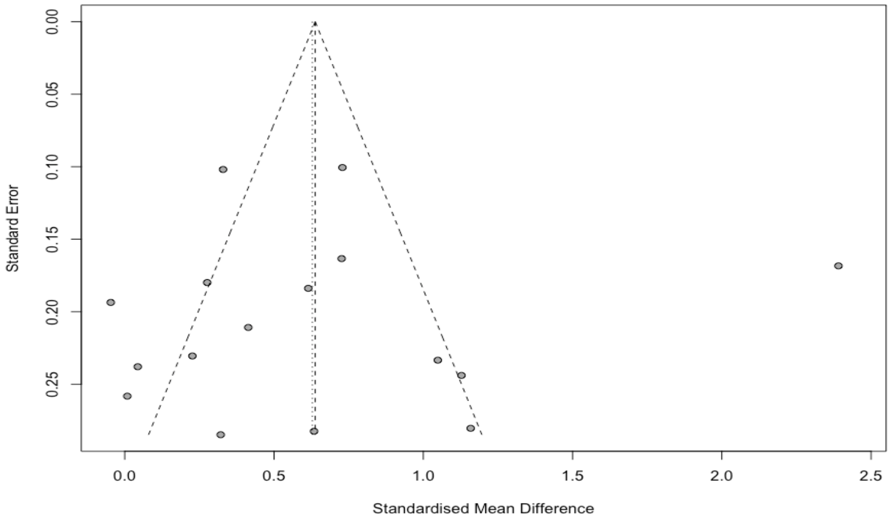

Figure 5. Funnel Plot

From the funnel plot graph, you can see the position of each study in the X and Y axes. From the graph formed, most of them are around the end of the funnel plot. Asymmetric form of data distribution with a distribution skewed to the right. However, the asymmetrical shape of the funnel plot does not necessarily indicate that the study data is publication biased.

Egger's Test

The Egger regression test, a quantitative method commonly used to test asymmetry in forest plots, involves a specific process. This test is where the intercept Y = 0 from a linear regression of the normalized effect estimate (estimate divided by its standard error) against precision (the inverse of the standard error of the estimate). The Eggers test function is used in the RStudio application to carry out Egger's Regression Test. A symmetrical data distribution, as indicated by the test, suggests a lack of bias in the articles being analysed. On the other hand, a non-symmetrical distribution could point to potential bias. Therefore, the results of Egger's test are crucial in determining the reliability of the data..

CONCLUSION

The research results show a Q value of 163.54 with a p-value of $0.0001 < \alpha$ (0.05), so it can be concluded that there is heterogeneity in the data observed regarding research on the effectiveness of virtual reality media on learning outcomes. The I2 value of 90.8% indicates the substantial heterogeneity category. For this reason, the random effect size model is used. The research results showed a random effect size of 0.6285 with a p-value of $0.0001 < \alpha$ (0.05). A value of 0.6285 indicates the influence is in the medium category. The results of the research show that there are differences in effectiveness from different continents (Q value = 8.24 and p-value $0.02 > \alpha$ (0.05)). There is no significant difference in the effectiveness of virtual reality media on learning outcomes in terms of educational level (Q = 7.39 and p-value $0.02 < \alpha$ (0.05)). The results show that the data distribution is symmetrical, this indicates that there is not a single study that is biased or has article bias.

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