



The Effectiveness of Virtual Reality and Augmented Reality Implementation in Improving Vocational Education Practical Skills: A Meta-Analysis Study

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ABSTRACT

(AR) and (VR) are considered effective educational tools for promoting meaningful learning processes, increasing student engagement, and encouraging active participation. However, there are still differences of opinion among academics regarding the extent to which these learning media actually help students develop their practical skills. Using a meta-analysis methodology, this study aims to thoroughly examine the effectiveness of using (VR) and (AR) in improving practical skills in vocational education. The PRISMA approach, which includes identification, screening, and inclusion steps, was used to screen scientific publications published in the last five years (2020–2025) that were accessible through Google Scholar and SCOPUS. The field of research and year of publication were the basis for the inclusion criteria. Of the 546 items found, 6 were eligible for analysis. Significance tests and effect size calculations were used to analyze the data. With an effect size of 0.754 and a p-value of $0.025 < 0.05$, the meta-analysis findings indicate that the use of VR and AR has a moderate impact on improving practical skills and is free from potential data bias. These findings have important implications for educators and policymakers who wish to use VR and AR as crucial teaching and learning techniques.

1. Introduction

Vocational education plays a strategic role in preparing skilled workers who are able to adapt to the needs of modern industry. The characteristics of vocational learning, which emphasize practical skills, require the availability of adequate, safe, and efficient practical facilities. However, various studies show that the implementation of practical training in vocational schools often faces obstacles, such as limited tools and materials, safety risks, high operational costs, and limited training time (Bödding et al., 2025). These conditions have prompted educational institutions to seek alternative learning models that can provide practical experience without relying entirely on physical facilities (Howard & Davis, 2023).

In this context, immersive technologies such as Virtual Reality (VR) and Augmented Reality (AR) are increasingly being adopted as innovative learning media in vocational education. VR technology

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allows students to practice in realistic three-dimensional simulated environments, while AR combines virtual objects into the real world to facilitate procedural understanding. Recent research reports that the integration of VR and AR can significantly improve students' knowledge mastery, procedural skills, and learning motivation (Liu et al., 2024). In fact, several studies have proven that VR and AR can create safe and personalized repetitive practice experiences, thereby effectively supporting the strengthening of technical skills (Ravichandran & Mahapatra, 2023).

Meta-analysis results show that VR and AR technologies have a positive effect on learning outcomes in the cognitive, affective, and psychomotor domains (Bödding et al., 2025). For example, it was reported that the use of Mixed Reality in vocational education produced a significant effect size on practical skills (behavioral outcomes). Similarly, a meta-analysis (Howard & Davis, 2023) noted that AR is three-fifths of a standard deviation more effective than alternative learning methods in improving learning performance. These findings are in line with (Castillo-Castro et al., 2021), which concluded that VR plays an important role in improving technical skills competencies in various training contexts.

However, several studies highlight methodological constraints in VR and AR implementation studies that may affect the generalization of findings. Many studies use small samples, pretest–posttest designs without control groups, learning outcome measurements that focus only on perception, and highly variable intervention durations (Chiang et al., 2022). In addition, most studies emphasize technological aspects rather than pedagogical design, so that not all VR and AR implementations have a maximum impact on students' practical skills (Wei et al., 2025). The heterogeneity of research designs, types of devices, and evaluation methods is a strong reason for conducting a meta-analysis specifically in the field of vocational education.

On the other hand, the challenges of implementing VR and AR in vocational schools also include teacher readiness, curriculum integration, infrastructure availability, and the initial investment costs for hardware and software (Din et al., 2024). Research (Ravichandran & Mahapatra, 2023) shows that the successful implementation of VR and AR is greatly influenced by school management support, teacher training, and the quality of learning design. This confirms that the effectiveness of VR and AR does not only depend on technology alone, but also on the readiness of institutions to adopt it.

Meanwhile, scientific studies in the fields of health and engineering show that VR and AR can improve skill retention, accuracy of actions, and task completion time efficiency (Sung et al., 2024). However, these findings cannot be fully generalized to the context of vocational education, given the differences in competency characteristics and learning environments. Therefore, a comprehensive scientific synthesis is needed to systematically summarize empirical evidence and assess the moderating factors that influence the successful implementation of VR and AR in vocational education.

Therefore, it is important to conduct a meta-analysis that examines the effectiveness of VR and AR implementation in improving vocational education skills. This meta-analysis will not only provide a comprehensive overview of the magnitude of the effects of VR and AR on practical skills, but also identify factors that influence the effectiveness of interventions, such as instructional design, type of technology, field of expertise, duration of intervention, and methods of skill assessment. The results of this study are expected to serve as a scientific basis for the development of educational policies, learning designs, and technology investment strategies in vocational institutions in the coming years (Bödding et al., 2025); (Liu et al., 2024).

2. Methodology

This study uses the meta-analysis method. Meta-analysis is a systematic approach to collecting, reviewing, and analyzing data from a number of published studies. The purpose of meta-analysis is to combine findings from a group of studies that examine the same research question with a specific focus through statistical methods. Research data was obtained through searches on Google Scholar and Scopus within the publication range of 2020-2025.

The steps taken to obtain results or data in this study were carried out systematically through several stages. First, the researcher downloaded and installed the JASP application as the main software for data analysis. Second, Google Scholar was used to search for and download articles relevant to the research topic, after which the collected articles were organized. The selected articles were then numbered to facilitate the identification process. Next, the researcher recorded the students' test scores (t) and the number of research subjects (N), which were compiled into a summary table of average scores as the basis for analysis. The next stage was to analyze the data using JASP software to obtain valid and reliable results. Finally, the researcher drew conclusions based on the analysis, providing comprehensive answers to the research questions.

The method used in this study also adopted a Systematic Literature Review (SLR) approach. Articles were collected from the Google Scholar and SCOPUS databases. Articles in these databases were searched using several keywords to ensure that all articles related to cooperative learning were collected optimally. The keywords used were: "Virtual Reality" OR "VR" AND "Augmented Reality" OR "AR" AND "Vocational Education" AND "Practical Skills." The search was also limited to publications from 2020-2025 to ensure the inclusion of the most recent articles. All articles matching the keywords were processed as the initial research dataset. In the article screening process, this study adopted the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) method (Cevikbas & Kaiser, 2022).

The article screening process based on the PRISMA method is presented in Figure 1. Based on the search results, the search team obtained 546 articles related to this research topic. 495 articles did not meet the criteria and 5 articles were removed for other reasons. Thus, 500 articles were screened and 46 articles were searched for and downloaded. Of the 46 articles, 30 articles met the criteria, but 16 articles were not included in the implementation of VR and AR in vocational schools. After review, 6 articles were obtained that were declared valid and relevant to the research topic for mapping.

Effect size is used to measure the impact of treatment in various systematic review studies, including meta-analyses. A popular and intuitively understandable effect size index is Cohen's d , which is calculated by subtracting the control group mean from the experimental group mean, then dividing it by the combined standard deviation of both groups. Effect size in this study is used to measure the impact of treatment in various systematic studies, including meta-analyses. In this context, effect size is calculated by comparing the average learning outcomes between the experimental group and the control group, then analyzed to determine significant differences. In addition, standard errors are calculated to ensure the accuracy of the effect size values obtained.

Data processing was performed using the JASP program, with the analysis stages including determining the effect size of each study, measuring heterogeneity, and calculating the overall effect size. The results of the analysis were visualized in the form of a forest plot. Meanwhile, publication bias was analyzed using a funnel plot, Egger's test, and Fail-Safe N calculation. This analysis aimed to provide a comprehensive overview of the consistency of research findings and the reliability of data in meta-analysis.

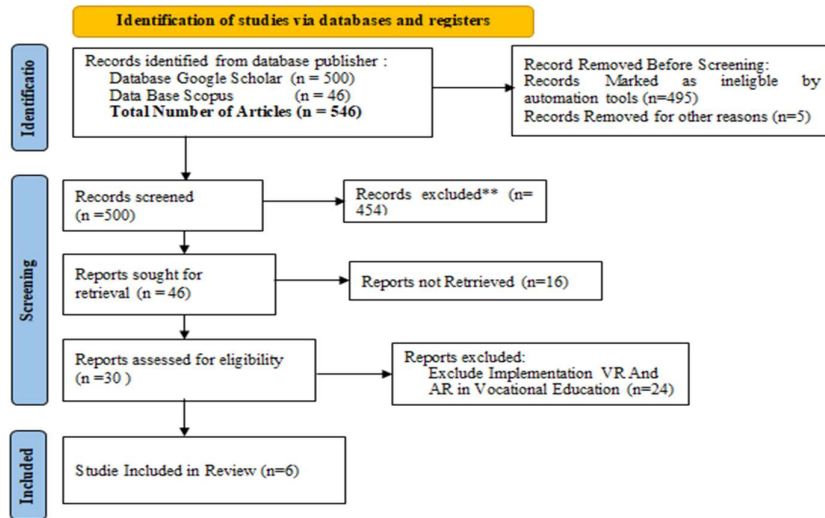


Fig.1. PRISMA Flow Chart

3. Results

Data search in this study was conducted using Google Scholar and Scopus with the keywords “Virtual Reality” AND “Augmented Reality” AND “Vocational Education” AND “Practical Skills”, and 546 articles were obtained. However, of the 546 articles, only 6 articles could be used as data for meta-analysis. In addition, data on sample size, mean, and standard deviation were collected in the experimental and control classes. With the effect size values collected in each study, it can be seen how much of an impact Virtual Reality and Augmented Reality have on improving students' practical skills. The following summarizes the meta-analysis data on the implementation of Virtual Reality and Augmented Reality in Table 1. Based on the data in Table 1, it can be seen that the largest sample size is 60, the highest average in the control class is 76.1 with a standard deviation of 7.385. The highest average in the experimental class is 85.7 with a standard deviation of 10.524. The highest effect size is 1.702 with a standard deviation of 0.229. The following presents the level of data heterogeneity in Table 2.

Tabel 1. Data Recapitulation of AR dan VR Meta-Analysis

Researches	Control Class			Experimental Class			d	Se
	N	M	Sd	N	M	Sd		
(Thomann et al., 2024)	32	2.47	1.08	40	3.3	1.3	0.687	0.243
(Kablitiz et al., 2023)	37	12.49	4.36	42	14.98	4.03	0.595	0.509
(Susilo et al., 2024)	60	74.2	7.1	60	82.5	6.3	1.237	0.199
(Mizian et al., 2025)	30	69.42	7.24	30	81.5	6.95	1.702	0.299
(Herlandy et al., 2020)	35	70.09	15.443	35	59.04	16.42	-0.693	0.245
(Suryana, 2025)	15	76.1	7.385	15	85.7	10.524	1.056	0.384

Tabel 2. Heterogeneous data tests

	Q	df	p
Omnibus test of Model Coefficients	5.017	1	0.025
Test of Residual Heterogeneity	51.880	5	<0.001

Note. *p* -values are approximate.

Note. The model was estimated using Restricted ML method

This test aims to determine whether the data is heterogeneous. Based on Table 3, the results show that the six studies analyzed are heterogeneous with a value of ($Q = 51.880$; $p < 0.001$). Based on the results of this test, it is concluded that the data used in the meta-analysis is consistent for assessing the implementation of Virtual Reality and Augmented Reality in improving students' practical skills. The overall effect test is presented in Table 3. Statistical analysis was performed to determine the significance level of the implementation of Virtual Reality and Augmented Reality in improving student skills. The effect size test was performed using the Wald data analysis technique. Based on Table 4, the value is $z = 2.240$; $p < 0.025$. With a lower limit of 0.094 and an upper limit of 1.413. The effect size is 0.754. This proves that the implementation of Virtual Reality and Augmented Reality has a high and significant positive impact on students' practical skills. This is in accordance with the category based on Cohen's d , which states that the ES value is 0.2 = small, 0.5 = medium, and 0.8 = large. The following Forest Plot graph is presented in Figure 2.

Tabel 3. Effect Size Coefficients

	Estimate	Standard Error	z	p	95% Confidence Interval	
					Lower	Upper
Intercept	0.754	0.337	2.240	0.025	0.094	1.413

Note. Wald test.

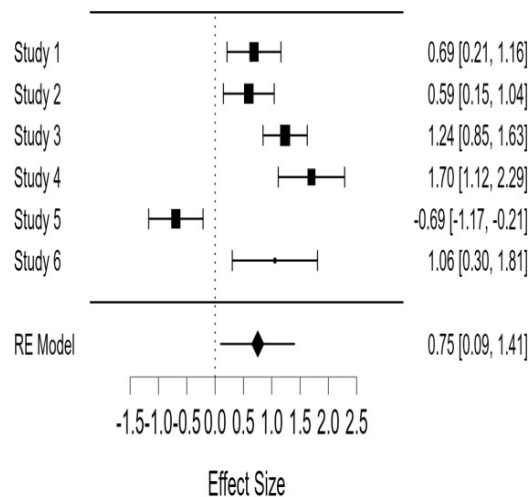


Fig. 2. Forest Plot

Based on Figure 2, the forest plot shows that the lowest value of the effect size is 1.41 and the highest value is 0.09. With an overall effect size average of 0.75 and a significance level of 95%, this indicates that Virtual Reality and Augmented Reality have a high and significant positive impact of 0.75 on practical skills. The funnel plot results are presented in Figure 3. Based on Figure 3, the funnel plot results displayed with dot symbols indicate that the data distribution is symmetrical and unbiased. The symmetrical funnel plot is presented in Table 5.

Tabel 4. Eiger Test (Regression Test for Funnel Plot Asymmetry)

	z	p
sei	0.530	0.596

Based on Table 4, the Egger test results show a z value of 0.530 with a p value of 0.596. Since the p value is > 0.05, it can be concluded that there is no significant evidence of asymmetry in the funnel plot. This indicates that the risk of publication bias in this study is relatively low.

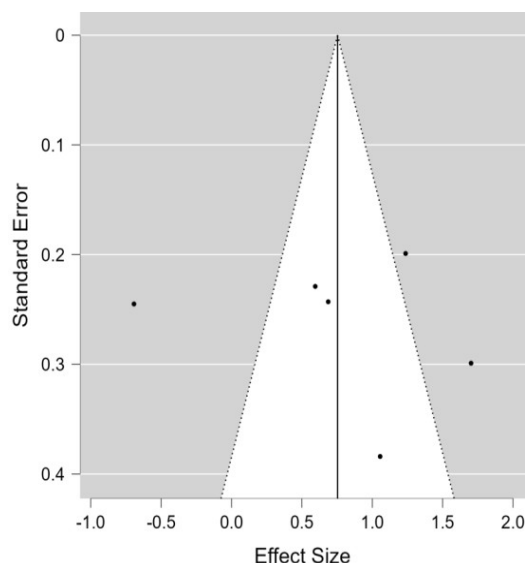


Fig. 2. Plot Funnel

Tabel 5. Hasil Bias Metode Fail-Safe N Rosenthal

	Fail-Safe N	Significance of the Target	Observed Significance
Rosenthal	105.000	0.050	<0.001

Based on Table 5, Rosenthal's N test failed. If the safe failure value is $N > 5K+10$, then it can be concluded that there is no publication bias in this meta-analysis study. The value of $5K+10$ is = 40. This finding shows that $N (105) > 5K+10$. It is concluded that the 6 studies in this meta-analysis are free from publication bias.

Based on the mapping of the six studies analyzed, the implementation of virtual reality and augmented reality has been proven to have a positive and significant effect on students' practical skills. The meta-analysis shows that the highest average score in the control class was 76.1 with a standard deviation of 7.385. The highest average in the experimental class was 85.7 with a standard deviation of 10.524. The highest effect size was 1.702 with a standard deviation of 0.229. The overall effect size value was 0.754 with a significance level of $p < 0.025$, indicating a high and significant positive impact of the implementation of Virtual Reality and Augmented Reality on improving students' skills. The forest plot graph also shows effect size values between 0.09-1.41 with an overall average of 0.754 at a 95% significance level. The heterogeneity test results show that the 6 studies analyzed are heterogeneous ($Q = 51.880$; $p < 0.001$), meaning that the data variation is quite large but still consistent in assessing the impact of implementing Virtual Reality and Augmented Reality on improving student skills.

A meta-analytic synthesis of research conducted over the past five years shows that the implementation of Virtual Reality (VR) and Augmented Reality (AR) consistently has a positive impact on improving practical skills in vocational education. This impact is particularly evident in improvements in procedural accuracy, work efficiency, and a reduction in practical errors, which

are key indicators of vocational competence. Various experimental studies and meta-analyses report moderate to high effect sizes, particularly in the fields of engineering, manufacturing, health, and manual skills-based trades. These findings reinforce the view that immersive learning environments can provide practical experiences that closely resemble real-world working conditions, thereby supporting the formation of psychomotor skills more optimally than conventional demonstration methods (Howard et al., 2021) ; (Chiang et al., 2022) ; (Radianti et al., 2020) ; (Maricuțoiu et al., 2023) ; (Thomann et al., 2024) ; (Steen et al., 2024) ; (Bödding et al., 2025) ; (Long et al., 2025).

The effectiveness of VR and AR in improving practical skills cannot be separated from the theoretical framework of experiential learning and situated learning. Virtual environments allow learners to engage directly in authentic simulations, make mistakes without fatal consequences, and repeat procedures until they reach the expected level of competence. A number of systematic studies confirm that this mechanism is highly relevant to the characteristics of vocational education, which emphasizes learning by doing. In addition, VR and AR provide opportunities for individualized learning, where learners can learn at their own pace and according to their individual needs, something that is difficult to achieve in conventional workshop practices with limited tools and time (Radianti et al., 2020).

However, the meta-analysis results also show variations in effectiveness influenced by the type of technology and learning design. High-immersion Virtual Reality tends to increase engagement and motivation to learn, but has the potential to cause excessive cognitive load if not balanced with good instructional design. Conversely, Augmented Reality is more flexible and easier to integrate into hands-on practice because it can display digital instructions on real objects. A number of studies show that AR is very effective for procedural tasks that require step-by-step guidance, while VR is superior in simulating complex or high-risk work environments. This confirms the importance of the task–technology fit principle in the implementation of VR and AR in vocational education (Chiang et al., 2022) ; (Steen et al., 2024).

From a learning transfer perspective, most studies report that skills acquired through VR and AR can be transferred to real-world work contexts, particularly structured skills. However, evidence of long-term transfer is still limited because the majority of studies only measure short-term learning outcomes (pretest–posttest). Several longitudinal studies show that without reinforcement through real-world practice, skills acquired from virtual simulations may decline. Therefore, VR and AR should be positioned as complements to practical learning, not complete replacements. Integration between virtual simulations, workshop practice, and industrial internships is the most recommended strategy to ensure the sustainability of skill mastery (Howard et al., 2021) ; (Cheng, K.-H., & Tsai, 2022).

The practical implications of these findings suggest that vocational education institutions need to adopt VR and AR strategically and systematically. Procuring technology without pedagogical readiness and human resources has the potential to yield limited benefits. Several studies emphasize that training lecturers and instructors is a key factor in the successful implementation of VR and AR. Educators need to understand not only the technical aspects of using the devices, but also strategies for integrating the technology into competency-based curricula. In addition, institutional policy support and long-term budget allocation are essential to ensure the sustainability of immersive technology implementation.

Based on the findings of this meta-analysis, several recommendations can be made. First, the development of VR and AR learning in vocational education must be based on industry needs and real work competencies. Second, learning designs need to be equipped with scaffolding, direct feedback, and performance-based assessments. Third, the evaluation of the effectiveness of VR and

AR should not only focus on cognitive aspects, but also psychomotor skills and work readiness. Fourth, collaboration between vocational institutions and the industrial world needs to be strengthened to ensure the relevance of simulation content to the demands of the workplace.

4. Conclusions

Based on the discussion of the meta-analysis results, it can be concluded that the application of Virtual Reality (VR) and Augmented Reality (AR) significantly contributes to improving practical skills in vocational education. This immersive technology has been proven effective in strengthening psychomotor skills, procedural understanding, and student engagement through contextual learning experiences that resemble real-world work situations. However, the effectiveness of VR and AR is greatly influenced by learning design, the suitability of the technology to the characteristics of practical tasks, and the competence of educators in managing technology-based learning. Furthermore, findings indicate that VR and AR are more effective when combined with hands-on practice in workshops or industries, thereby supporting the transfer of skills from the simulation environment to the real world of work in a more optimal and sustainable manner. Therefore, it is recommended that vocational institutions integrate VR and AR pedagogically, strengthen educator competencies, and encourage further experimental and longitudinal research to ensure sustainable skill transfer.

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