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EFFECTIVENESS OF AUGMENTED REALITY TECHNOLOGY IN STRENGTHENING SCIENCE CONCEPTUAL LEARNING AT THE PRIMARY SCHOOL LEVEL

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Abstract

This study examines the effectiveness of Augmented Reality (AR) technology in strengthening science conceptual learning at the primary school level through a systematic literature review. The review synthesizes recent studies published between 2021 and 2026 and indexed in major academic databases, including Scopus, Web of Science, ScienceDirect, SpringerLink, ERIC, and Google Scholar. Relevant articles were selected based on criteria related to the use of AR in primary science education, conceptual understanding, learning outcomes, engagement, and science process skills. The findings indicate that AR contributes positively to students' understanding of abstract, microscopic, spatial, and dynamic science concepts by integrating three-dimensional visualization, real-world contexts, and interactive learning experiences. AR is particularly effective when combined with inquiry-based learning, flipped classroom strategies, collaborative activities, guided questioning, and teacher facilitation. In addition to conceptual understanding, AR supports motivation, curiosity, spatial ability, higher-order thinking, and active participation. However, its effectiveness is influenced by instructional design quality, content relevance, cognitive load, teacher competence, device availability, technical support, and school infrastructure. Poorly designed AR applications may distract students or increase cognitive overload without improving learning meaningfully. The study concludes that AR should be positioned as a pedagogical tool embedded within structured science instruction rather than as a standalone technological innovation. Future research should examine long-term concept retention, misconception reduction, transfer of learning, cost-effectiveness, inclusive access, and implementation across diverse primary school contexts. These findings provide practical implications for teachers, schools, developers, and policymakers seeking to integrate AR into science education effectively in equitable, sustainable, and developmentally appropriate ways.

Keywords: augmented reality; conceptual understanding; primary education; science learning; interactive learning media; systematic literature review.

Introduction

Digital transformation in education has encouraged the use of various interactive technologies to improve the quality of learning, including at the elementary school level. One of the technologies that is gaining more attention is *Augmented Reality* (AR), which is a technology that integrates virtual objects in the form of images, animations, videos, and three-dimensional models into a real-life environment. In science learning, AR is considered relevant because many scientific concepts, such as the solar system, the structure of body organs, energy changes, forces, and biological processes, are difficult to observe directly by students. Through three-dimensional visualization and real-time interaction, AR can help transform abstract concepts into more concrete, contextual, and easy-to-understand learning experiences (Chang et al., 2022; Xu et al., 2022).

At the elementary school level, mastery of science concepts is not only related to the ability to remember information, but also the ability to explain phenomena, connect concepts, use evidence, and apply knowledge in daily life. However, science learning is still often centered on textbooks, verbal explanations, and two-dimensional images, so students tend to memorize the material without gaining a deep conceptual understanding. Research shows that the integration of AR with inquiry-based learning can improve academic outcomes and engagement of elementary school students, especially for students with lower academic development. AR also allows learners to make observations, manipulation of objects, discussions, and investigations more actively (Wen et al., 2023).

Although research developments show the positive potential of AR, there is a phenomenal gap between technological advances and their application in science learning in elementary schools. The availability of smartphones and tablets is becoming more widespread, but their use in the classroom has not always been directed at strengthening understanding of concepts. In practice, technology is often used only as a medium of presentation or visual attraction, rather than as a tool to build knowledge through scientific activities. In addition, the implementation of AR still faces limitations in the form of device costs, content quality, teacher readiness, technical support, curriculum suitability, and access gaps between schools. This condition causes the potential of AR in improving science learning to be optimally utilized (Zhang & Yao, 2025).

The research problem that arises is the unclear level of effectiveness of AR technology in strengthening conceptual learning of science in elementary school students and the pedagogical conditions that determine its success. The use of AR does not automatically result in a better understanding because its effectiveness can be affected by visual design, interaction forms, duration of use, learning strategies, teacher support, learner characteristics, and material suitability. Three-dimensional visualizations that are not designed appropriately even have the potential to increase cognitive load or distract students from learning objectives. Therefore, AR needs to be understood as part of learning design, not just an additional technological device (Chang et al., 2022; Xu et al., 2022).

The research gap is also seen because some previous studies still discussed the influence of AR on learning outcomes, motivation, satisfaction, and student involvement in general without paying special attention to the formation of conceptual understanding of science in elementary school. The available research uses various topics, devices, duration of interventions, evaluation methods, and characteristics of students so as to produce findings that are not completely consistent. In addition, studies with long-term designs, large samples, diverse school contexts, and measurement of concept retention are still limited. Recent research also shows the need for studies on social interactions, collaboration, physical movement, and knowledge construction processes when students use AR (Mansour et al., 2025; Lu et al., 2025).

The incremental novelty of this study lies in the effort to focus the analysis on the effectiveness of AR in strengthening conceptual science learning at the elementary school level, not just assessing the improvement of learning outcome scores or motivation. This study integrates evidence on three-dimensional visualization, interactivity, inquiry-based learning, collaboration, and *embodied learning* as mechanisms that can explain how AR helps students understand scientific concepts. In addition to identifying the benefits, this study also analyzed pedagogical and technical factors that can strengthen or limit the effectiveness of AR. Thus, the study results in a more comprehensive understanding of the relationship between technological characteristics, learning design, and mastery of science concepts (Wen et al., 2023; Câmara Olim et al., 2024; Mansour et al., 2025).

The study of the effectiveness of AR technology is urgent because elementary school is a fundamental stage in shaping science literacy, curiosity, critical thinking skills, and a positive attitude towards science. Meta-analytical evidence suggests that AR exerts a positive influence on science learning achievement and high-level thinking skills, but such success remains dependent on the quality of its design and implementation strategies (Xu et al., 2022; Lu et al., 2025). Therefore, this study aims to analyze the effectiveness of AR in strengthening the understanding of science concepts of elementary school students, identify learning mechanisms that support its effectiveness, and formulate recommendations for teachers, media developers, schools, and policymakers in implementing AR in a pedagogical, inclusive, and sustainable manner.

Research Methods

This study uses a *systematic literature review* method to identify, evaluate, and synthesize research results regarding the effectiveness of *Augmented Reality technology* in strengthening the understanding of science concepts in elementary school students. The review process refers to the PRISMA 2020 guidelines, which emphasize transparency in the identification, screening, feasibility assessment, and determination stages of the articles analyzed (Page et al., 2021). The study procedure also adapts the SPAR-4-SLR framework, especially at the stage of assembly, organization, and evaluation of the literature so that the search and synthesis process can be carried out in a structured and accountable manner (Paul et al., 2021). Articles were searched through Scopus, Web of Science, ScienceDirect, SpringerLink, ERIC, and Google Scholar databases by a combination of keywords: "*augmented reality*," "*science learning*," "*conceptual understanding*," "*primary education*," "*elementary school*," and "*interactive learning media*." The search is focused on articles published in the period 2021–2026.

Inclusion criteria include journal articles that have gone through *a peer review process*, available in Indonesian or English, discuss the use of AR in science learning, involve elementary school students, and present findings related to concept understanding, learning outcomes, engagement, or learning experiences. Meanwhile, duplicate articles, proceedings that do not provide a complete text, research outside the context of basic education, and publications that only discuss the technical development of AR without learning evaluation are excluded from the study. Articles that met the criteria were then analyzed using thematic content analysis techniques by grouping information based on study characteristics, science materials, types of AR applications, learning design, forms of interaction, learning outcomes, and implementation constraints. The findings of each article were compared and synthesized narratively to identify patterns of effectiveness, supporting factors, limitations of previous research, and recommendations for the application of AR in science learning in elementary schools. The procedure supports a transparent, systematic, and replicable literature review (Page et al., 2021; Paul et al., 2021).

Results and Discussion

Results

The results of the literature review show that *Augmented Reality* technology has a positive influence on students' conceptual understanding of science. AR helps students obtain more concrete representations of scientific objects, processes, and phenomena that were previously only explained through two-dimensional text or images. A meta-analysis by Chang et al. (2022) showed that the use of AR resulted in a positive impact on various levels of learning outcomes, especially knowledge and skill mastery. The findings are reinforced by Xu et al. (2022), who found that AR is effective in science learning because it allows learners to observe abstract and invisible phenomena directly. However, the level of effectiveness differs based on the level of education, type of material, tools used, duration of intervention, and learning strategies. Thus, AR is more appropriately understood as a medium that strengthens the concept formation process than as a substitute for all conventional learning methods.

The second finding suggests that AR's main strength lies in its ability to visualize abstract, complex, microscopic, or difficult to observe science concepts directly. The three-dimensional model allows students to observe the structure of body organs, the movement of celestial bodies, the arrangement of particles, energy changes, ecosystems, and various biological processes from various perspectives. The visualization helps students connect verbal information with spatial representations so that concepts become easier to understand. Zhang and Yao (2025) explain that AR can transform abstract scientific concepts into dynamic models that are more intuitive and interactive. Chen et al.'s (2025) research on fifth-graders also showed that AR-based experiential learning helps increase engagement in the investigation and understanding of the scientific process. However, visualization needs to be simplified to suit the cognitive development of elementary school students and not create an excessive burden of information.

The results of subsequent studies show that the effectiveness of AR increases when the technology is integrated with inquiry-based learning. In this learning, students not only observe virtual objects, but also formulate questions, collect information, make observations, test conjectures, discuss results, and draw conclusions. Wen et al. (2023) found that the integration of AR with an inquiry approach in elementary school science classes was able to improve academic outcomes and support active engagement of students, including students with lower initial abilities. In addition to improving conceptual mastery, AR also supports science process skills, such as observing, classifying, interpreting data, and explaining cause-and-effect relationships. Al-Awidi et al. (2025) show that image recognition-based AR applications contribute to the mastery of process skills and motivation to learn science. These findings confirm that AR interactivity needs to be directed towards structured scientific activities.

In addition to the cognitive aspect, the study found that AR has a positive influence on students' motivation, attention, curiosity, and involvement in science learning. The presentation of interactive digital objects makes learning activities feel more interesting than learning that only uses textbooks. Arici (2024) shows that the use of AR in science education supports environmental literacy, self-regulation, and learning motivation. Meta-analysis by Prasetya et al. (2024) also shows that AR-based learning experiences can increase attention, perception of material relevance, confidence, and student satisfaction. In younger age groups, the use of AR glasses also results in behavioral, academic, cognitive, and social engagement during science learning activities (Geng et al., 2026). However, the element of technological novelty can have a temporary attraction effect so that increased motivation does not necessarily indicate the formation of a conceptual understanding that lasts in the long term.

Studies also show that AR has the potential to improve high-level thinking skills, spatial understanding, and the ability to connect science concepts with real situations. When learners can manipulate three-dimensional objects, change the position of observation, or see the gradual changes of a process, they gain the opportunity to compare, analyze, predict, and explain phenomena. Tiep and Huong (2025) found that the *flipped classroom model* combined with AR improved academic outcomes, learning interest, and understanding of abstract concepts of fourth and fifth grade students. Improvements are mainly found in matter that has spatial-temporal characteristics, such as the movement of the earth and the moon. These results show that AR is particularly relevant for materials that require an understanding of changes in space, position, shape, and time. However, its effectiveness depends on the existence of directional questions, teacher explanations, and reflection activities after students interact with digital objects.

In addition to these benefits, the results of the study identified a number of limitations in the application of AR in elementary school science learning. Technical constraints include device limitations, camera and sensor quality, application stability, internet access, development costs, and system maintenance. From the pedagogical side, teachers face difficulties in choosing an application that fits the curriculum, managing classes, providing mentoring, and connecting the AR experience with conceptual goals. Fearn and Hook (2023) emphasize that the implementation of AR requires the design of educational services that pay attention to the needs of teachers, students, curriculum, and the school environment in an integrated manner. Nikou (2024) found that perceptions of educational benefits, uses, and immersion levels influence the intention of prospective elementary school teachers to use AR. Meanwhile, Zhang and Yao (2025) highlight the cost of devices, teacher training, technological maturity, and resource inequality as the main barriers to wider adoption.

Discussion

The effectiveness of AR in reinforcing science conceptual learning can be explained through the integration of visual representation, verbal information, direct interaction, and contextual experiences. Elementary school learners generally have an easier time understanding concepts when abstract information is connected to objects that can be observed and manipulated. AR provides a bridge between the real world and digital representations so that learners not only receive explanations, but also experience the process of forming meaning. The findings of Chang et al. (2022) and Xu et al. (2022) suggest that visualization and interactivity are important mechanisms that support knowledge acquisition. However, the abundance of animations, symbols, sounds, and information at the same time can divide attention and increase cognitive load. Therefore, the AR display should be simple, relevant, and purposeful. Every digital object needs to have a clear learning function, not just used to create an interesting or modern impression.

The findings of the study also confirm that the success of AR is determined more by pedagogical design than by technological sophistication. AR, which is only used to display three-dimensional objects, has the potential to produce passive learning if students are not given the opportunity to ask questions, investigate, discuss, and explain the results of their observations. The integration of AR with inquiry learning allows learners to build concepts through scientific activities, while integration with *flipped classrooms* provides an opportunity to learn the initial material independently and use class time for more in-depth exploration. The results of Wen et al. (2023) and Tiep and Huong (2025) show that AR becomes more effective when it is equipped with learning stages, assignments, assessments, and teacher assistance. Thus, AR technology is not a single variable that guarantees success, but rather one of the components in a learning ecosystem that includes strategies, content, teachers, learners, and evaluation.

The practical implication of these findings is the need to improve teacher competence in aspects of technology, pedagogy, and science materials. Teachers need to be able to evaluate the accuracy of the application content, the suitability of visualization with the age of students, ease of use, data security, and its connection to curriculum outcomes. Training should not only teach how to operate an app, but also how to design directional questions, manage group work, address technical glitches, and measure changes in conceptual understanding. Nikou (2024) shows that perceptions of the value of education and the usefulness of AR play an important role in shaping the acceptance of prospective teachers. Fearn and Hook (2023) also show that user needs to be placed as the basis for implementation design. Therefore, schools need to provide technical support, preparation time, adequate tools, and a community of practice so that the use of AR does not depend on the individual abilities of a particular teacher.

Overall, AR can be judged to be effective in strengthening understanding of science concepts at the elementary school level, but those conclusions need to be placed within the limits of the available evidence. Some studies still use limited samples, short-duration interventions, diverse instruments, and measurements that focus more on test results immediately after learning. Research on long-term retention, change in misconceptions, knowledge transfer, the needs of students with special needs, and cost-effectiveness is still limited. K–12 studies also show that the scope of AR research is not evenly distributed across all levels, science topics, and characteristics of learners (Botkin et al., 2025). Subsequent research needs to use more robust longitudinal and experimental designs, compare different forms of AR, and consider the initial knowledge and representational competence of learners. This approach will result in more accurate conclusions about when, how, and for whom AR is most effectively used in elementary school science learning.

Conclusion

Based on the results of the literature review, *Augmented Reality technology* is effective in strengthening the understanding of science concepts in elementary school students through three-dimensional visualization, direct interaction, and the presentation of abstract scientific phenomena to be more concrete and contextual. The use of AR is also able to increase motivation, engagement, science process skills, spatial skills, and high-level thinking, especially when combined with inquiry-based learning, *flipped* classrooms, discussions, and teacher mentoring. Nonetheless, the effectiveness of AR depends not only on technological sophistication, but also on the quality of learning design, suitability of the material with the cognitive development of students, teacher competence, availability of devices, and school support. Therefore, AR needs to be implemented as part of a structured learning strategy, not just an additional visual medium. Further research needs to examine concept retention, misconception change, long-term effectiveness, and the application of AR in a more diverse school context so that its benefits for science learning can be understood more comprehensively.

Bibliography

Al-Awidi, H., Abumosa, M., & Al-Mughrabi, A. (2025). The effect of mobile image recognition-based augmented reality application on students' acquisition of science processing skills and motivations to learn science. *Interactive Learning Environments, 33*(2), 1238–1249. doi:10.1080/10494820.2024.2367020

Arici, F. (2024). Investigating the effectiveness of augmented reality technology in science education in terms of environmental literacy, self-regulation, and motivation to learn science. *International Journal of Human–Computer Interaction, 40*(24), 8476–8496. doi:10.1080/10447318.2024.2310921

Botkin, M. D., & Trespalacios, J. H. (2026). Identifying virtual/augmented reality research in K–12 science education: A scoping study. *TechTrends, 70*, 138–149. doi:10.1007/s11528-025-01138-1

Câmara Olim, S., Nisi, V., & Romão, T. (2024). Augmented reality interactive experiences for multi-level chemistry understanding. *International Journal of Child-Computer Interaction, 42*, Article 100681. doi:10.1016/j.ijcci.2024.100681

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*, Article 104641. doi:10.1016/j.compedu.2022.104641

Fearn, W., & Hook, J. (2023). A service design thinking approach: What are the barriers and opportunities of using augmented reality for primary science education? *Journal of Technology and Science Education, 13*(1), 329–351. doi:10.3926/jotse.1394

Geng, G., Green, K., Telford, A., & Zhu, Y. (2026). Engaging young minds: How smart augmented reality glasses transform learning experiences in AR smart glasses immersive virtual learning environments. *Journal of Science Education and Technology*. Advance online publication. doi:10.1007/s10956-026-10299-4

Lu, Z., Chiu, M. M., Wang, S., Mao, W., & Lei, H. (2025). Effects of augmented reality on students' higher-order thinking: A meta-analysis. *Journal of Educational Computing Research, 63*(3), 728–747. doi:10.1177/07356331241309644

Mansour, N., Aras, C., Kleine Staarman, J., & Alotaibi, S. B. M. (2025). Embodied learning of science concepts through augmented reality technology. *Education and Information Technologies, 30*, 8245–8275. doi:10.1007/s10639-024-13120-0

Nikou, S. A. (2024). Factors influencing student teachers' intention to use mobile augmented reality in primary science teaching. *Education and Information Technologies, 29*, 15353–15374. doi:10.1007/s10639-024-12481-w

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*, Article n71. doi:10.1136/bmj.n71

Paul, J., Lim, W. M., O'Cass, A., Hao, A. W., & Bresciani, S. (2021). Scientific procedures and rationales for systematic literature reviews: SPAR-4-SLR. *International Journal of Consumer Studies, 45*(4), O1–O16. doi:10.1111/ijcs.12695

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*, Article 100926. doi:10.1016/j.ssaho.2024.100926

Tiep, P. Q., & Huong, N. T. (2025). Building a flipped classroom model combined with augmented reality to improve the effectiveness of teaching natural and social sciences in primary schools. *Educational Process: International Journal, 18*, Article e2025445. doi:10.22521/edupij.2025.18.445

Wen, Y., Wu, L., He, S., Ng, N. H.-E., Teo, B. C., Looi, C. K., & Cai, Y. (2023). Integrating augmented reality into inquiry-based learning approach in primary science classrooms. *Educational Technology Research and Development, 71*(4), 1631–1651. doi:10.1007/s11423-023-10235-y

Xu, W.-W., Su, C.-Y., Hu, Y., & Chen, C.-H. (2022). Exploring the effectiveness and moderators of augmented reality on science learning: A meta-analysis. *Journal of Science Education and Technology, 31*(5), 621–637. doi:10.1007/s10956-022-09982-z

Zhang, J., Li, G., Huang, Q., Feng, Q., & Luo, H. (2022). Augmented reality in K–12 education: A systematic review and meta-analysis of the literature from 2000 to 2020. *Sustainability, 14*(15), Article 9725. doi:10.3390/su14159725

Zhang, S., & Yao, Z. (2025). The challenge of the application of augmented reality in science education in China: A systematic review. *Disciplinary and Interdisciplinary Science Education Research, 7*, Article 4. doi:10.1186/s43031-025-00123-1