JPPIPA 12(9) (2026)

Jurnal Penelitian Pendidikan IPA

http://jppipa.unram.ac.id/index.php/jppipa/index

The Role of Augmented Reality (AR) and Virtual Reality (VR) in Enhancing Conceptual Understanding and Student Engagement in Chemistry Education: A Literature Review

Azmir Djauhari[1*], Ucia Mahya Dewi[2], Arlin Maya Sari[3], Nurul Afni Sinaga[4]

[1] SMAN 1 Lhokseumawe, Lhokseumawe, Indonesia.
[2] Department of Chemistry Education, Universitas Malikussaleh, Lhokseumawe, Indonesia.
[3] Department of Physics Education, Universitas Malikussaleh, Lhokseumawe, Indonesia.
[4] Department of Mathematics Education, Universitas Malikussaleh, Lhokseumawe, Indonesia.

Received: July 7, 2026
Revised: September 23, 2026
Accepted: October 2, 2026
Published: October 31, 2026

Corresponding Author:
Azmir Djauhari
azmir.jauhari@gmail.com

DOI: 10.29303/jppipa.v12i10.15948

Open Access

© 2026 The Authors. This article is distributed under a (CC-BY License)

Abstract: This study reviews the effectiveness of Augmented Reality (AR) and Virtual Reality (VR) in chemistry education, with a focus on conceptual understanding and student engagement. The study used a literature review approach. Data were collected by reviewing articles on Augmented Reality (AR) and Virtual reality (VR). The literatures used in this study is based on secondary data, specifically research articles from scientific journals and conference proceedings. The selected articles were limited to those published between 2025 and 2026. A total of 12 national and international journal articles were analyzed, gathered using the Publish or Perish 8 application and sourced through Google Scholar. The analysis indicates that Augmented Reality (AR) and Virtual Reality (VR) offer strong potential to improve both understanding and engagement in chemistry learning. The findings reveal that AR and VR significantly enhance students' understanding of abstract chemistry concepts by providing interactive three-dimensional visualizations of atomic structures, molecular geometry, and chemical processes. These technologies enable students to explore complex phenomena more effectively than conventional methods, resulting in improved learning outcomes and a reduction in misconceptions.

Keywords: Augmented Reality (AR); Chemistry education; Virtual Reality (VR)

Introduction

Chemistry is often perceived as a challenging subject due to its abstract nature and the need to understand phenomena that cannot be directly observed. Concepts such as atomic structure, molecular geometry, and chemical reactions require strong visualization skills, which many students struggle to develop through conventional teaching methods. This limitation often leads to difficulties in understanding the relationships between macroscopic, microscopic, and symbolic representations (Jaber & BouJaoude, 2012). Recent studies indicate that students continue to face considerable difficulties in linking complex chemical representations, especially when instruction relies mainly on static, two-dimensional learning media (Wu et al., 2001). Furthermore, Ningrum et al. (2026) argued that application of learning medium play a significant role in enhancing interest and understanding among students regarding abstract chemistry concepts. The effectiveness of instructional media is expected to be even greater when the media developed are visually appealing and creativity designed (Nahadi et al., 2025). As a result, learning outcomes are often suboptimal, and misconceptions frequently occur. The study found that the majority of students experienced misconceptions in chemistry because of incorrect prior conceptions and the abstract characteristics of the learning material (Shiddiqi et al., 2024). Damsi & Suyanto (2023) mentioned that students' misconceptions in chemistry are primarily

How to Cite:
Djauhari, A., Dewi, U. M., Sari, A. M., & Sinaga, N. A. (2026). The Role of Augmented Reality (AR) and Virtual Reality (VR) in Enhancing Conceptual Understanding and Student Engagement in Chemistry Education: A Literature Review. *Jurnal Penelitian Pendidikan IPA*, *12*(10), 1–10. https://doi.org/10.29303/jppipa.v12i10.15948

caused by internal cognitive factors, particularly the mismatch between their pre-existing conceptions and the scientifically accepted concepts presented during instruction. To minimize misconceptions, Yovanie (2024) recommended to apply learning medium, as its interactive learning environment helps students visualize abstract chemical concepts more accurately and promotes meaningful conceptual understanding.

The rapid development of digital technology offers new opportunities to address these challenges. The integration of innovative technologies into education has become increasingly important. Augmented Reality (AR) and Virtual Reality (VR) are among the emerging tools that have gained attention for their potential to transform science learning (Zhao et al., 2023). These technologies enable the visualization of abstract concepts in interactive three-dimensional environments, allowing students to engage more actively with the learning material. Recent meta-analyses indicate that the use of AR and VR in education consistently enhances student motivation, engagement, conceptual understanding, and cognitive skills (Chang et al., 2022).

Previous studies have shown that AR and VR can enhance both conceptual understanding and student engagement mainly in abstract concept in chemistry education (Trinova & Parni, 2026). Students are able to explore complex chemical phenomena more clearly, which leads to improved comprehension and reduced misconceptions. In addition, the interactive feature of these technologies can increase motivation and participation in the learning process. Despite these advantages, the implementation of AR and VR in education still faces several challenges, including limited access, high costs, and lack of teacher readiness (Wu at al., 2001). With a structured and planned approach, AR and VR can become catalysts for transforming chemistry learning in an effective and sustainable way. Moreover, their effectiveness largely depends on how well they are integrated into the curriculum and aligned with instructional objectives (Krajcik et al., 2008). Without careful planning, the use of AR/VR may remain a mere novelty that does not significantly impact student learning outcomes.

Despite the growing body of literature, there remains a lack of comprehensive reviews that synthesize recent evidence on both AR and VR specifically within chemistry education while simultaneously examining their contributions to conceptual understanding, student engagement, and the pedagogical factors that determine successful implementation. Most previous reviews either investigate AR or VR separately, emphasize technological development, or evaluate educational outcomes across multiple disciplines without focusing on the distinctive conceptual characteristics of chemistry.

Therefore, this study fills this gap by providing an updated literature review that integrates recent research on both AR and VR in chemistry education. Unlike previous reviews, this study not only evaluates the effectiveness of applying technologies in improving conceptual understanding and student engagement but also identifies common instructional strategies, implementation challenges, and pedagogical factors that influence successful adoption. The findings are expected to provide a comprehensive reference for educators, curriculum developers, and researchers in designing evidence-based chemistry learning environments that effectively integrate involving technologies.

Therefore, this study aims to examine the effectiveness of AR and VR in chemistry education through a literature review. The focus is on analyzing their impact on students' conceptual understanding and engagement, as well as identifying key factors that influence their successful implementation. This is in line with Kljun et al. (2020) who emphasized that the current status, opportunities, and challenges of AR in education largely depend on how the technology is pedagogically integrated rather than on its mere availability. Similarly, Rojas-Sánchez et al. (2023), Sa'adi et al. (2024), and Akbar et al. (2024) through their bibliometric analysis, confirmed that the effectiveness of VR and AR in educational settings is consistently mediated by instructional design factors.

Method

This current study employed a Literature Review method, which involves analyzing and examining scientific studies derived from various sources such as research articles from scientific journals, research reports, proceedings from national and international seminars, and academic theses (Snyder, 2019). This approach aims to generate conclusions that contribute to the development of new theories or ideas (Ahmed et al., 2025). The literatures used in this study is based on secondary data. Secondary data refer to data that have been previously collected and published by other researchers, institutions, or organizations for purposes other than the current study (Ll et al., 2020). These data are used to provide theoretical foundations, empirical evidence, and contextual information for the research. specifically research articles from scientific journals and conference proceeding (Öztürk et al., 2024). The selected articles were limited to those published between 2025 and 2026.

The research articles used as data sources were obtained through the Publish or Perish 8 application and retrieved via Google Scholar. A total of 12 articles were included in this study. The keywords used in the search

and identification process were learning media, augmented reality, virtual reality and teaching chemistry. The articles analyzed in this study met several inclusion criteria which are presented in Table 1.

Table 1. Inclusion criteria

Type	Inclusion
Article Type	Research articles
Publication Year	2025–2026
Source of Article	National and International journals and conference proceedings
Journal Status	Indexed journals and international conference proceedings
Sample	Students (Junior High, Senior High, and Higher Education levels)

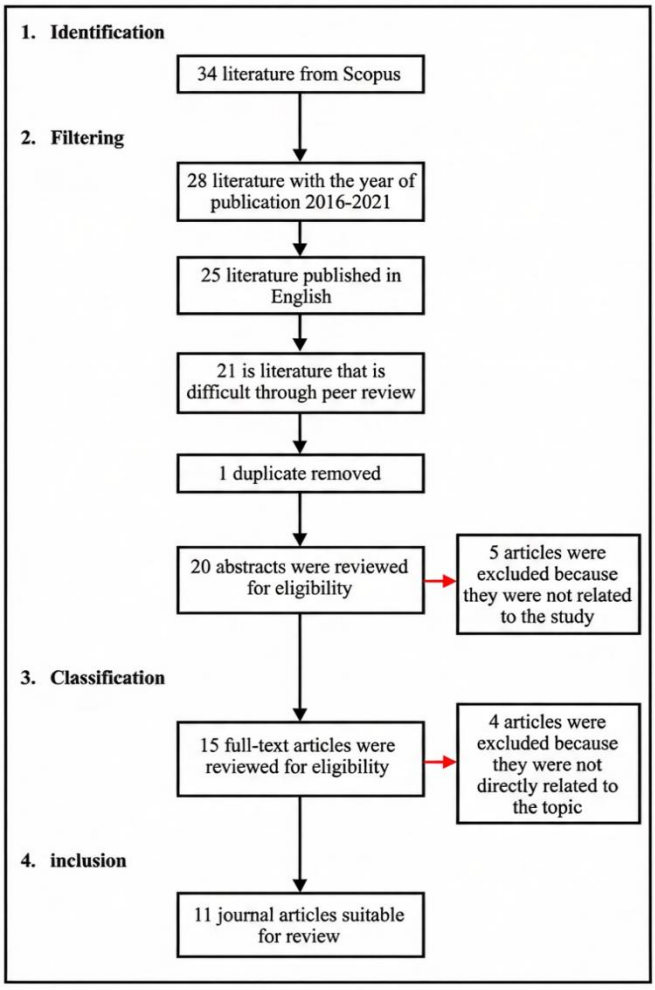


Figure 1. Systematic review methodology for AR/VR in chemistry education

The article search using the Publish or Perish 8 application through Google Scholar initially identified 34 articles. During the data extraction stage, 14 articles were excluded due to a high level of content similarity with other articles. As a result, 20 articles remained for the next stage of extraction. The following stage was the eligibility assessment. At this stage, 8 articles were excluded because they did not meet the inclusion criteria. Therefore, the final stage resulted in 12 articles that were eligible and used as data sources in this study.

The systematic review process consisted of four main steps: identification, filtering, classification, and inclusion. In the identification phase, relevant literature was initially searched and collected from a database to form the primary pool of studies. Next, the filtering step applied specific criteria such as publication year, language, peer-review status, and duplicate removal to narrow down the results. During the classification phase, the remaining articles were further assessed by reviewing their abstracts and full texts to determine their relevance and eligibility for the study. Finally, the inclusion step selected the articles that fully met all criteria and were deemed suitable for the final review. All the steps can be seen in Figure 1.

Result and Discussion

The findings of this literature review were obtained through a process of examining, analyzing, and synthesizing articles that passed the extraction stage (Page et al., 2021; Phillips & Barker, 2021). The focus of the analysis is on Augmented Reality and virtual reality learning media in teaching chemistry. By synthesizing evidence from empirical studies, this review identifies various research trends, evaluates the educational benefits and limitations of AR and VR, and highlights future research directions for integrating technologies into chemistry teaching and learning (Siddaway et al., 2019; Gough et al., 2017; Xiao & Watson, 2019). The analysis was conducted by comparing the characteristics of each study, including research objectives, educational level, chemistry topics, research design, technological features, and reported learning outcomes. In addition, attention was given to similarities and differences among the selected studies to identify the patterns regarding the implementation of AR and VR in chemistry education. The article data are presented in Table 2.

The findings synthesized from the twelve studies demonstrate a consistent trend that Augmented Reality (AR) and Virtual Reality (VR) are effective educational technologies for improving chemistry learning, particularly in topics that require visualization of abstract concepts (Ibáñez & Delgado-Kloos, 2018; Akçayır & Akçayır, 2017). Across studies published in 2025–2026, AR and VR consistently outperformed conventional instructional approaches by enhancing students' conceptual understanding, learning achievement, engagement, and practical skills. This finding is consistent with recent evidence reported by

Raziana et al. (2025) where an Android-based virtual chemistry laboratory (Chemvilative) significantly improved students' conceptual understanding and post-test achievement compared with conventional learning by providing interactive visualizations and accessible virtual experiments. Merchant et al. (2014) reported that virtual reality-based instruction significantly improves students' learning outcomes compared with traditional teaching, particularly when interactive simulations and well-designed instructional strategies are employed.

Table 2. Articles review

Author and Year	Journal	Research Title	Research Findings
Neji et al. (2025)	FNAS-JMSE	Effects of Virtual and Augmented Reality Teaching Strategies on Students' Understanding of Chemistry Practical Activities	The findings revealed that the use of Virtual Reality (VR) and Augmented Reality (AR) teaching strategies significantly improved students' understanding and academic achievement in chemistry practical activities compared to conventional teaching methods. Students exposed to VR and AR obtained higher posttest scores. The integration of these technologies also enhanced student participation and engagement during practical sessions. Therefore, VR and AR are effective instructional strategies for improving students' performance and conceptual understanding in chemistry.
Dani & Zamhari (2025)	Journal of Educational Chemistry (JEC)	Developing Interactive Augmented Reality Learning Media to Introduce Chemistry Laboratory Equipment in Senior High School	The findings show that the developed Augmented Reality (AR) learning media (AR-LAB) is highly valid and feasible for use in chemistry learning. Expert validation results reached 91.67% for both material and media aspects, categorized as very good. Teacher assessment also showed a high feasibility level of 93.60%. Student testing indicated very positive responses, with maximum scores in the very good category. The AR-based application effectively introduces laboratory equipment through interactive 3D visualization, making it easier, more engaging, and accessible for students to understand chemistry laboratory tools.
Tania & Sukarmin (2025)	JURNAL EDUSCIENCE	Augmented Reality-Based Virtual Laboratory Application as Chemistry Learning Media for Acid-Base Titration Material	The findings indicate that the developed augmented reality-based virtual laboratory application is valid, practical, and effective for chemistry learning. The validity results show a good category for both content and construct. Practicality is reflected in high student response (96%) and active participation (93.32%), categorized as outstanding. Effectiveness testing shows a significant improvement in student learning outcomes, proven by differences between pretest and posttest scores. The application enhances students' understanding through interactive and visual learning, and serves as an alternative solution to limited laboratory facilities.
Agussalim (2025)	Arfak Chem: Chemistry Education Journal	The Role of Augmented Reality in Supporting Deep Learning within the Merdeka Curriculum: A Systematic Literature Review in Chemistry Education	The findings show that Augmented Reality (AR) consistently improves students' conceptual understanding, higher-order thinking skills, and engagement in chemistry learning. AR supports multi-level chemical representations and facilitates deeper learning experiences. The study also reveals that AR aligns well with the principles of the Merdeka Curriculum, including project-based learning, authentic assessment, and differentiated instruction. Therefore, AR is identified as an effective and strategic innovation to promote deep and meaningful learning in chemistry education. Further research is needed to explore its long-term impact and integration with inquiry-based learning models.
Fadhilah & Nasution (2025)	JIPK	Development of Chemistry E-Modules Based on Augmented Reality Technology on Hydrocarbon Material	The findings indicate that the developed Augmented Reality (AR)-based chemistry e-module is highly feasible, valid, and practical for learning. Validation results from material experts (90.91%) and media experts (92%) fall into the highly feasible category. Teacher responses (99%) and student responses (91.34%) show strong positive acceptance. The AR-based e-module effectively supports interactive and innovative learning, helping students better understand abstract concepts, particularly hydrocarbons, and has strong potential for wider classroom implementation.
Jia et al. (2025)	Education Insights	Construction of Application Mode of Virtual Reality (VR)	The findings show that the implementation of Virtual Reality (VR) in hazardous chemistry experiment teaching effectively reduces safety risks and overcomes limitations in laboratory resources. The developed VR-

Author and Year	Journal	Research Title	Research Findings
		Technology in Hazardous Chemistry Experiment Teaching	based teaching model, grounded in constructivism, situational cognition, and embodied cognition theories, promotes active learning through interactive virtual environments. It enhances students' experimental skills, safety awareness, and engagement. Additionally, VR supports the digital transformation of chemistry education and improves the overall effectiveness of experimental learning.
Shertayeva et al. (2026)	Journal of Technology and Science Education	Methods of Utilizing Visualization and VR/AR Technologies in the Development of Chemistry Projects for 8th-Grade Students	The findings show that the integration of visualization, Virtual Reality (VR), and Augmented Reality (AR) technologies has a strong positive effect on students' learning in chemistry. Students in the experimental group demonstrated higher understanding and motivation compared to those taught using traditional methods. The use of 3D visualization, interactive media, and project-based learning enhances conceptual understanding and supports the development of scientific thinking. These technologies are effective in improving both learning outcomes and student engagement in chemistry education.
Ghani (2026)	Journal of Science and Mathematics Letters	Integrating Augmented Reality in Chemistry Education: The Impact of the Augmented Reality Chemistry Student Investigation (AR-CSI) Module on Content Knowledge and 21st Century Skills	The findings indicate that the integration of the Augmented Reality (AR)-based AR-CSI module significantly improves students' content knowledge and 21st-century skills in chemistry learning. The use of AR enhances students' understanding of abstract concepts through interactive visualization. It also promotes critical thinking, collaboration, and problem-solving skills. Furthermore, AR-based learning increases student engagement and supports more effective and meaningful learning experiences in chemistry education.
Freitas et al. (2026)	INTED2026 Proceedings	Project-Based Learning Applied to the Development of an Augmented Reality Application for Chemistry Teaching	The findings show that the integration of Project-Based Learning (PBL) with an Augmented Reality (AR) application effectively improves students' understanding of abstract chemistry concepts, particularly molecular geometry and electronic clouds. The AR application enhances visualization through interactive 3D models, increasing student engagement and motivation. Teacher validation indicates clearer conceptual understanding compared to traditional methods. Additionally, the PBL approach supports the development of problem-solving, autonomy, and technical skills. This combination proves effective in creating meaningful and innovative learning experiences in chemistry education.
Nguyen et al. (2026)	Journal of Information Technology Education: Research	Exploring Pathways for Integrating Augmented Reality in Chemistry Teaching: Mediating TPACK Framework for Effective Instruction	The findings show that the integration of Augmented Reality (AR) in chemistry teaching is strongly influenced by teachers' Technological Pedagogical and Content Knowledge (TPACK). Pedagogical Content Knowledge (PCK), Technological Content Knowledge (TCK), and Technological Pedagogical Knowledge (TPK) significantly contribute to TPACK, with TPK identified as the strongest predictor. The study reveals that effective AR integration depends more on the interaction between pedagogy and technology rather than technical skills alone. Therefore, strengthening teachers' pedagogical and integrative competencies is essential for improving AR-based chemistry instruction.
Saman et al. (2026)	ICoSCI 2026 (IEEE Conference)	Enhancing Secondary-Level Polymer Chemistry Learning with Gamified Augmented Reality: Development and Evaluation of Gameful Experience and Usability	The findings show that the developed gamified Augmented Reality (AR) application (Poly-AR) effectively enhances students' learning experience in polymer chemistry. The application improves visualization of complex molecular structures through interactive 3D models and increases student engagement through gamification elements. Evaluation results indicate high usability (mean score 4.60/5) and strong gameful experience (mean score 5.78/7), reflecting efficiency, effectiveness, and user satisfaction. The AR-based approach successfully addresses difficulties in understanding abstract concepts and supports more engaging and interactive chemistry learning.
Dalili et al. (2026)	INTED2026 Proceedings	Designing for Spatial Understanding: A	The findings show that the use of Virtual Reality (VR) (ChemVR) effectively supports students' spatial understanding in organic

Author and Year	Journal	Research Title	Research Findings
		Virtual Reality Approach to Undergraduate Organic Chemistry	chemistry, particularly in topics such as stereochemistry, chirality, and molecular conformations. Students reported improved visualization of 3D structures, better understanding of complex concepts, and increased interest compared to traditional methods. The VR experience was easy to use, even for beginners, and feasible within standard learning time. Overall, VR provides meaningful support for enhancing conceptual understanding and engagement in organic chemistry learning.

One of the most important findings is the improvement in students' conceptual understanding and academic achievement. Experimental studies by Neji et al. (2025), Tania & Sukarmin (2025), Shertayeva et al. (2026), Ghani (2026), Freitas et al. (2026), and Dalili et al. (2026) consistently reported significant increases in posttest scores after implementing AR- or VR-based learning. These findings are also supported by Dunnagan et al. (2020), Elford et al. (2022), Sari et al. (2022), and Yamtinah et al. (2023), who demonstrated that Augmented Reality media based on tetrahedral chemical representations provides accurate three-dimensional visualization of chemical concepts and facilitates students' understanding of microscopic structures that are difficult to interpret using conventional learning resources. These improvements can be explained by the ability of applying technologies to visualize microscopic and three-dimensional chemical phenomena that are difficult to represent using conventional textbooks or two-dimensional images. Interactive visualization enables learners to manipulate molecular structures, observe particle interactions dynamically, and establish meaningful connections among macroscopic observations, submicroscopic processes, and symbolic representations. Consequently, AR and VR support the construction of more accurate mental models while reducing cognitive barriers associated with abstract chemistry concepts.

Another aspect is the enhancement of student engagement and motivation. Most studies reported that students showed greater interest, participation, and enthusiasm during learning activities when AR or VR was integrated into instruction. Neji et al. (2025) observed higher participation during chemistry practical activities, while Tania & Sukarmin (2025) reported outstanding levels of student participation (93.32%) and positive responses (96%). Similarly, Saman et al. (2026) demonstrated that gamified AR significantly enhanced students' learning experiences, supported by high usability and gameful experience scores. These findings are consistent with Wong et al. (2021) and Whatoni & Sutrisno (2022), who found that the use of Augmented Reality in higher education chemistry significantly increased students' enthusiasm, satisfaction, and active participation while improving their understanding of molecular structures through interactive three-dimensional visualization.

Similarly, Guaya et al. (2023), Low et al. (2022), Prasetya et al. (2024), and Silva et al. (2023) reported that AR-based learning positively influenced students' motivation across the four dimensions of Keller's ARCS model, namely attention, relevance, confidence, and satisfaction, indicating that the technologies support both cognitive and affective aspects of learning. Dinther et al. (2023) further argued that applying virtual reality promotes meaningful chemistry learning by connecting abstract chemical concepts with authentic contexts, encouraging students to become more actively involved in inquiry and exploration rather than passively receiving information. These findings indicate that learning environments encourage active participation by transforming students from passive recipients of information into active learners who interact directly with virtual objects and simulations. Increased engagement is particularly important because sustained behavioral, emotional, and cognitive engagement supports deeper processing of scientific concepts, improves persistence in learning tasks, and ultimately contributes to better academic achievement.

Conclusion

The reviewed studies indicate that Augmented Reality (AR) and Virtual Reality (VR) are effective instructional tools in chemistry education. These technologies enhance students' conceptual understanding by transforming abstract concepts into interactive and visual representations. Through AR and VR, students can more clearly examine atomic structures, molecular geometry, and chemical processes. This enhanced visualization supports deeper comprehension, resulting in improved learning outcomes and a reduction in misconceptions. AR and VR also increase student engagement. Students show higher interest, participation, and motivation during learning activities. Interactive features encourage active learning and curiosity. As a result, students become more involved in the learning process. This literature review concludes that Augmented Reality (AR) and Virtual Reality (VR) are effective and promising technologies for

enhancing chemistry education, particularly in improving students' conceptual understanding and learning engagement. Based on the analysis of 12 national and international journal articles published between 2025 and 2026, AR and VR provide three-dimensional learning experiences that help students visualize abstract chemistry concepts, such as atomic structures, molecular geometry, and chemical processes, more effectively than conventional teaching methods. Augmented reality facilitates visualization of microscopic chemical concept, enabling students to better understand molecular structures, chemical bonding, atomic structures, and other abstract chemistry topics that are difficult to represent using conventional instructional media. As a result, these technologies contribute to better learning outcomes, increased student motivation and participation, and a reduction in misconceptions. Augmented Reality-supported learning module on chemical bonding significantly improved students' learning interest and motivation while facilitating the visualization of three-dimensional molecular structures. Overall, the findings suggest that integrating AR and VR into chemistry instruction can serve as an innovative and effective approach to support meaningful learning and improve the quality of science education.

Acknowledgments
All author would like to thank to all parties who has supported this research.

Author Contributions
Writing, reviewing and editing, A.D.; conceptualization, U.M.D.; project administration, A.M.S.; supervision, A.S.

Funding
This research received no external funding.

Conflicts of Interest
There is no conflict of interest.

References

Agussalim, H. (2025). The Role of Augmented Reality in Supporting Deep Learning within the Merdeka Curriculum: A Systematic Literature Review in Chemistry Education. *Arfak Chem: Chemistry Education Journal*, *8*(2), 772–785. https://doi.org/10.30862/accej.v8i2.1111

Ahmed, S. K., Mohammed, R. A., Nashwan, A. J., Ibrahim, R. H., Abdalla, A. Q., Ameen, B. M. M., & Khdhir, R. M. (2025). Using Thematic Analysis in Qualitative Research. *Journal of Medicine, Surgery, and Public Health*, *6*, 100198. https://doi.org/10.1016/j.glmedi.2025.100198

Akbar, R. B. W., Fadhilah, R., & Hadiarti, D. (2024). Development of Augmented Reality-Based Modules for Chemistry Bonding Materials at Taman Mulia Pontianak High School. *Jurnal Penelitian Pendidikan IPA*, *10*(12), 10109–10115. https://doi.org/10.29303/jppipa.v10i12.8507

Akçayır, M., & Akçayır, G. (2017). Advantages and Challenges Associated with Augmented Reality for Education: A Systematic Review of the Literature. *Educational Research Review*, *20*, 1–11. https://doi.org/10.1016/j.edurev.2016.11.002

Chang, H.-Y., Binali, T., Liang, J.-C., Chiou, G.-L., Cheng, K.-H., Lee, S. W.-Y., & Tsai, C.-C. (2022). Ten Years of Augmented Reality in Education: A Meta-Analysis of (Quasi-) Experimental Studies to Investigate the Impact. *Computers & Education*, *191*, 104641. https://doi.org/10.1016/j.compedu.2022.104641

Dalili, S., Yeh, C., & Qorbani, H. S. (2026). Designing for Spatial Understanding: A Virtual Reality Approach to Undergraduate Organic Chemistry. *20th International Technology, Education and Development Conference*, 1598. https://doi.org/10.21125/inted.2026.1598

Damsi, M., & Suyanto, S. (2023). Systematic Literature Review: Multiple-tier Diagnostic Instruments in Measuring Student Chemistry Misconceptions. *Jurnal Penelitian Pendidikan IPA*, *9*(5), 8–21. https://doi.org/10.29303/jppipa.v9i5.2600

Dani, A., & Zamhari, M. (2025). Developing Interactive Augmented Reality Learning Media to Introduce Chemistry Laboratory Equipment in Senior High School. *Journal of Educational Chemistry (JEC)*, *7*(1), 51–64. https://doi.org/10.21580/jec.2025.7.1.21090

Dinther, R. V., Putter, L. D., & Pepin, B. (2023). Features of Immersive Virtual Reality to Support Meaningful Chemistry Education. *Journal of Chemical Education*, *100*(4), 1537–1546. https://doi.org/10.1021/acs.jchemed.2c01069

Dunnagan, C. L., Dannenberg, D. A., Cuales, M. P., Earnest, A. D., Gurnsey, R. M., & Gallardo-Williams, M. T. (2020). Production and Evaluation of a Realistic Immersive Virtual Reality Organic Chemistry Laboratory Experience: Infrared Spectroscopy. *Journal of Chemical Education*, *97*(1), 258–262. https://doi.org/10.1021/acs.jchemed.9b00705

Elford, D., Lancaster, S. J., & Jones, G. A. (2022). Exploring the Effect of Augmented Reality on Cognitive Load, Attitude, Spatial Ability, and Stereochemical Perception. *Journal of Science Education and Technology*, *31*(3), 322–339. https://doi.org/10.1007/s10956-022-09957-0

Fadhilah, N. F., & Nasution, H. A. (2025). Development of Chemistry E-Modules Based on Augmented

Reality Technology on Hydrocarbon Material. *Jurnal Inovasi Pembelajaran Kimia*, *7*(1), 124–133. https://doi.org/10.24114/jipk.v7i1.67921

Freitas, A., Junior, A. S., Almeida, B., & Souza, C. (2026). Project-Based Learning Applied to the Development of an Augmented Reality Application for Chemistry Teaching. *20th International Technology, Education and Development Conference*, 1020. https://doi.org/10.21125/inted.2026.1020

Ghani, N. S. H. A. (2026). Integrating AugmentedReality in Chemistry Education: The Impact of the Augmented Reality Chemistry Student Investigation (AR-CSI) Module on Content Knowledge and 21st Century Skills. *Journal of Science and Mathematics Letters*, *14*(1), 46. https://doi.org/10.37134/jsml.vol14.1.5.2026

Gough, D., Oliver, S., & Thomas, J. (2017). *An Introduction to Systematic Reviews*. SAGE Publications Ltd. https://doi.org/10.4135/9781036234942

Guaya, D., Meneses, M. Á., Jaramillo-Fierro, X., & Valarezo, E. (2023). Augmented Reality: An Emergent Technology for Students' Learning Motivation for Chemical Engineering Laboratories During the COVID-19 Pandemic. *Sustainability*, *15*(6), 5175. https://doi.org/10.3390/su15065175

Ibáñez, M.-B., & Delgado-Kloos, C. (2018). Augmented Reality for STEM Learning: A Systematic Review. *Computers & Education*, *123*, 109–123. https://doi.org/10.1016/j.compedu.2018.05.002

Jaber, L. Z., & BouJaoude, S. (2012). A Macro–Micro–Symbolic Teaching to Promote Relational Understanding of Chemical Reactions. *International Journal of Science Education*, *34*(7), 973–998. https://doi.org/10.1080/09500693.2011.569959

Jia, M., Zhang, M., Du, Y., Ruan, D., & Liao, T. (2025). Construction of Application Mode of Virtual Reality (VR) Technology in Hazardous Chemistry Experiment Teaching. *Education Insights*, *2*(6), 160–167. https://doi.org/10.70088/qh6pmf60

Kljun, M., Geroimenko, V., & Pucihar, K. Č. (2020). Augmented Reality in Education: Current Status and Advancement of the Field. In V. Geroimenko (Ed.), *Augmented Reality in Education* (pp. 3–21). Springer International Publishing. https://doi.org/10.1007/978-3-030-42156-4_1

Krajcik, J., McNeill, K. L., & Reiser, B. J. (2008). Learning-Goals-Driven Design Model: Developing Curriculum Materials that Align with National Standards and Incorporate Project-Based Pedagogy. *Science Education*, *92*(1), 1–32. https://doi.org/10.1002/sce.20240

Ll, P., E, V., Cm, W., J, K., & Re, M. (2020). Use of Secondary Data Analyses in Research: Pros and Cons. *Journal of Addiction Medicine and Therapeutic Science*, 058–060. https://doi.org/10.17352/2455-3484.000039

Low, D. Y. S., Poh, P. E., & Tang, S. Y. (2022). Assessing the Impact of Augmented Reality Application on Students' Learning Motivation in Chemical Engineering. *Education for Chemical Engineers*, *39*, 31–43. https://doi.org/10.1016/j.ece.2022.02.004

Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of Virtual Reality-Based Instruction on Students' Learning Outcomes in K-12 and Higher Education: A Meta-Analysis. *Computers & Education*, *70*, 29–40. https://doi.org/10.1016/j.compedu.2013.07.033

Nahadi, N., Widarti, H. R., Shidiq, A. S., Siswaningsih, W., Nurhadi, A. R., Rahmawati, T., Nais, M. K., Anggraeni, R. D., Rifa, H. A., Chotimah, R. C., Ayuni, A. D., Aphelia, L. C., & Oktaviani, T. (2025). Development of Website-Based Creative Content as Learning Media on Molecular Geometry. *Jurnal Penelitian Pendidikan IPA*, *11*(4), 900–908. https://doi.org/10.29303/jppipa.v11i4.10116

Neji, H. A., Anari, M. I., Bayim, B. A., Agube, C. C., & Arorim, O. O. (2025). Effects of Virtual and Augmented Reality Teaching Strategies on Students' Understanding of Chemistry Practical Activities. *Faculty of Natural and Applied Sciences Journal of Mathematics, and Science Education*, *7*(2), 1–8. https://doi.org/10.63561/fnas-jmse.v7i2.1084

Nguyen, M. D., Nguyen, Q. V., Nguyen, H. K., & Cao, T. V. G. (2026). Exploring Pathways for Integrating Augmented Reality in Chemistry Teaching: Mediating TPACK Framework for Effective Instruction. *Journal of Information Technology Education: Research*, *25*, 13. https://doi.org/10.28945/5741

Ningrum, S. F., Fitriani, & Kurniasih, D. (2026). Development of Digital Comic Media on Atomic Structure Material for Grade X to Enhance Quality Education. *Jurnal Penelitian Pendidikan IPA*, *12*(3), 642–647. https://doi.org/10.29303/jppipa.v12i3.12157

Öztürk, O., Kocaman, R., & Kanbach, D. K. (2024). How to Design Bibliometric Research: An Overview and a Framework Proposal. *Review of Managerial Science*, *18*(11), 3333–3361. https://doi.org/10.1007/s11846-024-00738-0

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., … Moher, D. (2021). The PRISMA 2020 Statement: An Updated Guideline for Reporting Systematic Reviews. *BMJ*, n71. https://doi.org/10.1136/bmj.n71

Phillips, V., & Barker, E. (2021). Systematic Reviews: Structure, Form and Content. *Journal of Perioperative Practice*, *31*(9), 349–353. https://doi.org/10.1177/1750458921994693

Prasetya, F., Fortuna, A., Samala, A. D., Rawas, S., Mystakidis, S., Syahril, S., Waskito, W., Primawati, P., Wulansari, R. E., & Kassymova, G. K. (2024). The Impact of Augmented Reality Learning Experiences Based on the Motivational Design Model: A Meta-Analysis. *Social Sciences & Humanities Open*, *10*, 100926. https://doi.org/10.1016/j.ssaho.2024.100926

Raziana, E., Yamtinah, S., & Djono, D. (2025). Chemvilative: Enhancing Conceptual Understanding in Chemistry Through an Android-Based Virtual Laboratory. *Jurnal Penelitian Pendidikan IPA*, *11*(3), 678–686. https://doi.org/10.29303/jppipa.v11i3.9885

Rojas-Sánchez, M. A., Palos-Sánchez, P. R., & Folgado-Fernández, J. A. (2023). Systematic Literature Review and Bibliometric Analysis on Virtual Reality and Education. *Education and Information Technologies*, *28*(1), 155–192. https://doi.org/10.1007/s10639-022-11167-5

Sa'adi, P., Misbah, M., Arlinda, R., Harto, M., & Muhammad, N. (2024). Bibliometric Analysis: Augmented Reality in Science Education Research Trends. *Jurnal Penelitian Pendidikan IPA*, *10*(1), 12–24. https://doi.org/10.29303/jppipa.v10i1.6547

Saman, F. I., Shahbudin, F. E., & Rusmizi, M. S. (2026). Enhancing Secondary-Level Polymer Chemistry Learning with Gamified Augmented Reality: Development and Evaluation of Gameful Experience and Usability. *2026 International Conference on Cognitive Systems and Computer Interaction (ICoSCI)*, 1–5. https://doi.org/10.1109/ICoSCI66700.2026.11447709

Sari, D. R., Yamtinah, S., Ariani, S. R. D., Saputro, S., Vh, E. S., & Shidiq, A. S. (2022). Augmented Reality Media Validity based on Tetrahedral Chemical Representation with Aiken Validation Index. *Jurnal Penelitian Pendidikan IPA*, *8*(6), 3139–3145. https://doi.org/10.29303/jppipa.v8i6.2333

Shertayeva, N., Shagrayeva, B., Zhorabekova, A., Amirbekova, E., Kossauova, A., & Shertayev, Y. (2026). Methods of Utilizing Visualization and VR/AR Technologies in the Development of Chemistry Projects for 8th-Grade Students. *Journal of Technology and Science Education*, *16*(1), 233. https://doi.org/10.3926/jotse.3454

Shiddiqi, M. H. A., Arthamena, V. D., Ayyubi, M., Manarisip, A. J., & Aznam, N. (2024). Systematic Literature Review: Analysis of Misconception Problems and Diagnostic Instruments for Learning Chemistry. *Jurnal Penelitian Pendidikan IPA*, *10*(4), 168–179. https://doi.org/10.29303/jppipa.v10i4.5189

Siddaway, A. P., Wood, A. M., & Hedges, L. V. (2019). How to Do a Systematic Review: A Best Practice Guide for Conducting and Reporting Narrative Reviews, Meta-Analyses, and Meta-Syntheses. *Annual Review of Psychology*, *70*(1), 747–770. https://doi.org/10.1146/annurev-psych-010418-102803

Silva, M., Bermúdez, K., & Caro, K. (2023). Effect of an Augmented Reality App on Academic Achievement, Motivation, and Technology Acceptance of University Students of a Chemistry Course. *Computers & Education: X Reality*, *2*, 100022. https://doi.org/10.1016/j.cexr.2023.100022

Snyder, H. (2019). Literature Review as a Research Methodology: An Overview and Guidelines. *Journal of Business Research*, *104*, 333–339. https://doi.org/10.1016/j.jbusres.2019.07.039

Tania, A. P., & Sukarmin, S. (2025). Augmented Reality-Based Virtual Laboratory Application as Chemistry Learning Media for Acid-Base Titration Material. *Jurnal Eduscience (JES)*, *12*(5). https://doi.org/10.36987/jes.v12i5.7641

Trinova, Z., & Parni, P. (2026). The Integration of Virtual Reality (VR), Augmented Reality (AR), and Gamification in Developing Interactive Simulations for the Visualisation of Abstract Concepts in Science Education. *Indonesian Journal of Education (INJOE)*, *5*(2), 404-416. https://doi.org/10.5281/zenodo.19494679

Whatoni, A. S., & Sutrisno, H. (2022). Development of A Learning Module Supported by Augmented Reality on Chemical Bonding Material to Improve Interest and Motivation of Students Learning for Senior High School. *Jurnal Penelitian Pendidikan IPA*, *8*(4), 2210–2218. https://doi.org/10.29303/jppipa.v8i4.2057

Wong, C. H. S., Tsang, K. C. K., & Chiu, W.-K. (2021). Using Augmented Reality as a Powerful and Innovative Technology to Increase Enthusiasm and Enhance Student Learning in Higher Education Chemistry Courses. *Journal of Chemical Education*, *98*(11), 3476–3485. https://doi.org/10.1021/acs.jchemed.0c01029

Wu, H., Krajcik, J. S., & Soloway, E. (2001). Promoting Understanding of Chemical Representations: Students' Use of a Visualization Tool in the Classroom. *Journal of Research in Science Teaching*, *38*(7), 821–842. https://doi.org/10.1002/tea.1033

Xiao, Y., & Watson, M. (2019). Guidance on Conducting a Systematic Literature Review. *Journal of Planning Education and Research*, *39*(1), 93–112. https://doi.org/10.1177/0739456X17723971

Yamtinah, S., Vh, E. S., Saputro, S., Ariani, S. R. D., Shidiq, A. S., Sari, D. R., & Ilyasa, D. G. (2023). Augmented Reality Learning Media Based on Tetrahedral Chemical Representation: How Effective in Learning Process? *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(8), em2313. https://doi.org/10.29333/ejmste/13436

Yovanie, F. (2024). Learning Chemical Bonds in Terms of Identifying Difficulties, Misconceptions, Learning Media, and Learning Models: A Systematic Literature Review. *Jurnal Penelitian Pendidikan IPA*, *10*(6), 292–303. https://doi.org/10.29303/jppipa.v10i6.6823

Zhao, X., Ren, Y., & Cheah, K. S. L. (2023). Leading Virtual Reality (VR) and Augmented Reality (AR) in Education: Bibliometric and Content Analysis from the Web of Science (2018–2022). *Sage Open*, *13*(3), 21582440231190821. https://doi.org/10.1177/21582440231190821