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Integration of Augmented Reality in Chemistry Education to Enhance Students' Science Literacy: A Systematic Literature Review

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Abstract

Indonesia's persistently low science literacy scores in the 2022 PISA assessment highlight the urgent need for innovative approaches in chemistry education, one of which involves the integration of *Augmented Reality* (AR). This study aimed to systematically examine the effectiveness of AR integration in chemistry learning in improving students' science literacy through a *systematic literature review* (SLR) guided by the PRISMA framework. Literature searches were conducted across Scopus and Google Scholar databases using Boolean operator-based keyword combinations, initially retrieving 2,122 articles. Following deduplication, title and abstract screening, and full-text eligibility assessment, 36 articles published between 2021 and 2026 met all inclusion criteria and were included in the final analysis. Findings revealed a significant upward publication trend, particularly in 2024–2025. Research and Development designs predominated (37.8%), with interactive 3D visualization as the most widely applied AR type (32.4%) primarily on Android platforms. Acid-base chemistry, molecular structure, and atomic structure were the most frequently investigated topics. Notably, 83.3% of the reviewed articles reported that AR significantly and positively impacted science literacy and related learning outcomes. Bibliometric analysis using VOSViewer confirmed a substantial research gap between AR, chemistry education, and science literacy. This review affirms that AR represents a promising and accessible technology for improving science literacy in chemistry learning, while identifying opportunities for future studies employing more rigorous experimental designs and standardized measurement instruments.

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1. INTRODUCTION

Science literacy is a fundamental competency that determines an individual's ability to understand, interpret, and apply scientific concepts in real-life contexts (Wibowo et al., 2026). In the era of the Fourth Industrial Revolution and Society 5.0, science literacy serves as a crucial foundation for evidence-based decision-making, career development, and active participation in a knowledge-based society (Vieira & Tenreiro-Vieira, 2016). Globally, students' science literacy achievements are measured through the *Programme for International Student Assessment* (PISA), designed by the OECD to evaluate the ability of 15-year-old students to apply science in real-life contexts. The 2022 PISA results show that Indonesia ranked 68th out of 81 participating countries with a science literacy score of 383, far below the OECD average of 485, indicating that Indonesian students' science literacy skills still require serious attention and innovative learning interventions (OECD, 2023a). This outcome does not stand alone but is closely linked to the quality of the science learning process in schools, particularly in subjects that directly shape science literacy competencies, such as chemistry (Guo et al., 2022).

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Chemistry is a branch of science that studies the composition, structure, properties, and changes of matter, as well as the energy involved in these processes, encompassing three main levels of representation: macroscopic, microscopic, and symbolic (Harianto & Khery, 2017). It is the complexity of these three levels of representation that makes chemistry a subject considered difficult by most high school students. The difficulty in understanding abstract and invisible chemical concepts leads students to tend to merely memorize rather than build meaningful understanding, thereby hindering the achievement of true science literacy (Afrianti et al., 2025). Furthermore, the use of monotonous, teacher-centered teaching methods exacerbates students' low interest and engagement in the chemistry learning process (Prayunisa, 2022). This situation has driven educators and researchers alike to explore more innovative instructional approaches that can bring abstract chemical concepts to life in ways that are both concrete and contextually meaningful for students.

In response to these challenges, advancements in information and communication technology are opening up new opportunities for a more meaningful transformation of chemistry education (Liu et al., 2022). One technological innovation showing great potential in this context is Augmented Reality (AR). AR is a technology that integrates two-dimensional and three-dimensional virtual objects into the real environment directly and in real time, thereby creating a more contextual and immersive learning experience (Firdanu et al., 2020). In the context of science education, AR has proven capable of visualizing abstract concepts more realistically, thereby facilitating student understanding (Wulandari & Darmana, 2026). Various empirical studies have confirmed the effectiveness of AR in chemistry education, including in enhancing motivation and understanding of acid-base concepts (Domínguez Alfaro et al., 2022), facilitating the three-dimensional visualization of molecular structures (Levy et al., 2024), and improving learning outcomes on abstract chemistry topics (Afrianti et al., 2025). Adding to this, Guo et al. (2022) found that students' interest in technology, their independence in using it, and the availability of technological facilities at school have a significant positive impact on science literacy achievement.

Although the use of AR in chemistry education has been extensively studied, research specifically linking the implementation of AR to improvements in students' science literacy in the context of chemistry education remains very limited. The results of bibliometric mapping using VOSViewer on Scopus-indexed articles in this study indicate that the keywords "scientific literacy" and "science literacy" were not identified in the keyword co-occurrence network, although the keywords "augmented reality," "chemistry education," and "chemistry learning" emerged as dominant nodes. This visually indicates that the connection between AR, chemistry learning, and science literacy has not received adequate attention in the existing literature. This finding aligns with the bibliometric study by Wibowo et al. (2026), which analyzed 77 Scopus documents from 2018–2025 and concluded that the systematic integration of AR and science literacy within the context of science education remains underexplored, with research contributions from Indonesia still being very limited. Wibowo et al. (2026) explicitly acknowledge the limitations of their study, which did not include Indonesian-language literature and did not specifically address the context of chemistry learning. This gap is further reinforced by the fact that, of all the Scopus-indexed articles identified in this study, only two explicitly linked AR to science literacy in the context of chemistry education. The underrepresentation of Indonesian-language literature in existing international reviews is particularly significant given that Indonesia ranks among the lowest-performing countries in science literacy based on the 2022 PISA assessment, making locally produced research an essential source of context-specific evidence that global databases alone cannot provide. Therefore, a systematic review is needed that specifically synthesizes empirical evidence regarding the effectiveness of integrating AR into chemistry learning to improve science literacy among secondary school students, including from Indonesian-language literature, which has so far been underrepresented in international studies.

Based on the identified research gaps, this study aims to systematically examine the effectiveness of integrating Augmented Reality into chemistry instruction on improving students' science literacy through a synthesis of selected empirical research articles from 2021 to 2026 drawn from the Scopus and Google Scholar

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databases. To achieve this objective, this study formulates five research questions:

- **RQ1:** What is the distribution of publication trends and methodological characteristics of research on the integration of Augmented Reality in chemistry education published between 2021 and 2026?
- **RQ2:** What are the most commonly used types of Augmented Reality and device platforms in AR-based chemistry education research?
- **RQ3:** What chemistry topics are most frequently studied in Augmented Reality-based chemistry education research?
- **RQ4:** How effective is the use of Augmented Reality in chemistry education in improving students' science literacy?
- **RQ5:** What research trends and research gaps have been identified in studies on the integration of Augmented Reality with science literacy in chemistry education?

This study is expected to provide a comprehensive overview of trends, effectiveness, and remaining research gaps in this field, while also serving as a reference for educators, educational media developers, and researchers in designing AR-based chemistry learning strategies aimed at strengthening students' science literacy.

2. METHOD

This study employs a systematic literature review (SLR) approach that follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (Page et al., 2021) as a framework for systematic and transparent reporting. This approach was chosen because it allows for a comprehensive and replicable synthesis of scattered empirical evidence regarding the integration of Augmented Reality in chemistry learning to answer the five research questions formulated in this study (Snyder, 2019). Additionally, bibliometric analysis was conducted using VOSViewer software to map keyword co-occurrence networks to identify research trends and remaining research gaps (van Eck & Waltman, 2010).

A literature search was conducted in two major databases, Scopus and Google Scholar, in April 2026. The search strategy employed a combination of Boolean operator-based keywords tailored to the characteristics of each database. For the Scopus database, two combined queries were used, namely: (1) ("Augmented Reality") AND ("chemistry education" OR "chemistry learning") AND ("learning outcomes" OR "conceptual understanding" OR "motivation" OR "student achievement" OR 'STEM'), and (2) ("Augmented Reality") AND ("science education" OR "chemistry education" OR "chemistry learning" OR "STEM education") AND ("science literacy" OR "scientific literacy" OR "science achievement" OR "conceptual understanding"). As for the Google Scholar database, the search was conducted in three stages using the following query: (1) "Augmented Reality" "chemistry education" "scientific literacy"; (2) "Augmented Reality" "pembelajaran kimia" "literasi sains" (*Indonesian*); and (3) "Augmented Reality" "kimia" "literasi sains" (*Indonesian*).

The retrieved articles were then screened based on the inclusion and exclusion criteria established prior to the search, as presented in Table 1.

Table 1. Inclusion and exclusion criteria for articles in the study

Aspect	Inclusion	Exclusion
Document Type	Peer-reviewed research articles	Conference proceedings, books, book chapters, review articles, editorials, theses
Publication Year	2021-2026	Outside the specified year range
Language	English and Indonesian	Other than English and Indonesian
Indexing	Scopus / Sinta 1-6	Not indexed
Topic Relevance	AR in chemistry education measuring science literacy	Outside the context of chemistry or science education

The inclusion of articles from SINTA-indexed journals (levels 1–6) was intentionally designed to capture locally produced Indonesian research that is frequently underrepresented in international databases such as Scopus, yet contributes valuable contextual insights into AR-based chemistry learning within the Indonesian educational setting. To ensure methodological rigor across all included sources, a quality assessment was applied during the full-text eligibility stage. Specifically, articles from lower-ranked SINTA journals were evaluated against three criteria: (1) clear articulation of research objectives and methodology, (2) use of validated or expert-validated instruments, and (3) presentation of quantitative or qualitative results with

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sufficient detail for data extraction. Articles that did not meet these criteria were excluded regardless of their indexing level, ensuring that the synthesis was based on scientifically credible evidence across all accreditation tiers. The selection process was conducted in four stages in accordance with the PRISMA flowchart. First, the identification stage yielded a total of 2,122 articles, consisting of 33 articles from Scopus after applying filters for document type, year, and language, as well as 2,089 articles from Google Scholar obtained from three search queries, namely 742 English-language articles, 355 Indonesian-language articles from the second query, and 992 Indonesian-language articles from the third query. Second, duplicate articles were removed using Mendeley, resulting in 2,113 unique articles proceeding to the next stage. Third, screening based on titles and abstracts was conducted to filter out articles irrelevant to the research topic, yielding 42 articles that passed this stage. Fourth, a full-text eligibility assessment was carried out to verify that each article's methodology and content aligned with the established criteria, from which 36 articles were found to meet all criteria and were included in the final analysis. All stages of the selection process are visualized in the PRISMA Flow Diagram as presented in Figure 1.

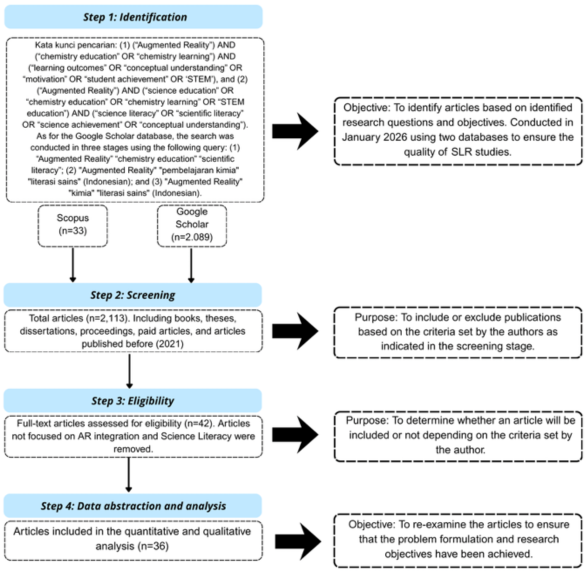

Figure 1. PRISMA flow diagram of the systematic literature review process

A bibliometric analysis was conducted using VOSViewer software version 1.6.20 on Scopus-indexed articles (n=26) obtained from the search phase. Only Scopus-indexed articles were included in the bibliometric analysis to ensure data standardization and metadata consistency, as Scopus provides structured keyword fields essential for co-occurrence network mapping, while the full set of 36 articles was used for the broader systematic review and synthesis. The analysis used the co-occurrence method with author keywords as the unit of analysis and a minimum occurrences threshold of 2. The mapping results showed that the keywords "augmented reality," "chemistry education," and "chemistry learning" emerged as dominant nodes in the network, while the keywords "scientific literacy" and "science literacy" were not identified in the co-occurrence network. This visually confirms the existence of a significant research gap between the use of AR in chemistry learning and the measurement of students' science literacy. The keyword co-occurrence map resulting from the VOSViewer analysis is presented in Figure 2.

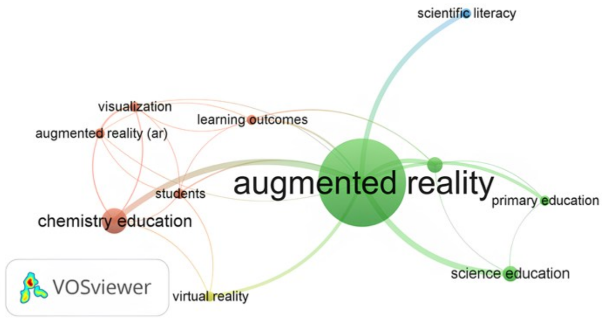

Figure 2. Map of keyword co-occurrence from the VOSViewer analysis

3. RESULT AND DISCUSSION

1. Characteristics

a. Number of Publications per Year

This study identified 36 research articles that met all inclusion criteria and were published between 2021 and 2026. The distribution of publications by year shows a significant upward trend, as illustrated in Figure 3.

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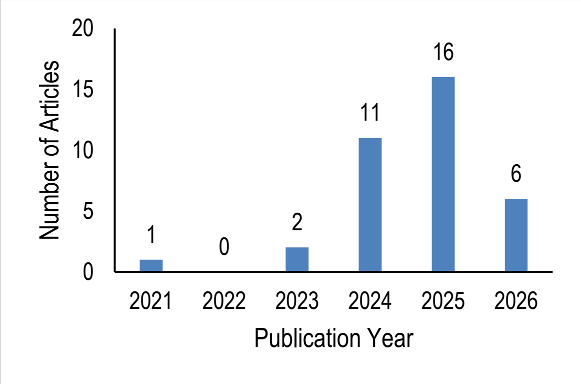

Figure 3. Number of publications per year on AR integration in chemistry learning (2021–2026)

The sharpest increase occurred in 2025 with 16 articles (43.2%), followed by 2024 with 11 articles (29.7%). In 2026, although data is not yet fully available because this study was conducted in April 2026, there are already 6 articles that meet the criteria (16.2%). Meanwhile, 2023 contributed 2 articles (5.4%) and 2021 contributed 1 article (2.7%). No articles meeting the criteria were found from 2022 in this study.

This growth trend aligns with the acceleration of digital transformation in the field of education following the COVID-19 pandemic, which has prompted researchers and educators to explore immersive technologies as an alternative to limited in-person learning (Wibowo et al., 2026). The increasing availability of affordable smartphones and easy access to AR development platforms such as Unity and Vuforia have also contributed to the growing number of studies in this field in recent years (Zhang & Yao, 2025).

b. Articles Selected and Analyzed

All analyzed articles are summarized in Table 2, which presents the key characteristics of each study, encompassing research design, type of AR employed, device platform, chemistry topic, measured variables, and main findings. Based on the analysis of these 36 articles, considerable diversity was identified in terms of methodology, technological approaches, and the breadth of chemistry topics examined.

Table 2. Characteristics of articles analyzed in the systematic literature review

Research Design	Type of AR	Platform	Chemistry Topic	Measured Variable	Main Finding	Reference
R&D (ADDIE)	AR-integrated e-module	Canva / Unity Hub	Circulatory system	Science literacy & critical thinking	Enhanced conceptual understanding of health-related chemistry issues	(Saragih & Pratama, 2026)
R&D (4D)	E-LAPD AR	Smartphone	Molecular structure	Visual-spatial intelligence	Improved visual-spatial intelligence in learning molecular structure	(Permatasari et al., 2026)
Mixed-method	3D interactive visualization	Android / iOS	Thermodynamics	Critical thinking	Significantly improved critical thinking and conceptual understanding	(Haryadi et al., 2026)
Experimental	3D interactive visualization	Smartphone & PC	Molecular structure, bonding, acid-base	Conceptual understanding, motivation	Enhanced motivation and deeper understanding across multiple chemistry topics	(Shertayeva et al., 2026)
R&D (ADDIE)	AR-integrated e-module	Laptop & Smartphone	Chemical bonding	Practicality	Supported interactive and contextual chemistry learning	(Wulandari & Darmana, 2026)
R&D (ADDIE)	Interactive digital AR	Smartphone	Biology-chemistry (local context)	Science literacy & engagement	Improved science literacy and appreciation of local cultural heritage	(Ramdiah et al., 2026)

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Research Design	Type of AR	Platform	Chemistry Topic	Measured Variable	Main Finding	Reference
Quasi-experimental	Marker-based AR (3D)	Smartphone	Acid-base, pH, oxides, salts	Learning outcomes, motivation, understanding	AR effectively improved learning outcomes and student motivation	(Ngoc Son et al., 2025)
R&D (ADDIE)	AR Smart-DIL	Android / iOS	Hydrocarbons & environmental pollution	Socioscientific reasoning, critical thinking	Improved socioscientific reasoning and 21st-century skills	(Nababan et al., 2025)
R&D (4D)	Phenomenon-based AR organizer	Visual media & module	Petroleum	Device validity & science literacy	Highly valid (Aiken's V = 0.86); supports science literacy development	(Widowati et al., 2025)
Quasi-experimental	Marker-based AR	Android	Atomic structure	Learning outcomes & motivation	AR significantly improved learning outcomes and motivation over control group	(Amdayani et al., 2025)
R&D	Marker-based AR	Android	Stereochemistry	Metacognitive skills & science literacy	Valid (4.46) and highly practical (4.75); improved science literacy	(Prasetyo et al., 2025)
Pre-experimental	3D visualization AR	Android	Acid-base	Digital science literacy	Effective; average 81.4% (good category), N-gain = 0.703 (moderate)	(Hafiza et al., 2025)
Quasi-experimental	3D visualization AR	Smartphone / PC	Chemical bonding	Critical thinking, creativity, science literacy	SCCrT+AR significantly improved critical thinking and science literacy simultaneously	(Saadi et al., 2025)
Community service	Metaschool AR (3D objects)	Assemblr Edu / Smartphone	Molecular structure & bonding	Teachers' AR literacy & digital skills	Improved teachers' competency in developing AR-based learning media	(Sari & Damanik, 2025)
Quasi-experimental	Digital flipbook	Web / Smartphone	Analytical chemistry	Critical thinking & science literacy	PjBL-based flipbook more effective than conventional textbooks	(Sari et al., 2025)
Community service	Unity-based 3D AR	Unity / Android	Fundamentals of AR	Technology literacy	Significantly improved AR understanding and Unity-based development skills	(Najib et al., 2025)
Community service	Ethnoscience AR + AI	Smartphone	Distillation	Science literacy	Ethnoscience-integrated AR and AI effectively improved science literacy	(Akbar et al., 2025)
Mixed methods	SSI-AR simulation	Microteaching lab	Socioscientific issues	Scientific argumentation	SSI-AR effectively improved scientific argumentation skills	(Nugraha et al., 2025)
R&D (ADDIE)	AR-integrated digital module (MODUSA)	Smartphone (Unity & Canva)	Acid-base concepts	Conceptual understanding	Significant improvement in conceptual understanding (Sig. 0.000 < 0.05); N-gain index 0.56	(Rahayu et al., 2025)

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Research Design	Type of AR	Platform	Chemistry Topic	Measured Variable	Main Finding	Reference
					(moderate category); module validation score 87.65%; students reported positive responses on design (94.33%), accessibility (91%), and functionality (92.83%)	
Systematic review	Marker & location-based AR	Unity3D / Android	Organic & inorganic chemistry	AR trends, benefits, challenges	AR improved motivation; implementation constrained by infrastructure and device limits	(Zhang & Yao, 2025)
Quantitative descriptive	Non-AR (literacy assessment)	-	Colligative properties of solutions	Science literacy (epistemic knowledge)	Average science literacy 73.3% (sufficient); highest on explaining scientific process	(Ulwan et al., 2024)
R&D (Borg & Gall)	AR-based e-learning	Android	Atomic structure & chemical equilibrium	Literacy & numeracy	Highly feasible; AR improved literacy and numeracy over conventional approach	(Cahyana et al., 2024)
R&D (ADDIE)	AR-based printed book	Android	Chemical bonding	Media feasibility & literacy	Highly feasible; AR supported abstract concept comprehension in chemical bonding	(Yuendita & Dina, 2024)
Quantitative	Interactive AR application	Smartphone / tablet	Acid-base titration	Science literacy & conceptual understanding	Improved science literacy and conceptual understanding; positive learning experience	(Kartini et al., 2024)
R&D (ASSURE)	AR interactive card	Android	Atomic structure	Learning outcomes & conceptual understanding	Significant improvement in learning outcomes and conceptual understanding	(Aminudin et al., 2024)
Quasi-experimental	Mobile AR (inquiry-based)	Smartphone / tablet	Hydrocarbons	Science process skills	Inquiry-based mobile AR improved science process skills and conceptual mastery	(Setiawaty et al., 2024)
Quantitative	Tablet-based AR	iPad	Polymer chemistry	Learning interest & conceptual understanding	AR improved student interest and engagement in polymer chemistry learning	(Syskowski, Lathwesen, Kanbur, et al., 2024)
Qualitative	Virtual laboratory AR	Smartphone	General chemistry experiments	Science process skills	Technology-enhanced virtual lab improved science process skills in chemistry	(Wang, 2024)
Mixed methods	Zap AR (audio-visual)	Smartphone / tablet	Electrochemistry (electrolysis)	Science literacy & conceptual understanding	AR perceived as more engaging than conventional	(Syskowski, Lathwesen,

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Research Design	Type of AR	Platform	Chemistry Topic	Measured Variable	Main Finding	Reference
					methods; improved science literacy	Maurer, et al., 2024)
Quasi-experimental	Marker-based AR	Android / Web	Environmental chemistry	Science literacy	STEAM-integrated marker-based AR significantly enhanced students' science literacy	(Asyri & Asyri, 2024)
R&D (ADDIE) + Quasi-experimental	AR-integrated SSI content (CHEMICLE)	Smartphone (Corel Draw X7)	Chemical bonding (ionic, covalent, metallic)	Chemical literacy skills	Significant difference between experiment and control class (ANCOVA sig. 0.012 < 0.05); experiment class post-test mean 80.06 vs. control 71.34; material validation 91.58%, media validation 91.33%, student response 91.57%	(Sulistina & Hasanah, 2024)
Training implementation	AR simulation	Science classroom	Simulations & modeling	Pre-service teachers' competency	AR integration in teacher training essential for developing science teachers' skills	(Krug et al., 2023)
R&D (ADDIE)	AR-based e-module	Mobile	Molecular geometry & intermolecular interactions	Conceptual understanding (multiple representations)	AR e-module facilitated understanding through macro-micro-symbolic representations	(Aulia et al., 2023)
Experimental	AR virtual experiment	Mobile	Daniell cell (electrochemistry)	Conceptual understanding	AR virtual experiment successfully visualized abstract electrochemical reactions	(Tarng et al., 2021)
R&D (ADDIE)	AR-integrated interactive e-module	Web / Mobile	Buffer solution	Science literacy & learning independence	Valid, practical, and effective in improving science literacy and learning independence	(Khairani et al., 2025)
R&D	Marker-based AR	Android	Molecular structure & ethnochemistry	Science literacy & problem-solving	Ethnoscience-integrated AR significantly improved science literacy and problem-solving	(Hadisaputra et al., 2025)

In terms of research design, the Research and Development (R&D) approach dominated with 14 articles (37.8%), reflecting the research community's focus on the development and validation of AR-based educational media products. The quasi-experimental design ranked second with 6 articles (16.2%), followed by community service activities with 4 articles (10.8%), mixed-method and quantitative designs with 3 articles each (8.1%), experimental and pre-experimental designs with 2 articles each (5.4%), and qualitative designs with 1 article each (2.8%).

2. Types of AR Used in Chemistry Learning

An analysis of the types of AR used in 36 articles reveals a diversity of technological approaches that reflects the rapid pace of innovation in this field. Interactive 3D visualization was the most commonly used

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type, appearing in 12 articles (32.4%). This technology allows students to interact directly with three-dimensional representations of invisible chemical concepts, such as molecular structures, chemical bonds, and reaction mechanisms, making learning much more concrete and meaningful (Aulia et al., 2023; Shertayeva et al., 2026).

Marker-based AR ranked second with 6 articles (16.2%). This approach uses physical markers in the form of cards or images that, when aimed at by a device's camera, display virtual objects on top of them. The advantage of marker-based AR lies in its ease of implementation in conventional classrooms without requiring complex infrastructure, making it highly relevant for the context of secondary schools in Indonesia (Amdayani et al., 2025; Asyri & Asyri, 2024). AR-based e-modules were developed in 4 articles (10.8%), AR virtual labs in 2 articles (5.4%), and AR simulations and mobile AR in 1 article each (2.7%). There were also 4 articles (10.8%) that used interactive digital media other than pure AR, yet remained relevant as they discussed the development of science literacy within the context of technology-assisted chemistry learning.

In terms of platforms, Android-based smartphones dominate the implementation, accounting for a total of 20 articles (54.1%) when combining those that specifically mention Android and those that refer to smartphones in general. The high usage of the Android platform reflects a broader level of accessibility among students, particularly in developing countries like Indonesia, making Android-based AR implementation considered more inclusive and realistic for deployment on a larger scale (Ngoc Son et al., 2025). Two articles used both Android and iOS platforms simultaneously, while the remainder utilized iPads, web browsers, or a combination of web and mobile platforms.

3. Chemistry Topics in AR-Based Learning

A review of the scope of chemistry topics taught revealed wide variation, indicating that AR has the potential to be applied across various topics in the chemistry curriculum. Acid-base concepts, pH, and titration were the most frequently studied topics, appearing in 5 articles (13.9%). This is understandable given that the chemical processes in acid-base reactions occur at a submicroscopic level that cannot be observed directly, so AR visualization provides significant added value in helping students build accurate mental representations (Kartini et al., 2024; Ngoc Son et al., 2025).

Molecular structures and chemical bonds were examined in 3 articles each (8.1%), followed by atomic structures in 3 articles (8.1%). These topics are inherently abstract and exist at a microscopic level that is difficult to visualize through conventional media; thus, the use of AR in the form of interactive 3D visualization makes a very significant contribution to students' conceptual understanding (Aminudin et al., 2024; Permatasari et al., 2026). Other topics such as electrochemistry, hydrocarbons, polymer chemistry, and buffer solutions were each examined in 2 articles (5.4%), while thermodynamics, stereochemistry, organic chemistry, environmental chemistry, and chemical ethnoscience were each discussed in 1 article.

This diversity of topics simultaneously reveals a notable imbalance in the existing literature, where AR research in chemistry education remains heavily concentrated on subjects perceived as the most abstract, while other equally complex topics such as chemical kinetics, chemical equilibrium, and thermochemistry have received very little attention from an AR-based instructional perspective. This gap represents a substantial opportunity for future research endeavors aimed at developing and empirically testing the effectiveness of AR across a broader range of chemistry topics that have yet to be meaningfully explored.

4. Effectiveness of AR in Improving Science Literacy

An analysis of the measured variables and key findings from 36 articles provides a promising picture of the effectiveness of AR in the context of chemistry learning. A total of 19 articles (52.8%) explicitly measured science literacy or its components as the dependent variable, while other variables examined included conceptual understanding, cognitive learning outcomes, learning motivation, critical thinking, science process skills, as well as the suitability and practicality of the media. Overall, 31 of the 36 articles (83.3%) reported positive outcomes associated with AR implementation in chemistry learning. It should be noted that this figure reflects the frequency of studies reporting statistically significant improvements rather than a pooled effect size, given that a formal meta-analysis was not conducted due to the considerable heterogeneity in research designs, outcome measures, and assessment instruments across the included studies.

Among the articles that explicitly measure science literacy, Saadi et al. (2025) found that the AR-assisted SCCrT learning model for chemical bonding significantly improved students’ critical thinking, creative thinking, and science literacy simultaneously compared to conventional learning. In line with this, Asyri & Asyri (2024) reported that a marker-based AR-assisted STEAM approach to environmental chemistry material was able to create an immersive learning environment that tangibly improved students’ science literacy scores. Meanwhile, Hadisaputra et al. (2025) demonstrated that integrating 3D molecular visualization with local ethnoscience contexts via AR effectively contextualizes abstract concepts, thereby significantly boosting students’ science literacy and problem-solving skills. Hafiza et al. (2025) also reported that 3D visualization-based AR in acid-base material effectively improves students’ digital science literacy with an average achievement of 81.4% (good category) and an N-gain score of 0.703 (moderate category). In a related vein, (Sulistina & Hasanah, 2024) demonstrated that AR-integrated socio-scientific issues content on chemical bonding significantly improved students' chemical literacy skills, with the experimental class post-test mean (80.06) substantially exceeding that of the control class (71.34) (ANCOVA sig. = 0.012)

The effectiveness of AR in enhancing science literacy can be understood through several interrelated mechanisms. AR facilitates the simultaneous presentation of multiple representations of chemical concepts, encompassing the macroscopic, microscopic, and symbolic levels that constitute the three essential representational dimensions in chemical literacy (Aulia et al., 2023). Beyond this, the interactive nature of AR encourages students' active engagement throughout the learning process, which in turn strengthens their ability to apply scientific knowledge in real-life contexts as one of the core competencies within the PISA science literacy framework (OECD, 2023b). The 3D visualizations generated by AR further assist students in constructing more accurate mental models of chemical phenomena that are invisible to the naked eye, allowing misconceptions to be progressively minimized while simultaneously deepening the quality of their scientific reasoning (Shertayeva et al., 2026).

These mechanisms find strong theoretical grounding in several established learning frameworks. The capacity of AR to simultaneously present visual and verbal representations of chemical phenomena aligns with Mayer's Cognitive Theory of Multimedia Learning, which posits that learning is deepened when information is processed through both visual and auditory channels in a coordinated manner (Mayer, 2009). Furthermore, the facilitation of macroscopic, microscopic, and symbolic representations through AR is consistent with the chemistry triplet framework, which underscores the importance of connecting macroscopic, submicroscopic, and symbolic levels of chemical representation to build meaningful conceptual understanding, as the inability to integrate these three levels often underlies students' persistent difficulties in chemistry (Talanquer, 2022). Additionally, the active and exploratory nature of AR interactions supports a constructivist perspective, in which students construct knowledge through direct engagement with the learning environment rather than passive reception of information (Vygotsky, 1980). Together, these theoretical lenses reinforce the empirical evidence gathered in this review and help explain why AR consistently demonstrates positive effects on students' science literacy across diverse chemistry topics and instructional contexts.

5. Research Trends and Gaps

While the overall findings point to the effectiveness of AR in chemistry learning, a closer examination of the 36 reviewed articles reveals several methodological and thematic gaps that warrant further attention from the research community. First, as confirmed by the VOSViewer keyword co-occurrence map (Figure 2), the connections between AR, chemistry education, and science literacy remain very weak within the existing research network. Of all the articles analyzed, only a small fraction explicitly designed their research with science literacy as the primary variable using comprehensively validated instruments. The majority of studies still measure proxy variables such as conceptual understanding or cognitive learning outcomes, which do not necessarily reflect the construct of science literacy holistically according to the PISA framework.

Beyond the identified research gaps, the reviewed studies also highlight several recurring challenges encountered during AR implementation in chemistry classrooms that warrant systematic attention.

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Technical constraints emerged as the most frequently reported barrier, including device compatibility issues, limited battery life during extended AR sessions, and the need for stable internet connectivity in schools with inadequate infrastructure, particularly in rural Indonesian settings. Several studies also noted that students with limited digital technology experience required additional orientation time before engaging productively with AR applications, which in some cases reduced the instructional time available for chemistry content delivery. From a pedagogical standpoint, a number of researchers noted the difficulty of balancing the visual appeal of AR with the depth of scientific content, as the engaging nature of AR visualizations occasionally drew students' attention away from the underlying conceptual learning objectives. These implementation challenges underscore the importance of designing AR applications that are not only technically robust but also pedagogically grounded, ensuring that the technology serves as a vehicle for meaningful chemistry learning rather than a novelty that competes with it.

In addition to these implementation challenges, the widespread reliance on R&D designs without adequate effectiveness testing constitutes a notable methodological limitation in the body of research analyzed. Experimental research using quasi-experimental or randomized controlled trial designs that include a control group is still urgently needed to provide more convincing evidence of causality regarding the impact of AR on science literacy. The scope of the chemistry material examined remains focused on specific topics, while many other equally abstract topics have not yet received attention from an AR approach perspective. On the other hand, research integrating AR with the cultural context and local wisdom of Indonesia, as pioneered by Akbar et al. (2025) and Hadisaputra et al. (2025) through an ethnoscience approach, remains very limited, even though such an approach is highly relevant for enhancing the contextualization and meaningfulness of chemistry learning for Indonesian students.

A cross the 36 reviewed studies, the evidence gathered across these 36 studies carries meaningful practical implications for a range of stakeholders in chemistry education. For educators, the results affirm that AR, particularly interactive 3D visualization and marker-based AR implemented on Android platforms, represents an affordable yet empirically supported technology option that can be incorporated into everyday chemistry instruction without demanding costly infrastructure. For learning media developers, the gaps identified throughout this review point to the pressing need to design AR applications that are explicitly oriented toward building students' science literacy competencies in accordance with the PISA framework, rather than merely presenting visually appealing concept demonstrations. For researchers, this review opens extensive avenues for future investigation, especially studies employing more rigorous experimental designs, internationally standardized science literacy instruments, and broader thematic coverage of chemistry topics that have yet to be meaningfully explored through AR-based instructional approaches.

4. CONCLUSION

This systematic review synthesized 36 empirical research articles from 2021 to 2026 that examined the integration of Augmented Reality in chemistry education. The analysis results indicate a significant growth trend in publications, particularly in 2024–2025, with Research and Development design as the most dominant approach (37.8%), interactive 3D visualization as the most widely used type of AR (32.4%) on the Android platform, and acid-base chemistry and molecular structures as the most frequently studied chemistry topics.

Of the 36 articles analyzed, 83.3% reported positive outcomes associated with AR implementation in chemistry learning. However, it is important to draw a clear distinction between direct and indirect evidence of science literacy improvement. Among the 19 articles (52.8%) that explicitly measured science literacy as the primary dependent variable, all reported statistically significant improvements following AR integration, providing direct empirical support for the effectiveness of AR in this regard. The remaining articles measured related but distinct variables such as conceptual understanding, learning motivation, and science process skills, which constitute indirect evidence that is nonetheless indicative of AR's broader contribution to the development of science literacy competencies. This distinction underscores the need for future studies to adopt standardized, comprehensive science literacy instruments aligned with the PISA framework, rather than relying solely on proximal learning outcome measures.

Nevertheless, bibliometric analysis using VOSViewer confirms that the connections between AR, chemistry education, and science literacy remain very weak within the existing research network. Future research is recommended to employ a more rigorous experimental design, adopt standardized science literacy instruments based on the PISA framework, and broaden the thematic scope of chemistry topics investigated, while also incorporating local cultural knowledge and ethnoscience contexts into AR-based chemistry learning designs.

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6. REFERENCES

Afrianti, Savalas, L. R. T., & Hidayanti, E. (2025). Analisis Kesulitan Belajar Siswa dalam Memahami Konsep Kimia Laju Reaksi Kelas XI IPA SMA Negeri 1 Labuapi. *Chemistry Education Practice*, *8*(1), 233–240. https://doi.org/10.29303/cep.v8i1.9083

Akbar, J. S., Rumengan, S. M., Mokalu, Y. B., Akbar, A. F., & others. (2025). Pembuatan Disertai Pelatihan Inovasi Alat Praktikum Destilator Elektrik Terintegrasi Augmented Reality Berbasis Etnosains Berbantuan AI Pada Siswa MAK Madani Manado. *Jurnal Pengabdian Masyarakat Dan Riset Pendidikan*, *4*(2), 11651–11657.

Amdayani, S., Dibyantini, R. E., Syafriani, D., & Dalimunthe, M. (2025). Development of STEM-PjBL-Based Teaching Materials to Enhance Students' Science Literacy on Acid-Base Topic. *Jurnal Pendidikan MIPA*, *26*(3), 1289–1307.

Aminudin, N., Mutmainah, M., & others. (2024). Implementasi Teknologi Augmented Reality dalam Sains berbasis Android dengan Kartu Interaktif. *Jurnal Teknologi Terpadu*, *10*(2), 134–141.

Asyri, D., & Asyri, D. (2024). The Effectiveness of STEAM-Based Augmented Reality in Improving Students' Science Literacy Skills. *JKTP: Jurnal Kajian Teknologi Pendidikan*, *7*(4), 229–237.

Aulia, S., Linda, R., & others. (2023). Development of Multiple Representation-Based E-Modules Utilizing Augmented Reality in the Material of Molecular Shapes and Inter-Molecular Interactions. *AL-ISHLAH: Jurnal Pendidikan*, *15*(4), 6249–6261.

Cahyana, U., Lestari, I., Irwanto, I., & Suroso, J. (2024). Development of a mobile learning network for science with augmented reality and its impact on students' literacy and numeracy. *International Journal of Innovative Research and Scientific Studies*, *7*(2), 576–586.

Domínguez Alfaro, J. L., Gantois, S., Blattgerste, J., De Croon, R., Verbert, K., Pfeiffer, T., & Van Puyvelde, P. (2022). Mobile Augmented Reality Laboratory for Learning Acid–Base Titration. *Journal of Chemical Education*, *99*(2), 531–537. https://doi.org/10.1021/acs.jchemed.1c00894

Firdanu, R., Achmadi, S., & Adi Wibowo, S. (2020). Pemanfaatan Augmented Reality sebagai Media Pembelajaran mengenai Peralatan Konstruksi dalam Dunia Pendidikan Berbasis Android. *JATI (Jurnal Mahasiswa Teknik Informatika)*, *4*(2), 276–282. https://doi.org/10.36040/jati.v4i2.2657

Guo, Q., Qiao, C., & Ibrahim, B. (2022). The Mechanism of Influence Between ICT and Students' Science Literacy: a Hierarchical and Structural Equation Modelling Study. *Journal of Science Education and Technology*, *31*(2), 272–288. https://doi.org/10.1007/s10956-021-09954-9

Hadisaputra, S., Andayani, Y., Burhanuddin, A. H., & Irawan, J. (2025). Enhancing Scientific Literacy through Augmented Reality in Ethnochemistry: Exploring Students' Perceptions in Sasambo Cultural Context. *International Journal of Information and Education Technology*, *15*(11), 2538–2545.

Hafiza, U., Yerimadesi, Y., Andromeda, A., Arsih, F., Hendri, J., & Zuwita, A. (2025). Efektivitas media pembelajaran asam basa terintegrasi augmented reality terhadap literasi digital peserta didik. *Journal of Chemistry Education and Integration*, *4*(2), 75–86.

Harianto, A., & Khery, Y. (2017). PENGEMBANGAN MEDIA PEMBELAJARAN KIMIA BERBASIS ANDROID UNTUK PENUMBUHAN LITERASI SAINS SISWA PADA MATERI REAKSI REDOKS DAN ELEKTROKIMIA. *Hydrogen: Jurnal Kependidikan Kimia*, *5*(2), 35–47. http://ojs.ikipmataram.ac.id/index.php/hydrogen/index

Haryadi, R., Pujiastuti, H., & Utomo, D. W. (2026). Interactive visualization of thermodynamic concepts through augmented reality to improve critical thinking. *Computers and Education: X Reality*, *8*. https://doi.org/10.1016/j.cexr.2026.100137

Kartini, K. S., Yusa, I. M. M., Adnyana, I. N. W., & Putra, I. N. T. A. (2024). Impact of augmented reality on high school students' motivation and understanding of acid-base titration concepts. *Edelweiss Applied Science and Technology*, *8*(6), 7559–7569. https://doi.org/10.55214/25768484.v8i6.3638

Khairani, A., Zamsiswaya, Z., & Fauzi, I. M. (2025). Development of an E-Module Based on Multiple Representation Integrated with Islamic Education to Improve Scientific Literacy and Learning Independence of Students on Buffer Solution Material. *Journal of Natural Science and Integration*, *8*(2), 364–380.

Krug, M., Thoms, L.-J., & Huwer, J. (2023). Augmented reality in the science classroom—Implementing pre-service teacher training in the competency area of simulation and modeling according to the DiKoLAN framework. *Education Sciences*, *13*(10), 1016.

Levy, J., Chagunda, I. C., Iosub, V., Leitch, D. C., & McIndoe, J. S. (2024). MoleculAR: An Augmented Reality Application for Understanding 3D Geometry. *Journal of Chemical Education*, *101*(6), 2533–2539. https://doi.org/10.1021/acs.jchemed.3c01045

Liu, Q., Ma, J., Yu, S., Wang, Q., & Xu, S. (2022). Effects of an Augmented Reality-Based Chemistry Experiential Application on Student Knowledge Gains, Learning Motivation, and Technology Perception. *Journal of Science Education and Technology*, *32*(6), 153–167. https://doi.org/10.1007/s10956-022-10014-z

Mayer, R. E. (2009). *Multimedia Learning*. Cambridge University Press. https://doi.org/10.1017/CBO9780511811678

Nababan, K., Siregar, D. M., Tarigan, V., Purba, L. S. L., & Renta, R. (2025). Augmented Reality-Based Smart Digital Interactive Media to Enhance High School Students Socio-Scientific Reasoning in Chemistry. *Jurnal Pijar Mipa*, *20*(8), 1499–1506.

Najib, M. K., Syahrina, W. N. M., Fawaid, M. S., Mutiara, P. A., Aprilianyani, R. R., & others. (2025). PENGENALAN UNITY UNTUK PEMBELAJARAN KONSEP DASAR AUGMENTED REALITY DI SMK SEMEN GRESIK. *BHAKTI NAGORI (Jurnal Pengabdian Kepada Masyarakat)*, *5*(2), 876–882.

Ngoc Son, P., Dang, T. T. A., Hoai, V. T. T., Thai, H. M., Chu, V. T., & Nguyen, M. H. (2025). Augmented Reality to Enhance Chemistry Learning Outcomes in Vietnamese Lower Secondary Schools: A Quasi-Experimental Study on Acid-Base–pH–Oxide–Salt Topics. *European Journal of Educational Research*, *14*(4), 1259–1275.

Nugraha, Y., Tetep, T. W., Laili, M. R., & others. (2025). Socioscientific Issues Based on Augmented Reality in Enhancing Students Scientific Argumentation. *Journal of Hunan University Natural Sciences*, *52*(12).

OECD. (2023a). *PISA 2022 Results (Volume I)* (Vol. 1). OECD Publishing. https://doi.org/10.1787/53f23881-en

OECD. (2023b). *PISA 2022 Results (Volume II)* (Vol. 2). OECD Publishing. https://doi.org/10.1787/a97db61c-en

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*, *372*, 1–9. https://doi.org/10.1136/bmj.n71

Permatasari, P. Dela, Dwiningsih, K., & Kusmahardhika, N. (2026). Electronic Student Activity Sheet Integrated with Augmented Reality for Training Visual-Spatial Intelligence in Molecular Shapes. *Jurnal Pendidikan Sains Indonesia (Indonesian Journal of Science Education)*, *14*(1), 81–98.

Prasetyo, Y. D., Khodizah, A. T., & Saputra, N. A. B. (2025). Development of Smart Ethno-STEM (System of Mobile Augmented Reality Technology) in Organic Chemistry to Enhance Students' Metacognitive Skills and Scientific Literacy. *Jurnal Penelitian Pendidikan IPA*, *11*(12), 237–248.

Prayunisa, F. (2022). Analisa Kesulitan Siswa Kelas XI dalam Pembelajaran Kimia di Sman 1 Masbagik. *Journal of Classroom Action Research*, *4*(3), 1–5.

Rahayu, S., Asih, E. J. V. T., Ardyansyah, A., & Alam, M. D. (2025). Enhancing High School Students'

Conceptual Understanding of Acid-Base Chemistry through Augmented Reality Modules. *Educación Química*, *36*(4), 142–156. https://doi.org/10.22201/fq.18708404e.2025.4.90694

Ramdiah, S., Mayasari, R., Sukri, A., Putra, A. P., & Khery, Y. (2026). Sasirangan v'erse: A digital media innovation based on local wisdom for transforming biology education. *Multidisciplinary Science Journal*, *8*(3). https://doi.org/10.31893/multiscience.2026063

Saadi, P., Anggrah, H., Idris, A. R., Nasution, G. A., Riadi, P., Utami, V. N., & others. (2025). Implementation of the SCCrT–Augmented Reality Model to Improve Students' Critical and Creative Thinking Skills and Science Literacy in Chemical Bonding Concepts. *Jurnal Penelitian Pendidikan IPA*, *11*(12), 631–639.

Saragih, D. M., & Pratama, A. T. (2026). Development of AR-assisted socio-scientific issue e-modules on the circulatory system to enhance students' health literacy and critical thinking. *BIO-INOVED: Jurnal Biologi-Inovasi Pendidikan*, *8*(1), 9–26.

Sari, S. A., & Damanik, F. F. (2025). Development of Augmented Reality (Ar)-Based Interactive Digital Magazine Media for Class X Chemistry Bond Learning. *Jurnal Akademika Kimia*, *14*(4), 251–259.

Sari, S. A., Dewi, R. S., Saputra, K., Kembaren, A., Hasibuan, H., & Talib, C. A. (2025). Integration of analytical chemistry flipbooks based on project-based learning in improving critical thinking skills and scientific literacy to support SDG-4. *Jurnal Pendidikan IPA Indonesia*, *14*(1).

Setiawaty, S., Lukman, I. R., Imanda, R., Sudirman, S., & Rauzatuzzikrina, R. (2024). Integrating of mobile augmented reality applications through inquiry learning to improve students' science process skills and concept mastery. *Jurnal Pendidikan IPA Indonesia*, *13*(1), 90–102.

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), 233–247. https://doi.org/10.3926/jotse.3454

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

Sulistina, O., & Hasanah, S. M. (2024). Improving Chemical Literacy Skills: Integrated Socio-Scientific Issues Content in Augmented Reality Mobile. *International Journal of Interactive Mobile Technologies (IJIM)*, *18*(05), 135–147. https://doi.org/10.3991/ijim.v18i05.47923

Syskowski, S., Lathwesen, C., Kanbur, C., Siol, A., Eilks, I., & Huwer, J. (2024). Teaching with augmented reality using tablets, both as a tool and an object of learning. *Journal of Chemical Education*, *101*(3), 892–902.

Syskowski, S., Lathwesen, C., Maurer, N., Siol, A., Eilks, I., & Huwer, J. (2024). Interactive Learning with iPads and Augmented Reality: A Sustainability-Oriented Approach to Teaching Plastics Chemistry. *Sustainability*, *16*(8), 3342.

Talanquer, V. (2022). The Complexity of Reasoning about and with Chemical Representations. *JACS Au*, *2*(12), 2658–2669. https://doi.org/10.1021/jacsau.2c00498

Tarng, W., Lin, Y.-J., & Ou, K.-L. (2021). A virtual experiment for learning the principle of Daniell cell based on augmented reality. *Applied Sciences*, *11*(2), 762.

Ulwan, R., Enawaty, E., Muharini, R., Hairida, H., & Lestari, I. (2024). Description of Science Literacy Epistemic Knowledge Ability of Chemistry Education Students on the Material of Colligative Properties of Solutions. *Hydrogen: Jurnal Kependidikan Kimia*, *12*(6), 1512–1519.

van Eck, N. J., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84*(2), 523–538. https://doi.org/10.1007/s11192-009-0146-3

Vieira, R. M., & Tenreiro-Vieira, C. (2016). Fostering Scientific Literacy and Critical Thinking in Elementary Science Education. *International Journal of Science and Mathematics Education*, *14*(4), 659–680. https://doi.org/10.1007/s10763-014-9605-2

Vygotsky, L. S. (1980). *Mind in Society* (M. Cole, V. Jolm-Steiner, S. Scribner, & E. Souberman, Eds.).

Harvard University Press. https://doi.org/10.2307/j.ctvjf9vz4

Wang, L. (2024). Research on the Optimization and Practice of High School Chemistry Experiment Teaching under the New Curriculum Standard. *Frontiers in Educational Research*, *7*(12).

Wibowo, F. C., Darman, D. R., Salim, F., Prahani, B. K., & Samsudin, A. (2026). Knowledgeable integration hybrid AI joins augmented reality and science literacy: Prospects and challenges. *Social Sciences & Humanities Open*, *13*, 1–19. https://doi.org/10.1016/j.ssaho.2026.102566

Widowati, A. N., Agustini, R., & others. (2025). Development and Validity Analysis of a Phenomenon-Based Advance Organizer Chemistry Learning Tool for Training Science Literacy in High School Students. *Jurnal Penelitian Pendidikan IPA*, *11*(10), 664–676.

Wulandari, I. P., & Darmana, A. (2026). Pengembangan E-Modul Interaktif Berbasis Augmented Reality pada Materi Ikatan Kimia. *Panthera: Jurnal Ilmiah Pendidikan Sains Dan Terapan*, *6*(1), 46–59.

Yuendita, D., & Dina, D. (2024). Development of chemical literacy book on local wisdom of Madura culture based on augmented reality (AR). *Jurnal Penelitian Pendidikan IPA*, *10*(1), 346–359.

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*(1), 4.