REFLECTION JOURNAL
https://journal-center.litpam.com/index.php/RJ
reflectionjournal21@gmail.com

Desember, 2023 Vol. 3, No. 2
e-ISSN: 2808-1501
pp. 74-87

Augmented Reality in Education: A Meta-Analysis Of (Quasi-) Experimental Studies to Investigate the Impact

[1]Hunaepi, [2*]A.A Istri Agung Rai Sudiatmika, [3]Wirawan Fadly
[1]Program Studi Pendidikan Profesi Guru. Universitas Pendidikan Mandalika, Jl. Pemuda No.59A, Dasan Agung Baru, Kec. Mataram, Kota Mataram, Nusa Tenggara Bar. 83125, Indonesia
[3]Program Studi Ilmu Pendidikan, Program Pascasarjana. Universitas Pendidikan Ganesha. Jl. Udayana No.11, Banjar Tegal, Singaraja, Kabupaten Buleleng, Bali 81116. Indonesia
[3]Tadris IPA. IAIN Ponorogo. I. Pramuka No.156 Ronowijayan, Siman, Ponorogo, Jawa Timur 63471. Indonesia
*Corresponding Author e-mail: rai.sudiatmika@undiksha.ac.id

Diterima: Desember 2023; Revisi: Desember 2023; Diterbitkan: Desember 2023

Abstract
The objective of this study is to thoroughly examine the influence of AR on educational achievements by amalgamating findings from (quasi) experimental investigations. This study constitutes a meta-analysis approach, which involves analyzing previous research statistically. Specifically, it focuses on 15 articles meeting the determined criteria for data inclusion in this meta-analysis, encompassing: 1) Research Methodology: Restricted to studies carried out via experimental or quasi-experimental designs, 2) Pertinence to Research Variables: Emphasizing research directly investigating AR's impact on educational achievements, 3) Indexing: Inclusion of publications indexed by reputable databases like SINTA, DOAJ, Copernicus International, or Scopus. Statistical Measurements: Encompassing studies providing relevant statistical metrics ('r' and 't') concerning the relationship between the variables studied. The outcomes demonstrate that the evidence indicates a beneficial effect of AR in augmenting educational outcomes. This deduction is drawn from a considerable average estimated Effect Size (1.231) alongside an exceedingly low p-value (< 0.001), denoting a highly significant statistical association between AR and heightened educational achievements. Although the collective findings strongly support AR's advantageous impact on various educational aspects, further research is imperative to address acknowledged limitations and optimize the potential of AR technology in enhancing educational achievements, motivation, and engagement across diverse educational settings and student cohorts.

Keywords: Augmented Reality, Education, Meta-Analysis, Quasi Experimental

***How to** Cite:* Hunaepi, H., Sudiatmika, A. I. A. R., & Fadly, W. (2023). Augmented Reality in Education: A Meta-Analysis Of (Quasi-) Experimental Studies to Investigate the Impact. *Reflection Journal*, *3*(2), 74–87. https://doi.org/10.36312/rj.v3i2.1831

https://doi.org/10.36312/rj.v3i2.1831

INTRODUCTION

The global educational landscape is persistently exploring innovative and efficacious methodologies to enrich learning experiences and elevate educational achievements. With technological advancements playing a pivotal role, the advent of e-learning and diverse online platforms has notably augmented the educational paradigm. The concept of ubiquitous learning (u-Learning), which advocates for learning that is accessible anywhere and at any time through the widespread adoption of technology, underscores a significant shift towards a more continuous and accessible learning experience across various platforms and locales (Aljawarneh, 2020; Cárdenas-Robledo & Peña-Ayala, 2018)

Among the spectrum of technologies enhancing learning, Augmented Reality (AR) and Virtual Reality (VR) emerge as notable for providing immersive learning experiences through simulated or augmented real-world environments, thus making abstract concepts more palpable and engaging (Elmqaddem, 2019). Mobile Learning (m-learning), leveraging smartphones and tablets, offers unprecedented flexibility and personalization in learning by facilitating access to educational content on the move (Naveed et al., 2023). Additionally, the incorporation of games and gamification into learning activities enhances interactivity and enjoyment, thus motivating learners (Khaldi et al., 2023), while learning analytics offer insights into learners' behaviors and progress, aiding in the personalization of teaching methods (Elmoazen et al., 2023).

The integration of AR in education, distinct for blending digital information with the physical world, has significantly progressed, evolving traditional teaching methods and fostering new perspectives in the learning process (Billinghurst et al., 2015; Najmi et al., 2023; Zhang et al., 2022). This integration enriches the learning environment by combining the physical and virtual realms, enhancing cognitive processes through the real-time application of interactive technology (Reiska et al., 2015; Sampaio & Almeida, 2016).

Research indicates AR's crucial role in educational innovation, demonstrating its positive impact on learning outcomes, self-efficacy, attitudes, spatial ability, and motivation (Alqarni, 2021a; Ciloglu & Ustun, 2023; Estapa & Nadolny, 2015; Sahin & Yilmaz, 2020). Empirical studies further highlight AR's effectiveness in increasing student engagement, offering visual and experiential learning opportunities, facilitating personalized learning experiences, and enhancing motivation and real-world application skills (Chairunnisa et al., 2023; Ciloglu & Ustun, 2023; W.-T. Wang et al., 2023; X. Wang, 2012)

Despite these advantages, successful AR integration necessitates well-designed curriculum implementation, comprehensive teacher training, and continuous support, ensuring that technology complements rather than replaces traditional teaching methodologies. Ongoing research and development in AR applications aim to further elucidate its benefits and optimal educational uses (Shen & Tsai, 2023;Setiawan et al., 2022).

AR's potential extends beyond traditional educational technologies, offering immersive and interactive learning experiences that significantly improve cognitive learning, accessibility, student empowerment, collaborative learning, motivation, and the transformation of abstract concepts into tangible experiences (Makhat et al., 2021; Widodo et al., 2019). Its application has shown to enhance learning outcomes across various disciplines and promote deep learning impacts (Fernández-Enríquez & Delgado-Martín, 2020; Nechypurenko et al., 2023; Ozdamli & Hursen, 2017). Comparatively, AR's distinctive advantages include creating rich, customized learning environments and augmenting traditional textbooks with interactive elements, thus offering enhanced learning experiences (Sandnes & Eika, 2018; J.-R. Wang et al., 2012). The integration of xAPI in AR applications introduces new educational scenarios, supporting diverse teaching and learning processes (Farella et al., 2021). AR's versatility is further evidenced in its application across disciplines, providing innovative approaches to education that cater to various learning styles and preferences (Assem et al., 2022; Fernández-Enríquez & Delgado-Martín, 2020; Nechypurenko et al., 2023; Widiasih et al., 2021)

The incorporation of AR into educational settings signifies a transformative approach, offering immersive, interactive, and engaging learning experiences that hold the promise of substantially enhancing the quality and efficacy of education, thereby reaffirming AR's value as a pivotal tool in the evolution of pedagogical practices.

This meta-analysis aims to comprehensively investigate the impact of AR in educational contexts by synthesizing findings from (quasi) experimental studies. Although the integration of technology in education is quite promising, determining the real impact of Augmented Reality on learning outcomes is still a complex and evolving field of study. A number of individual studies have explored the efficacy of AR applications in a variety of educational settings, resulting in a wealth of information scattered across academic journals. As a result, there is a growing need to consolidate and systematically analyze these findings to draw strong conclusions about the overall impact of AR on student learning.

This research seeks to address the fragmented nature of existing research by conducting a meta-analysis that synthesizes the results of (quasi) experimental studies centered on Augmented Reality in educational environments. By collecting and analyzing data from various studies, this research aims to provide a comprehensive picture of the effectiveness of AR application on learning outcomes.

METHOD

Research Designoa

This study is a meta-analysis, which is a research method involving statistical analysis of previous research. Meta-analysis plays a crucial role in gathering knowledge across various scientific domains (Hansen et al., 2022). As a research approach, meta-analysis systematically evaluates and synthesizes existing research to draw meaningful conclusions and insights (Wood & Eagly, 2009). Meta-analysis aims

to consolidate quantitative data collected from multiple studies with the goal of presenting comprehensive findings within a specific investigative domain. Through the use of meta-analysis, researchers can combine quantitative results from relevant study samples and generalize these findings to address specific issues.

Eligibility Criteria

This study focuses on 15 articles. Establishing eligibility criteria is crucial to ensure the accuracy and precision of research findings (DemïR & Kaya, 2022). The predetermined data inclusion criteria in this meta-analysis include:

1. Research Methodology: Limited to studies conducted through experimental or quasi-experimental designs.
2. Relevance to Research Variables: Inclusion of studies directly exploring the impact of AR on learning outcomes.
3. Indexing: Consideration of publications indexed by leading databases such as SINTA, DOAJ, Copernicus International, or Scopus.
4. Statistical Measurements: Inclusion of studies providing relevant statistical values (such as 'r' and 't') related to the relationship between the studied variables.

These stringent criteria aim to facilitate the selection of high-quality studies specifically addressing the impact of AR on learning outcomes, thereby ensuring the accuracy and validity of the meta-analysis.

Data Coding

In meta-analysis, data coding serves to facilitate data collection and analysis (Rahman et al., 2023). Data coding in this meta-analysis study considers the country of origin, journal type, research sample, and effect size (ES). The criteria for effect size measurement can be seen in Table 2.

Data Analysis

In this research, the systematic collation of data was conducted using detailed tabulation sheets for each selected study, followed by a rigorous data analysis process utilizing the OpenMEE software. OpenMEE is adept at computing individual study effect sizes (ES), averaging these effect sizes across studies, and performing subgroup analyses within the dataset. This software stands out due to its open-source nature, which inherently supports greater user engagement, reduced costs, and enhanced quality, characteristics that are typically attributed to open-source software (Bruce et al., 2006). Furthermore, OpenMEE's provision of accessible and modifiable source code offers significant benefits, particularly to programmers, by enabling a deeper understanding and customization of the software (Carvalho, 2015).

OpenMEE's utility extends beyond its open-source benefits, distinguishing itself with an intuitive user interface designed specifically to facilitate a range of meta-analysis processes, particularly within the fields of ecology and evolutionary biology (Wallace et al., 2017). It encompasses comprehensive functionalities such as efficient data import/export, exploratory data analyses, advanced graphing capabilities, and the generation of summary tables. These features render OpenMEE an indispensable tool for researchers engaged in these disciplines, offering a level of ease and functionality that surpasses other meta-analysis software, especially for those conducting studies in ecology and evolutionary biology.

The software's unique combination of being open-source, coupled with its specialized design for ecology and evolutionary biology meta-analyses, ensures it is not only cost-effective and user-friendly but also deeply engaging for researchers. It facilitates a participatory approach to research, enabling users to directly interact with and contribute to the development and enhancement of the software. Consequently, OpenMEE emerges as a superior choice for researchers aiming to conduct their meta-analyses with efficiency and precision, particularly in the specified scientific domains, thereby establishing its value as a crucial resource in the arsenal of research tools available to the academic community.After obtaining the effect sizes, the next step involves categorizing them based on a predefined table.

Table 1. Effect Sice Criteria

Effect Size	Criteria
0 ≤ ES ≤ 0.2	Low
0.2 ≤ ES ≤ 0.8	Medium
ES ≥ 08	High

RESULTS AND DISCUSSION

After conducting a meta-analysis of 100 journals related to the impact of AR on learning outcomes, only 15 of those journals met the criteria to be included in the analysis. Subsequently, the qualified journals were utilized as data sources in this study to calculate the effect size values as outlined in Table 2.

Table 2. Output Data from Primary Studies Using OpenMEE Software

No	Writer	Grade	Region	Tipe Publikasi	Effect size	Category
1	Ozeren	Secondary school	Malaysia	Journal	4.32	High
2	Indriyani et al	SMP	Indonesia	Journal	2.92	High
3	Dewi	SD	Indonesia	Journal	2.39	High
4	Weng et al	SMP	Indoensia	Journal	0.18	low
5	Wahyu et al	SD	Indoensia	Journal	1.09	High
6	Sriadhi et al	College	Indoensia	Journal	-0.54	low
7	Yildirim	College	Turkey	Journal	0.53	Medium
8	Prasetya et al	SMK	Indonesa	Journal	0.66	Medium
9	Talan et al	Secondary school	Turkey	Journal	0.7	Medium
10	Sahin & Yilmaz	Secondary school	Turkey	Journal	1.1	High
11	Guvenir & Yildirimi	College	Turkey	Journal	0.68	medium
12	Dutta et al	College	India	Journal	1.83	High
13	Buditjahjanto & Irfansyah	SMK	Indonesia	Journal	1.08	High
14	Ziden et al	Secondary school	Malaysia	Journal	1.01	High
15	Alqarni	Elementary school	Saudi Arabia	Journal	1.69	High

Overall +1.231 (High Category)

From this analysis, there were 15 articles or studies observed, and the total effect size (ΣES) of all articles was 19.64. The average effect size of all articles was 1,309, and the average effect category was in the high category. So, based on the information provided, the average effect size of AR's influence on learning outcomes is 1,309 in the high category.

Estimated Effect Size (ES) from Journals

Tabel 3 Heterogeneity

tau^2	Q(df=14)	Het. p-Value	I^2
0.967	214.256	< 0.001	93.466

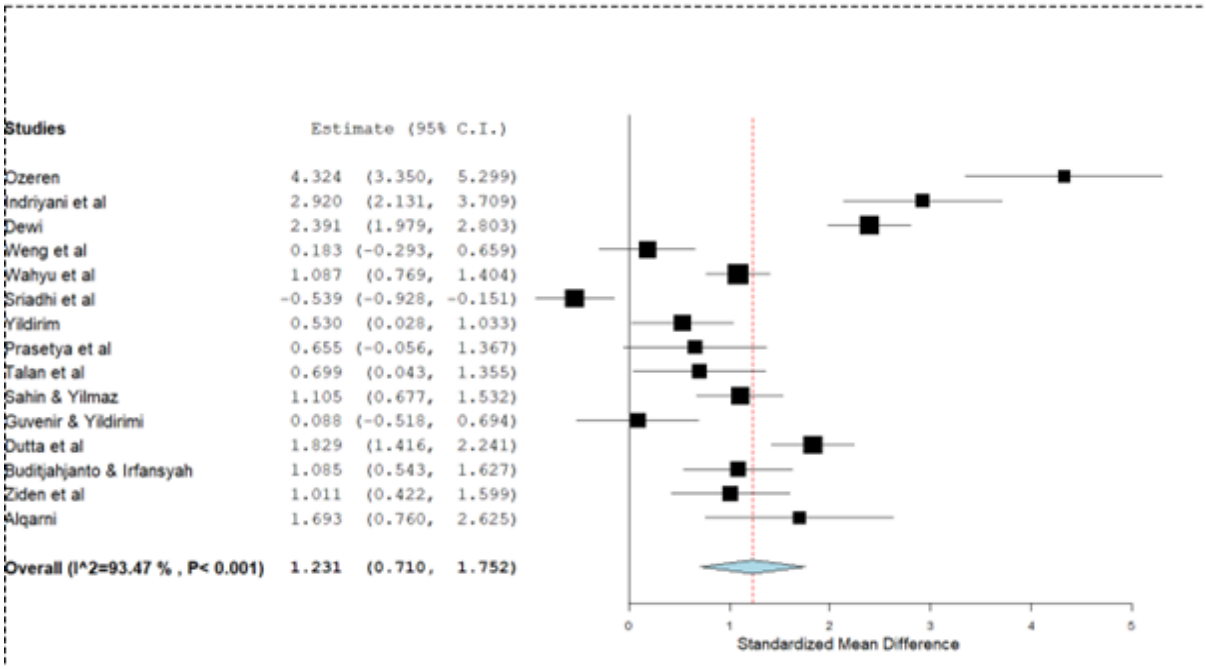
Tabel 4 Model result

Estimate	Lower bound	Upper bound	Std. error	p-Value
1.231	0.710	1.752	0.266	< 0.001

The average estimated Effect Size (ES) value from the journal analysis is 1.231, with a p-Value of < 0.001. The heterogeneity analysis indicates that the Tau squared value is 0.967, with an I^2 value of 93.466. This shows significant diversity in the variation among the analyzed journal studies.

From the presented data, it can be concluded that there is a positive effect of AR on enhancing learning outcomes. This is based on the significant average estimated Effect Size (1.231) with a very low p-value (< 0.001), indicating a high statistical significance in the relationship between AR and improved learning outcomes.

However, it is important to note that these findings are based on an analysis conducted on journals that may have significant diversity in their variance (I^2 of 93.466). Despite the significant positive effect, this diversity signifies substantial variation among the analyzed studies.



Data source:(Alqarni, 2021a; Buditjahjanto & Irfansyah, 2023; Dewi, 2020a; Dutta et al., 2023a; GUVENIR & GUVEN-YILDIRIM, 2023; Indriyani et al., 2023; Özeren & Top, 2023a; Prasetya et al., 2021a; Sahin & Yilmaz, 2020; Sriadhi et al., 2022; Wahyu, Suastra, Sadia, et al., 2020; Weng et al., 2020a; YILDIRIM, 2020; Ziden et al., 2022a)

Figure 1. Overall Effect: black plot is the Effect Size of each study; The blue plot is the overall average Effect Size

Figure 1 shows that most of the Effect Sizes are on the positive side (shown by the black plot), indicating that the use of AR has an impact on learning outcomes in each study (with the experimental class tending to be better than the control class). The further to the right a plot is, the greater the influence it exerts. Only one study showed a negative effect size, indicating that the use of AR did not have a significant impact on learning outcomes in that study. Overall, the Mean Effect Size reached 1.231 (shown in the blue plot) and is included in the high category. This Mean Effect Size confirms that overall, the use of AR has a significant influence on learning outcomes based on the overall study results.

Research findings show that there are 15 studies that empirically/practically identify and even explore the impact of using AR on student learning outcomes. A description of the results of these studies and a study of limitations and potential further research to be carried out to develop knowledge on this specific topic is described in Table 1.

Table 5. High effect on learning achievement

No	Author	Title	Result	Future direction
1	Ozeren, S & Ke p, E. 2023	The effects of augmented reality applications on the academic achievement and motivation of secondary school students	The effect of applying augmented reality on the academic achievement and motivation of secondary school students can provide valuable insight into the potential benefits of AR in improving academic achievement and motivation.	While the research by Özeren, S & Top, E. (2023) contributes to understanding the influence of AR applications on academic achievement and motivation in secondary education, there are opportunities for future research to address the identified limitations and explore new avenues for enhancing the effectiveness of AR in educational settings.
2	Dian, Indriyani, Muhfahroyin, Handoko Santoso. 2023	Pengaruh Model Pembelajaran Discovery Learning Berbasis Augmented Reality Terhadap Hasil Belajar	The Discovery Learning Learning Model Based on Augmented Reality provides a positive effect on improving Learning Outcomes	While the research by Dian, Indriyani, Muhfahroyin, Handoko Santoso (2023) contributes to understanding the influence of AR-based discovery learning on learning outcomes, there are opportunities for future research to address the identified limitations and explore new avenues for enhancing the effectiveness of AR in educational settings.
3	Wahyu, Yuliana; Suastra, I. Wayan; Sadia, I. Wayan; Suarni, Ni Ketut (2020)	The Effectiveness of Mobile Augmented Reality Assisted STEM-Based Learning on Scientific Literacy and Students' Achievement	The results revealed that: 1) The application of STEM-based learning assisted by Mobile Augmented Reality is quite effective in increasing students' scientific literacy. 2) The application of STEM-based learning assisted by Mobile	While the research by Wahyu, Yuliana; Suastra, I. Wayan; Sadia, I. Wayan; Suarni, Ni Ketut (2020) contributes to understanding the influence of mobile AR applications on scientific literacy and students' achievement in STEM education, there are opportunities for future research to address the identified limitations and explore

No	Author	Title	Result	Future direction
			Augmented Reality is effective in improving students' achievement. 3) There is a difference in the results of the students' scientific literacy and achievement between the students who are taught using STEM-based learning assisted by mobile augmented reality and students who are taught applying conventional learning	new avenues for enhancing the effectiveness of mobile AR in educational settings
4	Dilara Sahin a, Rabia Meryem Yilmaz (2020)	The effect of Augmented Reality Technology on middle school students' achievements and attitudes towards science education	The results revealed that the students were pleased and wanted to continue using AR applications in the future. They also showed no signs of anxiety when using AR applications. In addition, it was found that academic achievements and attitudes of the students in the experimental group showed a positive, significant and intermediate correlation.	While the research by Dilara Sahin and Rabia Meryem Yilmaz (2020) contributes to understanding the influence of AR technology on middle school students' achievements and attitudes towards science education, there are opportunities for future research to address the identified limitations and explore new avenues for enhancing the effectiveness of AR in educational settings.

No	Author	Title	Result	Future direction
5	Dutta et al 2023	Measuring the Impact of Augmented Reality in Flipped Learning Mode on Critical Thinking, Learning Motivation, and Knowledge of Engineering Students	The experimental outcomes indicate that the use of AR technology has a significant positive impact on the critical thinking skills, learning motivation, and knowledge gain of students. The study also found that critical thinking skills and learning motivation have a significant positive correlation with the knowledge gain of students in the experimental group.	While the research by Rubina Dutta, Archana Mantri, Gurjinder Singh & Narinder Pal Singh (2023) contributes to understanding the influence of AR in flipped learning mode on critical thinking, learning motivation, and knowledge of engineering students, there are opportunities for future research to address the identified limitations and explore new avenues for enhancing the effectiveness of AR in educational settings.
6	Buditjahjanto & Irfansyah 2023	Augmented reality on students' academic achievement viewed from the creative thinking level	The results showed that learning media and creative thinking levels affect cognitive and psychomotor learning outcomes. Cognitive learning outcomes of students using AR are higher than student learning outcomes using PowerPoint. Meanwhile, the psychomotor learning outcomes of students using AR are higher than those using PowerPoint. The learning media significantly affects cognitive learning outcomes with a p-value = 0.007, while the	While the research by RI Gusti Putu Asto Buditjahjanto and Juki Irfansyah (2023) contributes to understanding the influence of AR technology on students' academic achievement viewed from the creative thinking level, there are opportunities for future research to address the identified limitations and explore new avenues for enhancing the effectiveness of AR in educational settings.

No	Author	Title	Result	Future direction
			creative thinking level significantly affects psychomotor learning outcomes with a p-value = 0.016.	
7	Ziden et al (2022)	Effectiveness of Augmented Reality (AR) on Students' Achievement and Motivation in Learning Science	The paired t-test results showed that there was also a significant difference in students' motivation. The semi-structured interview showed that AR-NutricARd has the capabilities and intriguing aspects that encourage students to engage with the science subject. The findings of the study also showed that there is a significant relationship between motivation and achievement. Thus, a higher motivation implies increased student achievement.	While the research by Azidah Abu Ziden, Ahmad Aidil Abu Ziden, and Adu Emmanuel Ifedayo (2022) contributes to understanding the influence of AR technology on students' achievement and motivation in learning science, there are opportunities for future research to address the identified limitations and explore new avenues for enhancing the effectiveness of AR in science education
8	Alqarni 2021	Comparison of Augmented Reality and Conventional Teaching on Special Needs Students' Attitudes towards Science and Their Learning Outcomes	results supported that AR technology has the potential to enhance students with learning disabilities positive attitudes. The result shows that AR technology helped students in promoting positive attitudes towards students and	while the research by ATurki Alqarni (2021) contributes to understanding the influence of AR technology on special needs students' attitudes towards science and their learning outcomes, there are opportunities for future research to address the identified limitations and explore

No	Author	Title	Result	Future direction
			enhance students learning outcomes.	new avenues for enhancing the effectiveness of AR in special

The table provides a comprehensive overview of multiple studies exploring the impact of Augmented Reality (AR) technology on various aspects of education. These studies collectively suggest that AR applications have a generally positive influence on different facets of learning, including academic achievement, motivation, learning outcomes, scientific literacy, critical thinking, attitudes towards learning, and engagement among students. Key findings across these studies highlight several consistent themes:

1. Academic Achievement Enhancement: Multiple studies demonstrate a positive correlation between AR technology and improved academic achievement across different subjects and educational levels.
2. Motivation and Engagement: AR applications often increase students' motivation and engagement levels in learning activities. The interactive and immersive nature of AR appears to enhance interest and participation in educational content.
3. Learning Outcomes and Attitudes: AR technology positively influences learning outcomes, such as cognitive and psychomotor skills, as well as shaping positive attitudes towards subjects among students, including those with special needs.
4. Subject-specific Benefits: AR applications show promise in enhancing learning experiences in specific subject areas like STEM (Science, Technology, Engineering, and Mathematics) subjects, science education, and engineering.
5. Impact on Different Learning Modes: Whether in conventional classroom settings or in flipped learning models, AR technology consistently demonstrates positive impacts on critical thinking, knowledge gain, and learning motivation.

Despite these promising findings, the studies also acknowledge certain limitations and opportunities for further research:

1. Identified Limitations: The studies point out specific constraints or drawbacks in the methodologies, sample sizes, duration of the studies, or technological constraints associated with AR implementation in educational settings.
2. Opportunities for Future Research: There is a consensus across the studies about the need for future research to address these limitations. Additionally, researchers highlight the potential for further exploring new strategies to optimize AR's effectiveness in educational contexts. This includes addressing diverse student populations, refining the AR applications for specific learning objectives, and exploring ways to integrate AR seamlessly into various educational settings.

While the collective findings strongly support the positive influence of AR on various educational aspects, further research is essential to address the identified limitations and fully harness the potential of AR technology in enhancing learning outcomes, motivation, and engagement across different educational settings and student demographics.

CONCLUSION

The evidence suggests a favorable impact of AR on enhancing learning results. This conclusion is drawn from a substantial average estimated Effect Size (1.231) combined with an extremely low p-value (< 0.001), signifying a highly statistically significant connection between AR and heightened learning outcomes. Although the cumulative findings strongly endorse AR's beneficial influence on multiple educational facets, additional research remains crucial to tackle acknowledged constraints and maximize AR technology's potential in improving learning results, motivation, and engagement across diverse educational environments and student populations.

ACKNOWLEDGMENT

This research was completed due to support from the Education Science Study Program. Postgraduate Program, Universitas Pendidikan Ganesha

REFERENCES

Aljawarneh, S. A. (2020). Reviewing and exploring innovative ubiquitous learning tools in higher education. *Journal of Computing in Higher Education*, *32*(1), 57–73. https://doi.org/10.1007/s12528-019-09207-0

Alqarni, T. (2021a). COMPARISON OF AUGMENTED REALITY AND CONVENTIONAL TEACHING ON SPECIAL NEEDS STUDENTS' ATTITUDES TOWARDS SCIENCE AND THEIR LEARNING OUTCOMES. *Journal of Baltic Science Education*, *20*(4), 558–572. https://doi.org/10.33225/jbse/21.20.558

Alqarni, T. (2021b). COMPARISON OF AUGMENTED REALITY AND CONVENTIONAL TEACHING ON SPECIAL NEEDS STUDENTS' ATTITUDES TOWARDS SCIENCE AND THEIR LEARNING OUTCOMES. *Journal of Baltic Science Education*, *20*(4), Continuous. https://doi.org/10.33225/jbse/21.20.558

Assem, K., Turagulovna, A. G., Sharifullina, M. A., Bayakhmetovna, M. A., Rakhmetolinovna, A. G., & Kaiyrbekovich, O. M. (2022). Psychological and pedagogical innovative technologies for teaching English to university students. *Cypriot Journal of Educational Sciences*, *17*(6), 1914–1924. https://doi.org/10.18844/cjes.v17i6.7543

Billinghurst, M., Clark, A., & Lee, G. (2015). A Survey of Augmented Reality. *Foundations and Trends® in Human–Computer Interaction*, *8*(2–3), 73–272. https://doi.org/10.1561/1100000049

Bruce, G., Robson, P., & Spaven, R. (2006). OSS opportunities in open source software—CRM and OSS standards. *BT Technology Journal*, *24*(1), 127–140. https://doi.org/10.1007/s10550-006-0028-9

Buditjahjanto, I. G. P. A., & Irfansyah, J. (2023). Augmented reality on students' academic achievement viewed from the creative thinking level. *Journal of Technology and Science Education*, *13*(3), Article 3. https://doi.org/10.3926/jotse.1813

Cárdenas-Robledo, L. A., & Peña-Ayala, A. (2018). Ubiquitous learning: A systematic review. *Telematics and Informatics*, *35*(5), 1097–1132. https://doi.org/10.1016/j.tele.2018.01.009

Carvalho, M. S. (2015). Why open source? *Cadernos de Saúde Pública*, *31*(2), 221–222. https://doi.org/10.1590/0102-311XED010215

Chairunnisa, C., Sarifah, I., & Sutrisno, S. (2023). PENGEMBANGAN MEDIA AUGMENTED REALITY BERBASIS ANDROID PADA PEMBELAJARAN IPA KELAS V SEKOLAH DASAR. *JURNAL PENDIDIKAN DASAR*, *11*, 281–297. https://doi.org/10.46368/jpd.v11i2.885

Ciloglu, T., & Ustun, A. B. (2023). The Effects of Mobile AR-based Biology Learning Experience on Students' Motivation, Self-Efficacy, and Attitudes in Online Learning. *Journal of Science Education and Technology*, *32*(3), 309–337. https://doi.org/10.1007/s10956-023-10030-7

DemiR, M., & Kaya, M. (2022). Analysis of Constructivist Learning Model's Effects on Student Outcomes: A Second Order Meta-Analysis. *Kuramsal Eğitimbilim*, *15*(4), 938–957. https://doi.org/10.30831/akukeg.1122136

Dewi, R. K. (2020a). PEMANAFAATAN MEDIA 3 DIMENSI BERBASIS VIRTUAL REALITY UNTUK MENINGKATKAN MINAT DAN HASIL BELAJAR IPA SISWA KELAS V SD. *Jurnal Pendidikan*, *21*(1), 28–37. https://doi.org/10.33830/jp.v21i1.732.2020

Dewi, R. K. (2020b). PEMANAFAATAN MEDIA 3 DIMENSI BERBASIS VIRTUAL REALITY UNTUK MENINGKATKAN MINAT DAN HASIL BELAJAR IPA SISWA KELAS V SD. *Jurnal Pendidikan*, *21*(1), Article 1. https://doi.org/10.33830/jp.v21i1.732.2020

Dutta, R., Mantri, A., Singh, G., & Singh, N. P. (2023a). Measuring the Impact of Augmented Reality in Flipped Learning Mode on Critical Thinking, Learning Motivation, and Knowledge of Engineering Students. *Journal of Science Education and Technology*, *32*(6), 912–930. https://doi.org/10.1007/s10956-023-10051-2

Dutta, R., Mantri, A., Singh, G., & Singh, N. P. (2023b). Measuring the Impact of Augmented Reality in Flipped Learning Mode on Critical Thinking, Learning Motivation, and Knowledge of Engineering

Students. *Journal of Science Education and Technology*, *32*(6), 912–930. https://doi.org/10.1007/s10956-023-10051-2

Elmoazen, R., Saqr, M., Khalil, M., & Wasson, B. (2023). Learning analytics in virtual laboratories: A systematic literature review of empirical research. *Smart Learning Environments*, *10*(1), 23. https://doi.org/10.1186/s40561-023-00244-y

Elmqaddem, N. (2019). Augmented Reality and Virtual Reality in Education. Myth or Reality? *International Journal of Emerging Technologies in Learning (iJET)*, *14*(03), 234. https://doi.org/10.3991/ijet.v14i03.9289

Estapa, A., & Nadolny, L. (2015). The Effect of an Augmented Reality Enhanced Mathematics Lesson on Student Achievement and Motivation. *Journal of STEM Education*, *16*, 40.

Farella, M., Arrigo, M., Chiazzese, G., Tosto, C., Seta, L., & Taibi, D. (2021). Integrating xAPI in AR applications for Positive Behaviour Intervention and Support. *2021 International Conference on Advanced Learning Technologies (ICALT)*, 406–408. https://doi.org/10.1109/ICALT52272.2021.00129

Fernández-Enríquez, R., & Delgado-Martín, L. (2020). Augmented Reality as a Didactic Resource for Teaching Mathematics. *Applied Sciences*, *10*(7), 2560. https://doi.org/10.3390/app10072560

GUVENIR, E., & GUVEN-YILDIRIM, E. (2023). The Effect of Educational Film Supported Augmented Reality Applications on Academic Achievement and Motivation for Science Learning. *Journal of Education in Science Environment and Health*, *9*, 119–130. https://doi.org/10.55549/jeseh.1279771

Guvenir, E., & Guven-Yildirim, E. (2023). The Effect of Educational Film Supported Augmented Reality Applications on Academic Achievement and Motivation for Science Learning. *Journal of Education in Science, Environment and Health*, 119–130.

Hansen, C., Steinmetz, H., & Block, J. (2022). How to conduct a meta-analysis in eight steps: A practical guide. *Management Review Quarterly*, *72*(1), 1–19. https://doi.org/10.1007/s11301-021-00247-4

Indriyani, D., Muhfahroyin, M., & Santoso, H. (2023). Pengaruh Discovery Learning Berbasis Augmented Reality terhadap Hasil Belajar Siswa. *BIOLOVA*, *4*(2), Article 2. https://doi.org/10.24127/biolova.v4i2.4032

Khaldi, A., Bouzidi, R., & Nader, F. (2023). Gamification of e-learning in higher education: A systematic literature review. *Smart Learning Environments*, *10*(1), 10. https://doi.org/10.1186/s40561-023-00227-z

Makhat, A. Bo., Akhayeva, Zh. B., & Alzhanov, A. K. (2021). AUGMENTED REALITY IN THE LIFE OF A MODERN PERSON. *Vestnik of M. Kozybayev North Kazakhstan University*, *2 (51)*, 51–58. https://doi.org/10.54596/2309-6977-2021-2-51-58

Najmi, A., Alhalafawy, W., & Zaki, M. (2023). Developing a Sustainable Environment Based on Augmented Reality to Educate Adolescents about the Dangers of Electronic Gaming Addiction. *Sustainability*, *15*(4), 3185. https://doi.org/10.3390/su15043185

Naveed, Q. N., Choudhary, H., Ahmad, N., Alqahtani, J., & Qahmash, A. I. (2023). Mobile Learning in Higher Education: A Systematic Literature Review. *Sustainability*, *15*(18), 13566. https://doi.org/10.3390/su151813566

Nechypurenko, P. P., Semerikov, S. O., & Pokhliestova, O. Yu. (2023). Cloud technologies of augmented reality as a means of supporting educational and research activities in chemistry for 11th grade students. *Educational Technology Quarterly*, *2023*(1), 69–91. https://doi.org/10.55056/etq.44

Ozdamli, F., & Hursen, C. (2017). An Emerging Technology: Augmented Reality to Promote Learning. *International Journal of Emerging Technologies in Learning (iJET)*, *12*(11), 121. https://doi.org/10.3991/ijet.v12i11.7354

Özeren, S., & Top, E. (2023a). The effects of Augmented Reality applications on the academic achievement and motivation of secondary school students. *Malaysian Online Journal of Educational Technology*, *11*(1), 25–40. https://doi.org/10.52380/mojet.2023.11.1.425

Özeren, S., & Top, E. (2023b). The effects of Augmented Reality applications on the academic achievement and motivation of secondary school students. *Malaysian Online Journal of Educational Technology*, *11*(1), Article 1. https://doi.org/10.52380/mojet.2023.11.1.425

Prasetya, F., Fajri, B. R., Syahri, B., Ranuharja, F., Fortuna, A., & Ramadhan, A. (2021a). Improved learning outcomes of CNC programming through Augmented Reality jobsheet learning media. *INVOTEK: Jurnal Inovasi Vokasional Dan Teknologi*, *21*(3), 221–233. https://doi.org/10.24036/invotek.v21i3.957

Prasetya, F., Fajri, B. R., Syahri, B., Ranuharja, F., Fortuna, A., & Ramadhan, A. (2021b). Improved learning outcomes of CNC programming through Augmented Reality jobsheet learning media. *INVOTEK: Jurnal Inovasi Vokasional Dan Teknologi*, *21*(3), Article 3. https://doi.org/10.24036/invotek.v21i3.957

Reiska, P., Soika, K., Möllits, A., Rannikmäe, M., & Soobard, R. (2015). Using Concept Mapping Method for Assessing Students' Scientific Literacy. *Procedia - Social and Behavioral Sciences*, *177*, 352–357. https://doi.org/10.1016/j.sbspro.2015.02.357

Sahin, D., & Yilmaz, R. (2019). The effect of Augmented Reality Technology on middle school students' achievements and attitudes towards science education. *Computers & Education*, *144*, 103710. https://doi.org/10.1016/j.compedu.2019.103710

Sahin, D., & Yilmaz, R. M. (2020). The effect of Augmented Reality Technology on middle school students' achievements and attitudes towards science education. *Computers & Education*, *144*, 103710. https://doi.org/10.1016/j.compedu.2019.103710

Sampaio, D., & Almeida, P. (2016). Pedagogical Strategies for the Integration of Augmented Reality in ICT Teaching and Learning Processes. *Procedia Computer Science*, *100*, 894–899. https://doi.org/10.1016/j.procs.2016.09.240

Sandnes, F. E., & Eika, E. (2018). Visual Augmentation of Printed Materials with Intelligent See-Through Glass Displays: A Prototype Based on Smartphone and Pepper's Ghost. *2018 IEEE International Conference on Artificial Intelligence and Virtual Reality (AIVR)*, 267–273. https://doi.org/10.1109/AIVR.2018.00063

Setiawan, B., Rachmadtullah, R., Subandowo, M., & Retnani Srinarwati, D. (2022). Flashcard-Based Augmented Reality To Increase Students' Scientific Literacy. *KnE Social Sciences*. https://doi.org/10.18502/kss.v7i19.12441

Sriadhi, S., Hamid, A., Sitompul, H., & Restu, R. (2022). Effectiveness of Augmented Reality-Based Learning Media for Engineering-Physics Teaching. *International Journal of Emerging Technologies in Learning (iJET)*, *17*(05), Article 05. https://doi.org/10.3991/ijet.v17i05.28613

Wahyu, Y., Suastra, I. W., Sadia, I. W., & Suarni, N. K. (2020). The Effectiveness of Mobile Augmented Reality Assisted STEM-Based Learning on Scientific Literacy and Students' Achievement. *International Journal of Instruction*, *13*(3), 343–356. https://doi.org/10.29333/iji.2020.13324a

Wahyu, Y., Suastra, I. W., Sadia, I. W., & Suarni, N. K. (2020). The Effectiveness of Mobile Augmented Reality Assisted Stem-Based Learning on Scientific Literacy and Students' Achievement. *International Journal of Instruction*, *13*(3), 343–356.

Wallace, B. C., Lajeunesse, M. J., Dietz, G., Dahabreh, I. J., Trikalinos, T. A., Schmid, C. H., & Gurevitch, J. (2017). *Open MEE* : Intuitive, open-source software for meta-analysis in ecology and evolutionary biology. *Methods in Ecology and Evolution*, *8*(8), 941–947. https://doi.org/10.1111/2041-210X.12708

Wang, J.-R., Chen, S.-F., Tsay, R.-F., Chou, C.-T., Lin, S.-W., & Kao, H.-L. (2012). DEVELOPING A TEST FOR ASSESSING ELEMENTARY STUDENTS' COMPREHENSION OF SCIENCE TEXTS. *International Journal of Science and Mathematics Education*, *10*(4), 955–973. https://doi.org/10.1007/s10763-011-9307-y

Wang, W.-T., Lin, Y.-L., & Lu, H.-E. (2023). Exploring the effect of improved learning performance: A mobile augmented reality learning system. *Education and Information Technologies*, *28*(6), 7509–7541. https://doi.org/10.1007/s10639-022-11487-6

Wang, X. (2012). Augmented Reality: A new way of augmented learning. *eLearn*, *2012*(10), 2380716.2380717. https://doi.org/10.1145/2380716.2380717

Weng, C., Otanga, S., Christianto, S. M., & Chu, R. J.-C. (2020a). Enhancing Students' Biology Learning by Using Augmented Reality as a Learning Supplement. *Journal of Educational Computing Research*, *58*(4), 747–770. https://doi.org/10.1177/0735633119884213

Weng, C., Otanga, S., Christianto, S. M., & Chu, R. J.-C. (2020b). Enhancing Students' Biology Learning by Using Augmented Reality as a Learning Supplement. *Journal of Educational Computing Research*, *58*(4), 747–770. https://doi.org/10.1177/0735633119884213

Widiasih, Johan, H., & Pandiangan, P. (2021). *Development of a Physics Practicum Model Using Augmented Reality Technology: A Preliminary Analysis:* International Conference on Educational Sciences and Teacher Profession (ICETeP 2020), Bengkulu, Indonesia. https://doi.org/10.2991/assehr.k.210227.038

Widodo, S., Azizah, N., & Ikhwanudin, T. (2019). Teaching Mild Mentally Retarded Children using Augmented Reality. *International Journal of Learning, Teaching and Educational Research*, *18*(7), 184–199. https://doi.org/10.26803/ijlter.18.7.12

Wood, W., & Eagly, A. (2009, December 1). *Advantages of certainty and uncertainty*. https://www.semanticscholar.org/paper/Advantages-of-certainty-and-uncertainty-Wood-Eagly/15d78830ce6e886e6351cdc26a8d0fc73bc6970c

YILDIRIM, F. (2020). The Effect Of The Augmented Reality Applications In Science Class On Students' Cognitive And Emotional Learning. *Journal of Education in Science, Environment and Health*. https://doi.org/10.21891/jeseh.751023

Yildirim, F. S. (2020). The Effect of the Augmented Reality Applications in Science Class on Students' Cognitive and Affective Learning. *Journal of Education in Science, Environment and Health*, 259–267.

Zhang, J., Li, G., Huang, Q., Feng, Q., & Luo, H. (2022). Augmented Reality in K–12 Education: A Systematic Review and Meta-Analysis of the Literature from 2000 to 2020. *Sustainability*, *14*(15), 9725. https://doi.org/10.3390/su14159725

Ziden, A. A., Ziden, A. A. A., & Ifedayo, A. E. (2022a). Effectiveness of Augmented Reality (AR) on Students' Achievement and Motivation in Learning Science. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(4), em2097. https://doi.org/10.29333/ejmste/11923

Ziden, A. A., Ziden, A. A. A., & Ifedayo, A. E. (2022b). Effectiveness of Augmented Reality (AR) on Students' Achievement and Motivation in Learning Science. *Eurasia Journal of Mathematics, Science and Technology Education*, *18*(4), em2097. https://doi.org/10.29333/ejmste/11923