

The Use of Augmented Reality as an Innovative Medium in Quantum Physics Learning: A Systematic Literature Review Study

Intan Purnama Sari¹, Indah Septiana Fitri², Ayu Sekar Sari², Melly Ariska⁴,
Hamdi Akhsan^{5*}

^{1,2,3,4,5} Physics Education Study Program, Universitas Sriwijaya, Palembang, Indonesia

*Email: hamdiakhsan@fkip.unsri.ac.id

Abstract

Quantum physics is difficult to learn because it is abstract and its concepts are hard to visualize. This study examines how Augmented Reality (AR) can support quantum physics learning. It reviewed articles on AR and quantum physics published between 2018 and 2024. From 874 articles, 15 met the selection criteria and were analyzed in detail. The results show that AR helps students understand quantum physics better and increases their motivation to learn. Most studies report that AR allows students to visualize and interact with 3D representations, making concepts such as electron orbit, wave-particle duality, superposition, and the tunneling effect easier to understand. However, several challenges remain, including the need for adequate equipment, teacher training, and the high cost of developing AR applications. Future studies should investigate the long-term effectiveness of AR and develop more accessible applications. Overall, AR has strong potential to make quantum physics more engaging and easier to understand for students at different educational levels.

Keywords: Augmented Reality, Educational Innovation, Interactive Learning, Quantum Physics, Systematic Literature Review.

Article History:

Received: 26 November 2025

Accepted: 29 June 2026

Published: 20 October 2026

How to cite:

Sari, I.P., Fitri, I.S., Sari, A.S., Ariska, M., & Akhsan, H. (2026). The Use of Augmented Reality as an Innovative Medium in Quantum Physics Learning: A Systematic Literature Review Study. *Jurnal Literasi Pendidikan Fisika (JLPF)*, 7(2), 92-102. <https://doi.org/10.30872/jlpf.v7i2.6007>

Copyright © 2026 Jurnal Literasi Pendidikan Fisika (JLPF). This work is licensed under CC BY 4.0.

INTRODUCTION

Quantum physics is one of the most challenging branches of physics because its concepts are highly abstract, microscopic, and mathematically complex. Concepts such as wave-particle duality, quantum superposition, and quantum tunneling cannot be directly observed in everyday life, making them difficult for students to understand through conventional instruction. As a result, students at both secondary and tertiary education levels frequently experience misconceptions and conceptual difficulties when learning quantum phenomena (Ariantara et al., 2025). These challenges have become increasingly relevant in the digital era, where innovative learning technologies are needed to support meaningful understanding of complex scientific concepts (Kurniawan et al., 2024).

Augmented Reality is a technology that a lot of people are talking about in science education. Augmented Reality is a kind of technology that combines the real world with virtual objects that you can see in 3D. This lets users interact with things that they would not normally be able to see. For example, Augmented Reality can help students learn about science and physics (Barcali et al., 2022; Cai et al., 2021). Augmented Reality can help students understand ideas; it can also help reduce the amount of information they have to think about, and it can make them more interested and excited about learning. Augmented Reality is different from Reality (Wulandari et al., 2021). Virtual Reality completely replaces

the world, but Augmented Reality just adds to it. Augmented Reality uses images to help people understand the real world better, which makes it easier to use in real-life learning situations. Augmented Reality is really good, for learning because it combines the world with virtual objects like Augmented Reality does. (Minaee et al., 2022).

Research has shown that augmented reality or AR, is really good at helping people learn about physics topics.. When it comes to using AR to teach quantum physics, the information is all over the place. It is spread out across schools, learning goals, and technological designs. This makes it hard to figure out if AR is really working and how to use it properly, as noted by Vidak et al. (2022). Another issue is that no one has thoroughly reviewed all the research on AR in quantum physics education. Nobody has put together a summary of what works, what people are learning, what problems come up, and what might happen in the future with AR in quantum physics education.

Conducting a literature review is important because it gives a picture of what we already know. It helps find patterns and gaps in research. This, in turn, suggests what to study. A systematic review can also help teachers and researchers understand how Augmented Reality (AR) is currently being used in physics teaching. This understanding enables them to make choices about how to use AR in the classroom. This study reviews how AR is used in quantum physics education. It follows guidelines. The study looks at research trends and characteristics of studies that use AR to teach quantum physics. It includes what concepts are covered. It also looks at where the education takes place. Additionally, it examines what kinds of AR media are used. The study also looks at evidence that AR can help students understand concepts better, stay motivated, and be more engaged. It identifies challenges of using AR. Suggests what researchers should study next. By doing this analysis, the study aims to give teachers and researchers insights to integrate AR effectively in quantum physics education. The goal is to use Augmented Reality (AR) to improve learning and teaching in quantum physics. Augmented Reality (AR) can be a tool in quantum physics education.

METHODS

This study employed a Systematic Literature Review (SLR) method to examine previous research on the use of Augmented Reality (AR) in quantum physics learning. The review process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines. The procedures developed based on PRISMA 2020 (Page et al., 2021) were used as the main reference in conducting this study. This approach was selected to provide a comprehensive understanding of research trends, effectiveness, and challenges related to AR in quantum physics education. The SLR process was carried out systematically and transparently to provide a structured synthesis of the available literature and support the consistency of the review process (Mengist et al., 2020; Kitchenham & Charters, 2021). In addition, the application of PRISMA guidelines promotes clarity and transparency at each stage of the review process (Page et al., 2021; Moher et al., 2009). As highlighted by Lame (2019), such transparency also facilitates the identification and critical examination of potential limitations and biases throughout the review process.

The literature search was first conducted on 1 September 2025 and updated on 26 November 2025. Research articles were retrieved from Google Scholar, ERIC, DOAJ, IEEE Xplore, and Scopus. These databases were selected because they provide broad coverage of educational, technological, and interdisciplinary research, ensuring comprehensive access to studies related to Augmented Reality (AR) and physics education. The review focused on empirical studies that explicitly investigated the application of AR in physics or quantum concept learning and were published between 2015 and 2025. This publication period was chosen to capture recent developments in AR technologies and their educational applications. The review procedures included identification, screening, eligibility assessment, and inclusion based on the PRISMA 2020 framework. The Mixed Methods Appraisal Tool (MMAT) 2018 was employed to assess the methodological quality of the selected studies and enhance the rigor of the review process. Data were analyzed using a qualitative thematic approach to identify and categorize research trends, AR media types, quantum physics concepts addressed, learning outcomes, and reported challenges across the included studies (Chikon et al., 2025; Braun & Clarke,

2006)

The literature search was conducted online using combinations of keywords and Boolean operators. A total of 874 records were identified from the selected databases. Following the removal of duplicate records and records excluded for other reasons, the remaining records were screened based on their titles and abstracts. Studies that did not address the use of augmented reality (AR) in physics or quantum physics learning, were non-empirical, or did not meet the inclusion criteria were excluded. The remaining full-text reports were assessed for eligibility, and 15 studies were ultimately included in the review. Figure 1 illustrates the study selection process according to the PRISMA 2020 framework.

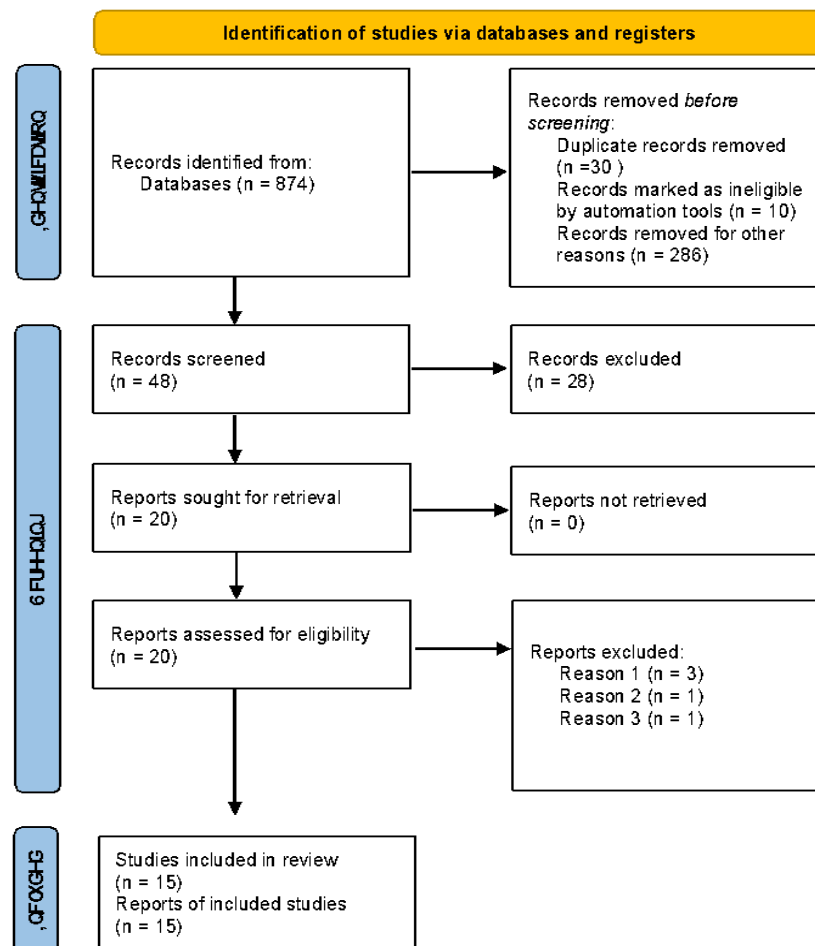


Figure 1. PRISMA Flow Diagram of the Study Selection Process

The selection criteria were applied to ensure that the included studies were relevant to the objectives of this review. The criteria covered the publication period, research topic, publication source, and focus on AR implementation in teaching and learning. The inclusion criteria are summarized in Table 1. Studies meeting these criteria were subsequently examined and categorized according to their authorship, publication year, research design, participants, type of AR media, and key findings.

Table 1. Inclusion Criteria

No.	Criterion	Description
1	Publication year	Studies published between 2015 and 2025.
2	Research topic	Studies addressing augmented reality (AR) in physics education or quantum learning.
3	Publication source	Articles published in indexed and reputable academic journals.
4	Research focus	Studies focusing on the implementation of AR in teaching and learning.

The methodological quality of the included studies was assessed using the Mixed Methods Appraisal

Tool (MMAT) 2018 (Hong et al., 2018). The assessment considered the methodological characteristics of each study, including research design, data collection, and data analysis. The results of the quality appraisal, together with the research designs, participant groups, and assessment descriptions, are presented in Table 2. Table 2 provides an overview of the methodological characteristics and appraisal results of the 15 included studies. The scores should be interpreted according to the MMAT criteria appropriate to each study design. These assessments provide context for interpreting the findings synthesized in the Results section.

Table 2. Methodological Quality of Reviewed Studies

No	Author & Year	Research Design	Subject	Validity of Methods	Description
1	(Cai et al., 2021)	Quasi experimental	University Students	4	Robust design, limited control, significant results.
2	(Abdullah et al., 2022).	Experimental study	School Students	4	Clear experimental design with measurable learning outcomes.
3	(Syskowski et al., 2024)	Experimental study	University Students	4	Strong experimental framework focusing on AR laboratory activities.
4	(Sahputri et al., 2022)	Quasi experimental	School Students	4	Valid statistical analysis with increased student engagement.
5	(Kurniawan et al., 2024)	Development research	University Students	3	Focuses on AR media development with limited testing.
6	(Radu et al., 2023)	Mixed method	University Students	5	Strong integration of quantitative and qualitative data.
7	(Tarng & Pei, 2023)	Experimental study	University Students	4	Valid method focusing on conceptual understanding.
8	(Sánchez et al., 2022)	Experimental study	University Students	4	Reliable observation of AR implementation in physics learning.
9	(Li et al., 2025)	Quasi experimental	School Students	4	Strong statistical analysis with moderate generalization.
10	(Sidik et al., 2024).	Literature review	University Students	3	Review-based findings with limited empirical validation.
11	(Marini et al., 2022)	Experimental study	General	4	Empirical study with clear measurement of learning outcomes.
12	(Vidak et al., 2022)	Systematic review	University Students	3	Review study analyzing AR use in physics education.
13	(Al-Hassan et al., 2020)	Meta-analysis	University Students	4	Strong meta-analytic approach evaluating AR learning effects.
14	(Ibáñez & Delgado-Kloos, 2018)	Systematic review	University Students	3	Analytical review discussing AR challenges in science education.
15	(Lai et al., 2019)	Quasi experimental	School Students	4	Valid instrument with cognitive load analysis.

RESULTS AND DISCUSSION

This section provides a comprehensive overview of the trends, effectiveness, and challenges associated with the use of Augmented Reality (AR) in quantum physics education based on the findings of this systematic literature review. The discussion below highlights the main findings from the included studies.

Results

A total of 15 studies met the established inclusion criteria and were subsequently analyzed to examine the characteristics, applications, and reported outcomes of augmented reality (AR) in quantum physics learning. The analysis focused on identifying the different types of AR media employed in the reviewed studies, the quantum physics concepts addressed through their implementation, and the educational levels of the participants involved. In addition, the reported findings of each study were examined to provide an overview of the outcomes associated with the use of AR in quantum physics

learning. The included studies were then organized and categorized according to these aspects to facilitate a systematic presentation and synthesis of the reviewed literature. The overall synthesis of the 15 studies, including their authorship, AR media types, quantum physics concepts, educational levels, and key findings, is presented in Table 3.

Table 3. Synthesis of Analyzed Research Articles

No	Author & Year	Types of AR Media	Concepts of Quantum Physics	Subject	Key Findings
1	(Cai et al., 2021)	AR Simulation App	Wave-particle duality	University Students	Improved conceptual understanding
2	(Abdullah et al., 2022).	AR Learning Media	Electron orbit	School Students	Increased achievement, satisfaction, and interest
3	(Syskowski et al., 2024)	AR in Experiments	Tunneling effect	University Students	Improved experimental skills and engagement
4	(Sahputri et al., 2022)	AR Gamification	Superposition	School Students	Higher engagement
5	(Kurniawan et al., 2024)	AR 3D Model	Electron orbit	University Students	More concrete visualization
6	(Radu et al., 2023)	AR Tutoring System	Wave-particle duality	University Students	Enhanced inquiry skills and learning experience
7	(Tarng & Pei, 2023)	VR/ AR	Superposition	University Students	Improved conceptual visualization
8	(Sánchez et al., 2022)	AR Learning	Tunneling effect	University Students	Increased conceptual understanding
9	(Li et al., 2025)	AR Learning System	Wave-particle duality	School Students	Increased engagement and conceptual understanding
10	(Sidik et al., 2024).	AR-based Physics Media	Wave-particle duality	University Students	Improved motivation and learning outcomes
11	(Marini et al., 2022)	Mobile AR	Electron orbit	General	Improved learning outcomes
12	(Vidak et al., 2022)	AR-based Learning	Superposition	University Students	Positive impact on physics understanding
13	(Al-Hassan et al., 2020)	AR-based Media	Wave-particle duality	University Students	AR in flipped classrooms enhances engagement and learning outcomes.
14	(Ibáñez & Delgado-Kloos, 2018)	AR Learning System	Wave-particle duality	University Students	AR enhances learning in STEAM by improving visualization engagement.
15	(Lai et al., 2019)	AR Reading System	Electron orbit	School Students	Reduced cognitive load and improved comprehension

As summarized in Table 3, the included studies employed different types of AR media to address a range of quantum physics concepts. The reported findings covered conceptual understanding, learning motivation, engagement, and other learning-related outcomes. To examine which quantum physics topics were most frequently addressed, the distribution of topics across the included studies is presented in Figure 2.

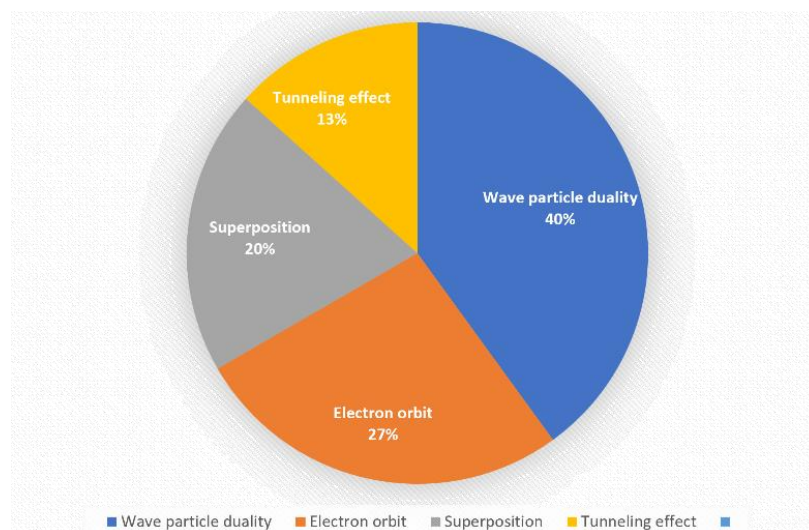


Figure 2. Distribution of AR-Based Quantum Physics Learning Topics

Figure 2 shows the distribution of quantum physics topics addressed in the 15 included studies. Wave–particle duality was the most frequently reported topic, appearing in six studies (40%). Electron orbitals and atomic models were reported in four studies (27%), followed by superposition in three studies (20%) and the tunneling effect in two studies (13%). These results describe the frequency with which each topic appeared in the reviewed literature; they do not indicate the comparative effectiveness of AR for individual topics. These findings are consistent with previous studies by Cai et al. (2021) and Tarng & Pei (2023), which confirm that such quantum concepts are highly abstract and difficult to visualize without the support of Augmented Reality (AR) technology. In addition, Maclean et al. (2022) explain that learning quantum physics requires visualization approaches capable of linking microscopic phenomena with students' conceptual understanding. The use of AR has also been shown to increase students' motivation and engagement in learning (Sánchez et al., 2022), and to provide a more intuitive spatial representation of quantum phenomena (Song et al., 2024).

In addition to the distribution of quantum physics topics, the educational levels represented in the included studies were examined. This analysis provides an overview of the contexts in which AR-based quantum physics learning has been investigated. Table 4 summarizes the number and percentage of studies involving university students, school students, and general participants.

Table 4. Distribution of Education Levels in the Analyzed Studies

Level of Education	Number of Articles	Percentage
University Student	10	67%
School Student	4	27%
General	1	6%
Total	15	100%

As shown in Table 4, 10 studies (67%) involved university students, four (27%) involved school students, and one (6%) involved general participants. This distribution indicates that the evidence reviewed in this study was concentrated at the university level, while fewer studies investigated AR-based quantum physics learning among school students.

The publication years of the included studies were examined to identify temporal patterns in research on AR-based quantum physics learning. Figure 3 presents the annual distribution of the included studies according to their publication years. Figure 3 shows that the number of publications remained relatively stable from 2018 to 2021, increased to a peak in 2022, and subsequently declined in 2023 before remaining stable in 2024. This pattern suggests that research interest in AR-based quantum physics education increased during the review period, although the evidence remains limited to the 15 studies included in this review. The observed trend should therefore be interpreted as a description of the

selected studies rather than a comprehensive measure of all research activity in this field.

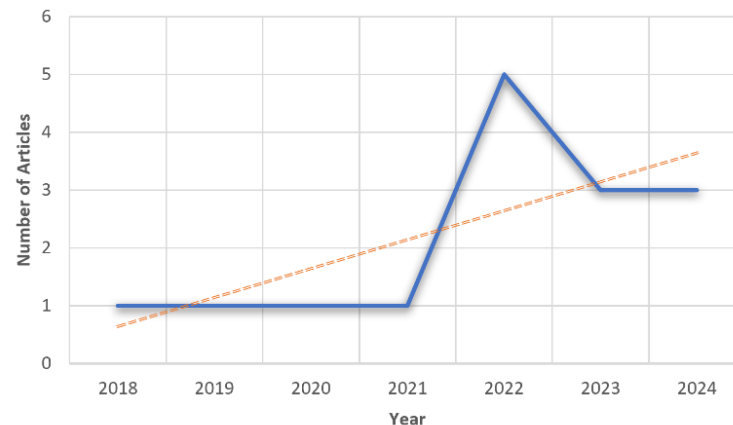


Figure 3. Annual Publication Trends in AR-Based Quantum Physics Education, 2018–2024

Figure 3 illustrates the annual publication trends of the studies included in this review. The number of publications remained stable at one article per year from 2018 to 2021, increased to five articles in 2022, and declined to three articles per year in 2023 and 2024. This pattern indicates a peak in research activity in 2022, followed by a lower but stable level of publication. However, these trends should be interpreted cautiously because the review included only 15 studies. The publication pattern describes the selected studies rather than the overall development of research on augmented reality (AR) in quantum physics education.

Discussion

A review of the literature indicates that the use of Augmented Reality (AR) in physics education, particularly quantum physics, has a positive impact on students' understanding of abstract concepts. Through three-dimensional visualization and interactive simulations, AR enables students to observe physical phenomena more concretely, potentially reducing cognitive difficulties. Cai et al. (2021) found that AR helps students understand wave–particle duality, whereas Egista et al. (2025) emphasized that AR primarily enhances learning motivation, although its effects on conceptual understanding remain limited. These findings suggest that the effectiveness of AR depends not only on the technology itself but also on instructional design and pedagogical integration. The importance of visualization is also highlighted by Tarng and Pei (2023), while Maclean et al. (2022) emphasized the need to connect microscopic phenomena with students' conceptual understanding. Sánchez et al. (2022) reported benefits of AR for motivation and engagement, and Song et al. (2024) highlighted its potential to provide more intuitive spatial representations of quantum phenomena.

Beyond conceptual understanding, AR-based learning media can increase student engagement through visual elements, interactivity, and simulations of complex physics concepts. AR-based educational games may further increase motivation through interactive and challenging activities that encourage curiosity and active participation (Sidik et al., 2024). In addition, 67% of the reviewed studies reported increased student interest or motivation, consistent with Rahmawati et al. (2022). Gamification elements, such as challenges, points, and visual feedback, can make learning more interactive and rewarding (Sidik et al., 2024). Abdullah et al. (2022) also identified AR as a promising instructional tool for helping students understand abstract concepts in a more practical and meaningful way. These findings indicate that AR may contribute to a more engaging learning experience, although increased motivation does not necessarily guarantee deeper conceptual understanding.

AR-based learning games may also support the development of 21st-century skills, including problem-solving, critical thinking, and collaboration. These competencies are particularly relevant to quantum physics, which requires students to analyze abstract phenomena logically and systematically.

Socrates and Mufit (2022) reported that AR in physics education can improve conceptual understanding, increase students' interest, enhance learning outcomes, and strengthen critical thinking skills. Wibowo (2023) similarly highlighted the potential of AR-based learning models to support critical thinking and collaboration. Marini et al. (2022) also reported the potential of AR to increase student engagement, although its broader educational impact depends on contextual and instructional factors. Furthermore, AR can function as a cognitive support tool by making abstract concepts more observable through interactive visualization (Sidik et al., 2024). Zhang and Yao (2025) associated three-dimensional AR visualization with enhanced cognitive engagement, while Radu et al. (2023) found that digital interaction can stimulate curiosity and strengthen students' focus. Nevertheless, without careful instructional planning, students may focus on visual features rather than the intended conceptual content.

Despite these potential benefits, the reviewed literature reveals several limitations. Most studies focus on educational media development and learning motivation, whereas research examining long-term knowledge retention, higher-order thinking skills, and collaborative or problem-based learning remains limited. Of the 15 studies analyzed, only two explicitly evaluated the impact of AR on higher-order thinking skills. In addition, most studies were conducted at the university level, leaving limited evidence regarding AR-based quantum physics learning in secondary schools. Other challenges include limited availability of AR-compatible devices, insufficient teacher preparedness, small sample sizes, and short intervention durations, which may restrict the generalizability of findings (Sidik et al., 2024). These limitations indicate the need for more in-depth investigations into the educational benefits of AR across different learning contexts.

Curriculum-related challenges also remain important barriers to optimizing AR-based educational games in physics learning. Difficulties in aligning these activities with existing curriculum requirements and learning objectives may require teachers to obtain additional training and appropriate instructional resources. Teacher readiness, device quality, and curriculum alignment are therefore important factors in successful implementation. Syskowski et al. (2024) emphasized that AR can be an effective learning tool when designed according to sound pedagogical principles rather than used merely as a visual enhancement. Teacher involvement in instructional design is also important to ensure that AR activities align with students' needs and intended learning outcomes.

To optimize AR implementation, schools and educational institutions need a systematic approach that considers technological infrastructure, teacher training, and curriculum integration. Investment in accessible AR devices and interactive learning software can help provide more equitable learning opportunities (Syskowski et al., 2024; Radu et al., 2023). Comprehensive teacher training is also essential to help educators design and implement AR-based learning activities effectively (Sidik et al., 2024). In addition, adaptive curriculum development should support the integration of educational games into physics instruction while considering infrastructure and teacher readiness (Abdullah et al., 2022). Developing simpler and more cost-effective AR media may further improve accessibility, particularly in schools with limited resources. Future research should also adopt longitudinal designs to determine whether improvements in conceptual understanding can be sustained over time.

Overall, AR-based educational games offer opportunities to support the understanding of abstract physics concepts through visualization, interactivity, and motivation (Zhang & Yao, 2025). Their integration may enrich teaching strategies and create more immersive and contextual learning experiences (Radu et al., 2023). However, further research is needed to establish their long-term effectiveness, contribution to higher-order thinking skills, and applicability across educational levels. This review contributes by synthesizing the implementation of AR specifically in quantum physics learning, an area that remains relatively underexplored, and by identifying research gaps concerning sustained learning outcomes, broader educational implementation, and pedagogical integration.

CONCLUSION

Based on a review of 15 studies, we found that using Augmented Reality in learning quantum physics really helps students. It improves their understanding, motivation, and engagement. The review looked

The Use of Augmented Reality...

at research and found that interactive 3D visuals make it easier for students to grasp hard quantum concepts. Augmented Reality applications have some features that help with this. However, the studies also had some limitations. These included groups of students, short periods of use, and issues with technology and teacher preparedness. The use of Augmented Reality in quantum physics learning shows potential. Students' conceptual understanding of quantum physics improves with Augmented Reality. The use of Augmented Reality also increases motivation and engagement in quantum physics learning.

This review has both practical implications. Theoretically, it adds to what we know about how Augmented Reality (AR) helps with learning quantum physics concepts. The findings also give insights for teachers, researchers, and policymakers on how to effectively use AR in physics teaching. This can be done through good lesson planning, training teachers, and having the technology in place. In the future, research should be done in a thorough and long-term way. This will help us understand how AR affects understanding, remembering, critical thinking, and student interest in learning environments. More research is needed to see how AR works over time. It should look at how AR affects learning in subjects and settings. The use of AR in education is still being studied. Researchers should keep looking into how it can be used.

Acknowledgements

The author would like to express sincere gratitude to the supervisor of the Physics Education Study Program, Sriwijaya University, for providing valuable guidance, constructive feedback, and continuous support throughout the completion of this study. The author also appreciates the support provided by the institution that facilitated the research and academic activities related to this work.

Conflict of Interest

The authors declare that they have no conflict of interest related to this study.

Funding

This research received no external funding.

Author Contributions

I.P.S., I.S.F., A.S.S., and M.A. contributed to conceptualization, methodology, investigation, data curation, formal analysis, and writing the original draft. H.A. contributed to conceptualization, supervision, validation, and reviewing and editing the manuscript. All authors reviewed and approved the final version of the manuscript and agreed to be accountable for their contributions.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics Approval and Consent to Participate

Ethical approval and informed consent were not applicable to this study because it involved a systematic review of previously published literature and did not recruit human participants or collect primary data from individuals.

Generative AI Declaration

The authors did not use generative AI tools in the preparation of this manuscript.

REFERENCES

- Abdullah, N., Baskaran, V. L., Mustafa, Z., Ali, S. R., & Zaini, S. H. (2022). Augmented Reality: The Effect in Students' Achievement, Satisfaction and Interest in Science Education. *International Journal of Learning, Teaching and Educational Research*, 21(5), 326–350. <https://doi.org/10.26803/ijlter.21.5.17>
- Al-Hassan, H. A. A., Suad, J. H., & Ali, H. H. (2020). Augmented Reality Technology in Education. *IOP Conference Series: Materials Science and Engineering*, 928(3). <https://doi.org/10.1088/1757-899X/928/3/032065>

The Use of Augmented Reality...

- Ariantara, R. G., Mupid, N. S. K., Fathinah, N. H., & Acquilla, R. A. (2025). Pengembangan Augmented Reality Learning Media for Semiconductor (ARLEMS) bagi Mahasiswa Fisika dengan Gaya Belajar Visual. *Jurnal Pembelajaran IPA Terpadu: PELITA*, 5(1), 140-156. <https://doi.org/10.54065/pelita.5.1.2025.692>
- Astuti, F. N., Suranto, S., & Masykuri, M. (2019). Augmented Reality for teaching science: Students' problem solving skill, motivation, and learning outcomes. *JPBI (Jurnal Pendidikan Biologi Indonesia)*, 5(2), 305–312. <https://doi.org/10.22219/jpbi.v5i2.8455>
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101. <https://doi.org/10.1191/1478088706qp0630a>
- Cai, S., Liu, C., Wang, T., Liu, E., & Liang, J. C. (2021). Effects of learning physics using Augmented Reality on students' self-efficacy and conceptions of learning. *British Journal of Educational Technology*, 52(1), 235–251. <https://doi.org/10.1111/bjet.13020>
- Hong, Q. N., Pluye, P., Fàbregues, S., Bartlett, G., Boardman, F., Cargo, M., Dagenais, P., Gagnon, M.-P., Griffiths, F., Nicolau, B., O'Cathain, A., Rousseau, M.-C., & Vedel, I. (2018). *Mixed methods appraisal tool (MMAT), version 2018: User guide*. Canadian Intellectual Property Office, Industry Canada.
- Ibáñez, M. B., & Delgado-Kloos, C. (2018). Augmented reality for STEM learning: A systematic review. *Computers and Education*, 123, 109–123. <https://doi.org/10.1016/j.compedu.2018.05.002>
- Kitchenham, B., & Charters, S. (2007). *Guidelines for performing systematic literature reviews in software engineering* (Version 2.3, EBSE Technical Report EBSE-2007-01). Keele University and University of Durham.
- Kurniawan, A., Jumadi, J., Kuswanto, H., & Syar, N. I. (2024). The 21st century education: A systematic literature review of transforming learning methods to foster critical thinking skills through augmented reality in science learning. *Jurnal Eduscience*, 11(3), 601–622.
- Lai, A. F., Chen, C. H., & Lee, G. Y. (2019). An augmented reality-based learning approach to enhancing students' science reading performances from the perspective of the cognitive load theory. *British Journal of Educational Technology*, 50(1), 232–247. <https://doi.org/10.1111/bjet.12716>
- Lame, G. (2019). Systematic literature reviews: An introduction. In *Proceedings of the 22nd International Conference on Engineering Design (ICED19)* (pp. 1633–1642). Cambridge University Press. <https://doi.org/10.1017/dsi.2019.169>
- Li, G., Luo, H., Chen, D., Wang, P., Yin, X., & Zhang, J. (2025). Augmented reality in higher education: A systematic review and meta-analysis of the literature from 2000 to 2023. *Education Sciences*, 15(6), Article 678. <https://doi.org/10.3390/educsci15060678>
- Maclean, C., Wolfe, A., Bhatti, S., Centino, A., & Ghannam, R. (2022). Virtual and augmented reality as educational tools for modern quantum applications. In *2022 29th IEEE International Conference on Electronics, Circuits and Systems (ICECS)* (pp. 1–4). IEEE. <https://doi.org/10.1109/ICECS202256217.2022.9970858>
- Marini, A., Nafisah, S., Sekaringtyas, T., Safitri, D., Lestari, I., Suntari, Y., Umasih, Sudrajat, A., & Iskandar, R. (2022). Mobile Augmented Reality Learning Media with Metaverse to Improve Student Learning Outcomes in Science Class. *International Journal of Interactive Mobile Technologies*, 16(7), 99–115. <https://doi.org/10.3991/ijim.v16i07.25727>
- Mengist, W., Soromessa, T., & Legese, G. (2020). Ecosystem services research in mountainous regions: A systematic literature review on current knowledge and research gaps. *Science of the Total Environment*, 702, Article 134581. <https://doi.org/10.1016/j.scitotenv.2019.134581>
- Minaee, S., Liang, X., & Yan, S. (2022). *Modern augmented reality: Applications, trends, and future directions*. arXiv. <https://doi.org/10.48550/arXiv.2202.09450>
- Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., McGuinness, L. A., Stewart, L. A., Thomas, J., Tricco, A. C., Welch, V. A., Whiting, P., & Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, 372, Article n71. <https://doi.org/10.1136/bmj.n71>

The Use of Augmented Reality...

- Radu, I., Huang, X., Kestin, G., & Schneider, B. (2023). How augmented reality influences student learning and inquiry styles: A study of 1-1 physics remote AR tutoring. *Computers & Education: X Reality*, 2, Article 100011. <https://doi.org/10.1016/j.cexr.2023.100011>
- Rahmawati, R., Kurnia, K., & Khaeruddin, K. (2022). Efektivitas penggunaan aplikasi EduMu pada pembelajaran fisika terhadap motivasi belajar peserta didik kelas XI IPA di SMA Muhammadiyah 1 Unismuh Makassar. *JPF (Jurnal Pendidikan Fisika) FKIP UM Metro*, 10(1), 114–122. <https://doi.org/10.24127/jpf.v10i1.4915>
- Sahputri, D. N., Vebrianto, R., & Radeswandari, R. (2022). Systematic Review of Education Games in Science Learning: Teachers and Students of Basic Education. *Jurnal Pendidikan Sains (JPS)*, 10(1), 45. <https://doi.org/10.26714/jps.10.1.2022.45-53>
- Sánchez, J., & Ramírez Díaz, M. H. (2022). Augmented reality in physics teaching. *European Journal of Physics Education*, 13(1), 14–27.
- Sidik, R. M., Wiliyanti, V., & Gunawan, I. (2024). Augmented Reality-based Physics Learning Media To Improve Students' Motivation And Learning Outcomes: A Systematic Literature Review Article History Abstract. *Jurnal Pembelajaran Fisika*, 12(2), 129–146. <https://doi.org/10.23960/jpf.v12.n2.202405>
- Socrates, T. P., & Mufit, F. (2022). The effectiveness of using augmented reality-based learning media in physics learning: Literature study. *Electrolyte*, 1(2), 4–11. <https://doi.org/10.54482/electrolyte.v1i02.160>
- Song, G., Wang, X., & Ghannam, R. (2024). Immersive quantum: A systematic literature review of XR in quantum technology education. *Computers & Education: X Reality*, 5, Article 100087. <https://doi.org/10.1016/j.cexr.2024.100087>
- Syskowski, S., Wilfinger, S., & Huwer, J. (2024). Impact and classification of augmented reality in science experiments in teaching—A review. *Education Sciences*, 14(7), Article 760. <https://doi.org/10.3390/educsci14070760>
- Tarng, W., & Pei, M.-C. (2023). Application of virtual reality in learning quantum mechanics. *Applied Sciences*, 13(19), Article 10618. <https://doi.org/10.3390/app131910618>
- Vidak, A., Movre Šapić, I., & Mešić, V. (2022). Augmented reality in teaching about physics: First findings from a systematic review. *Journal of Physics: Conference Series*, 2415(1), Article 012008. <https://doi.org/10.1088/1742-6596/2415/1/012008>
- Wulandari, S., Wibowo, F. C., & Astra, I. M. (2021). A review of research on the use of augmented reality in physics learning. *Journal of Physics: Conference Series*, 2019(1), Article 012058. <https://doi.org/10.1088/1742-6596/2019/1/012058>
- Zhang, S., & Yao, Z. (2025). The challenge of the application of augmented reality in science education in China: A systematic review. *Disciplinary and Interdisciplinary Science Education Research*, 7, Article 4. <https://doi.org/10.1186/s43031-025-00123-1>