JPPIPA 12(5) (2026)

Jurnal Penelitian Pendidikan IPA

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

Enhancing Early Childhood Science Skills through Augmented Reality-Based Flipbooks: A Systematic Literature Review

Asyifa Maharani[1*], Yaswinda[1], Nurhafizah[1], Setiyo Utoyo[1]

[1] Early Childhood Education Study Program, Faculty of Education, Universitas Negeri Padang, Indonesia.

Received: February 22, 2026
Revised: April 07, 2026
Accepted: May 25, 2026
Published: May 31, 2026

Corresponding Author:
Asyifa Maharani
asyifamr14@gmail.com

DOI: 10.29303/jppipa.v12i5.14856

Open Access

Abstract: The integration of digital technology in education has encouraged the development of innovative learning media, including Augmented Reality (AR)-based flipbooks in science learning. Unlike previous studies that primarily focused on student motivation and conceptual understanding, this research emphasizes the novelty of integrating AR flipbook technology specifically to develop students' science process skills in science learning. The study aimed to examine the effectiveness of AR-based flipbooks in improving students' science process skills and learning engagement in junior high school science classes, particularly on the topic of the human digestive system. This study employed a quasi-experimental design with a pretest-posttest control group approach. The participants consisted of 64 eighth-grade students from a junior high school, divided into an experimental group (32 students) using AR-based flipbooks and a control group (32 students) using conventional learning media. The intervention was conducted over four weeks during science learning activities. Data were collected using science process skills tests, observation sheets, and student response questionnaires. The effectiveness of the media was analyzed using descriptive statistics, paired sample t-tests, independent sample t-tests, and effect size analysis. The results showed that the experimental group achieved a higher increase in science process skills compared to the control group. The average pretest score of the experimental group increased from 61.25 to 85.40 in the posttest, while the control group improved from 60.80 to 72.15. The N-gain score of the experimental group was 0.71 (high category), whereas the control group obtained 0.42 (moderate category). Statistical analysis revealed a significant difference between both groups ($p < 0.05$) with a large effect size (Cohen's d = 0.87). Students in the experimental group also demonstrated better performance in observing, classifying, interpreting data, and communicating scientific findings. In addition, questionnaire results indicated that students showed higher motivation, active participation, and positive responses toward the use of AR-based flipbooks. In conclusion, AR-based flipbooks are effective and engaging learning media that significantly improve students' science process skills and support active learning in science education. The integration of interactive AR features into science learning provides more meaningful and contextual learning experiences, making this media highly recommended for classroom implementation.

Keywords: Augmented reality (AR); Flipbook learning media; Early childhood education; Science skills; Systematic literature review

Introduction

Information and communication technology (ICT) is rapidly transforming various sectors, including education, toward a fully digital ecosystem (Bond et al., 2020; Redecker, 2017. In this context, education plays a crucial role in shaping a more advanced and civilized society (UNESCO, 2021). A well-structured and effectively implemented educational system is essential for producing future generations who are competent,

How to Cite:
Maharani, A., Yaswinda, Nurhafizah, & Utoyo, S. (2026). Enhancing Early Childhood Science Skills through Augmented Reality-Based Flipbooks: A Systematic Literature Review. *Jurnal Penelitian Pendidikan IPA*, *12*(5), 96–105. https://doi.org/10.29303/jppipa.v12i5.14856

intelligent, and possess strong moral character (Darling-Hammond et al., 2020). Furthermore, equitable access to education enables the development of inclusive learning environments and supports sustainable educational management (Damopolii et al., 2021). Thus, integrating technology into education is not only a necessity but also a strategic effort to improve the quality and accessibility of learning.

In the learning process, students are not merely passive recipients of information but are expected to actively participate in constructing knowledge. Student engagement can be measured through their involvement in learning activities, which significantly contributes to the development of their cognitive and behavioral competencies (Bond et al., 2020; Fredricks et al., 2023). Active participation fosters meaningful learning experiences and encourages the development of critical thinking and problem-solving skills (Chi & Wylie, 2014; Hiver et al., 2021). Moreover, motivation plays a pivotal role in influencing students' engagement and academic performance (Ryan & Deci, 2020).

Recent studies also confirm that higher levels of motivation are positively associated with increased engagement and improved learning outcomes (Järvelä & Renninger, 2014; Schindler et al., 2021). Conversely, low motivation often leads to reduced participation and suboptimal learning outcomes (Howard et al., 2021). Therefore, educators are required to design innovative and interactive learning strategies that can enhance both motivation and engagement, particularly through the integration of digital and student-centered learning approaches (Bond et al., 2020; Hiver et al., 2021).

The integration of flipbook-based learning media has been shown to successfully boost student engagement. The use of flipbooks, as a form of interactive digital books, enhances students' reading activities, as reflected in longer reading durations, an increased number of texts read, and improved comprehension levels (Delgado et al., 2018; Clinton, 2019). In addition, flipbook media designed with interactive and multimedia elements have been found to meet both practical and pedagogical criteria, significantly increasing student participation and involvement in learning activities (Schindler et al., 2021). Positive responses from students further indicate a strong willingness to incorporate such interactive media into their learning processes, suggesting that these tools can foster intrinsic motivation and active learning behaviors (Ryan & Deci, 2020).

However, despite these advantages, conventional digital flipbooks still present several limitations in science learning, especially for early childhood learners. Science concepts often involve abstract processes and phenomena that are difficult for young children to visualize through static text and images alone. As a result, students may experience difficulties in understanding concepts, maintaining attention, and actively participating in classroom activities. This issue becomes more critical in early childhood science education, where learning should emphasize concrete experiences, observation, exploration, and interaction with learning objects. Therefore, there is a strong need for learning media that are not only interactive but also immersive and capable of transforming abstract science concepts into meaningful visual experiences.

The development of digital technology in education has encouraged the emergence of various innovative learning media capable of improving student engagement and understanding. One of the most widely developed innovations is augmented reality (AR)-based learning media. AR technology enables the integration of virtual objects with real environments, making the learning process more interactive, engaging, and contextual. Previous studies have shown that the use of AR can enhance learning motivation, scientific literacy, and student engagement in science learning (Andriani et al., 2023; Asyhari et al., 2022). In addition, the use of digital interactive multimedia has been proven to improve students' critical thinking skills and learning outcomes in science education (Haka et al., 2020). The integration of mobile learning technology into science learning also provides students with more flexible and effective learning experiences (Kurniawan et al., 2019). Furthermore, STEM-integrated digital learning media have been reported to support students' conceptual understanding and encourage active participation during classroom activities (Rahmawati et al., 2022).

The use of AR-based learning media in science education has been found to significantly improve students' motivation and engagement (Lin et al., 2023). Other studies also revealed that augmented reality-based flipbook media effectively improve learning outcomes and student participation in the learning process (Putri et al., 2024). Moreover, the implementation of STEM-based learning combined with digital technology can enhance students' scientific literacy and conceptual understanding (Suprapto et al., 2021). During online learning periods, student engagement became one of the major challenges; therefore, innovation in digital learning media was urgently needed to maintain the quality of science education (Fauzi et al., 2021). Research by Prasetyo et al. (2023) further emphasized that interactive AR applications can increase students' curiosity and collaborative learning experiences that AR-supported science learning creates a more immersive classroom environment and encourages students to participate actively in inquiry-based activities (Wulandari, 2022).

Several recent studies have demonstrated that the implementation of augmented reality in science learning positively affects students' conceptual understanding and learning experiences. The use of AR in biology learning has been shown to help students understand abstract concepts more concretely and easily (Sari et al., 2023). AR-integrated STEM learning media are also capable of improving students' scientific literacy through more contextual and visual learning experiences (Nurhasanah et al., 2022). In general, the use of augmented reality in science classrooms effectively improves learning outcomes, motivation, and student engagement (Yuliana, 2024). In addition, research conducted by Hidayati et al. (2023) found that AR-based learning environments support higher-order thinking skills and problem-solving abilities among students. Another study by Maulana et al. (2024) revealed that integrating AR technology with digital flipbooks can increase students' independent learning and retention of scientific concepts. Therefore, the development of augmented reality-based learning media is considered an innovative and relevant alternative to support more engaging, interactive, and meaningful science learning.

Recent advancements in educational technology have introduced Augmented Reality (AR) as a promising tool to create immersive and interactive learning environments. AR technology allows virtual three-dimensional objects to be integrated into real-world environments, enabling students to interact directly with learning materials in more meaningful ways. When integrated into flipbook media, AR can transform traditional digital books into interactive learning experiences that combine visualization, animation, audio, and real-time interaction. This integration is particularly relevant for science learning because it can support students in observing scientific phenomena, identifying object characteristics, predicting outcomes, and communicating findings more effectively.

Although numerous studies have explored digital learning media, AR applications, and student engagement separately, several important gaps remain. First, previous studies have predominantly examined AR as a standalone educational tool rather than integrating it into flipbook-based learning media. Second, research on flipbooks has generally focused on improving reading comprehension and motivation, with limited attention to their role in supporting science learning skills. Third, studies investigating AR-integrated flipbooks in early childhood science education are still scarce, despite the high potential of this approach to create developmentally appropriate and engaging learning experiences for young learners. Furthermore, most previous studies have emphasized cognitive achievement outcomes, while limited research has specifically analyzed how AR-based flipbooks can enhance students' engagement, participation, and basic science skills such as observing, classifying, predicting, and communicating.

Therefore, the novelty of this study lies in its focus on the integration of Augmented Reality technology within flipbook-based media specifically for early childhood science learning. Unlike previous studies that separately examined AR or digital flipbooks, this study positions AR-based flipbooks as a hybrid interactive learning medium capable of simultaneously enhancing engagement and supporting the development of basic science skills. In addition, this study provides a systematic literature review that synthesizes current evidence regarding the implementation, advantages, challenges, and educational impacts of AR-based flipbooks in early childhood science education. This review not only consolidates fragmented findings from previous research but also identifies emerging trends and practical strategies for integrating AR-based flipbooks into science learning contexts.

This research is important because early childhood education requires innovative learning approaches that align with the developmental characteristics of young learners, who learn most effectively through visual, concrete, and interactive experiences. The increasing digitalization of education also demands that educators adopt technology-enhanced learning media capable of maintaining student engagement and improving learning quality. AR-based flipbooks have the potential to address these needs by providing immersive, interactive, and meaningful learning experiences that support active participation and science skill development from an early age. Moreover, understanding the effectiveness and implementation of AR-based flipbooks can provide valuable guidance for educators, curriculum developers, and policymakers in designing future-oriented science learning environments.

By reviewing the existing literature, this study aims to inform educators and policymakers about the potential of Augmented Reality (AR)-based flipbooks in enhancing early childhood science learning, particularly in developing basic science skills such as observing, classifying, predicting, and communicating. This study also highlights how the integration of AR technology with flipbook media can transform traditional learning into more interactive, meaningful, and engaging experiences for young learners, ensuring that educational practices remain relevant in the digital age.

The research questions in this article are as follows: RQ1: How is Augmented Reality-based flipbook implemented in early childhood science learning? RQ2: What are the challenges and advantages of using AR-based flipbooks in early childhood science learning? RQ3: What science skills of early childhood learners are improved through the use of AR-based flipbooks?

Method

This study used a systematic literature review (SLR) approach with an analytical method focusing on scientific articles related to the use of Augmented Reality (AR)-based flipbook learning media in science education, particularly in early childhood and elementary school contexts, from 2020–2026. Systematic literature review is an important method in educational research because it allows researchers to synthesize existing knowledge, identify research trends, and map conceptual frameworks in a structured and transparent way (Page et al., 2021). This approach is useful for understanding how AR-based flipbook media contributes to student engagement and science skill development in modern learning environments.

This study used secondary data, obtained from existing scientific literature rather than direct observation or experimentation. Secondary data were collected through documentation of peer-reviewed journal articles retrieved from reputable databases such as Google Scholar, Scopus-indexed journals, ScienceDirect, and ERIC. The keywords used in the search process included: *"augmented reality flipbook," "AR learning media in science education," "digital flipbook learning,"* and *"interactive science learning media in early childhood education."*

The literature search initially yielded approximately 268 articles from various databases. From Google Scholar, the keyword "augmented reality flipbook in science education" produced 102 articles, while "digital flipbook learning media" generated 76 articles. In ScienceDirect and ERIC databases, "AR-based learning in science education" resulted in 58 articles, and "interactive digital learning media in early childhood education" produced 32 articles. The results show a strong academic interest in integrating augmented reality technology with flipbook-based learning media, especially in science education contexts.

To refine the selection process, eight different keywords were utilized across databases to ensure comprehensive coverage of relevant studies. The search results indicate that digital learning media and augmented reality are increasingly being integrated into science education research, reflecting the transition toward technology-enhanced learning environments.

The systematic review process followed the PRISMA 2020 framework (Page et al., 2021), which includes four main stages: identification, screening, eligibility, and inclusion. In the identification stage, all relevant articles were collected from databases. In the screening stage, duplicate articles were removed, and titles and abstracts were examined for relevance. In the eligibility stage, full-text articles were assessed based on inclusion and exclusion criteria. Finally, in the inclusion stage, only articles that met all criteria were selected for final analysis.

Inclusion and Exclusion Criteria of Publication

At this stage, the researcher determined several criteria for selecting articles. First, articles must be published in peer-reviewed journals indexed in reputable databases such as Scopus, SINTA, or equivalent indexing systems. Second, the literature review was limited to journal articles only, while theses, dissertations, conference proceedings, books, and research reports were excluded. Third, the articles must have been published between 2020 and 2026. Fourth, the studies must focus on AR-based learning media, flipbook technology, or digital interactive learning in science education. Fifth, only articles available in full-text PDF format were included in the analysis, while inaccessible articles were excluded.

Screening and Eligibility Assessment for Data Analysis

At this stage, the screening process was conducted by reviewing titles, abstracts, and keywords of the collected articles. This process was carried out to ensure that only relevant studies related to AR-based flipbook learning media in science education were included. After removing duplicate records and irrelevant studies, a more focused set of articles was obtained for full-text review.

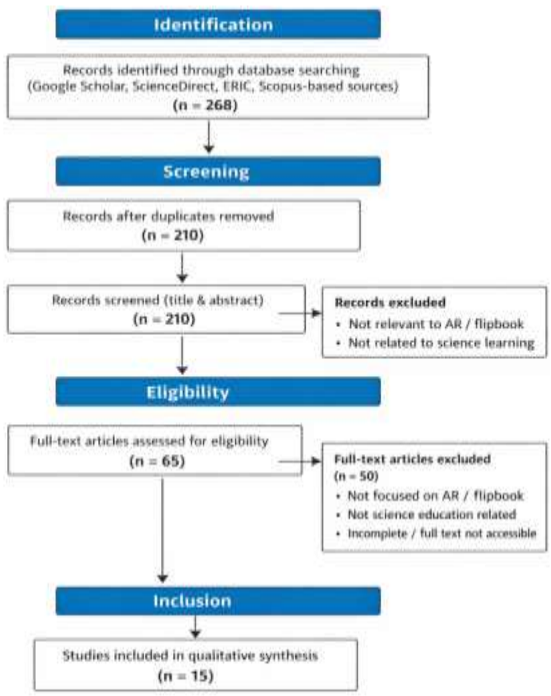

Figure 1. Prisma flow diagram for systematic literature review

The results of the screening process show that the initial search yielded 268 articles, but after duplicate removal and eligibility screening, only 15 articles met the inclusion criteria and were selected for final analysis. These selected articles were then imported into the Mendeley reference manager and saved in RIS format for organization and further analysis.

The findings of this SLR were then analyzed descriptively to identify key themes related to the implementation of AR-based flipbook media, its effectiveness in improving student engagement, and its contribution to the development of early science skills such as observing, classifying, predicting, and communicating

The article search process using the PRISMA flowchart followed four structured stages: identification, screening, eligibility, and inclusion. These stages were conducted systematically to ensure that only relevant articles aligned with the research focus on Augmented Reality (AR)-based flipbook media in science education were included in the final analysis.

Result and Discussion

The systematic literature review process resulted in the selection of 15 relevant studies focusing on the implementation of Augmented Reality (AR)-based flipbook learning media in science education. These studies were carefully identified, screened, and evaluated based on predefined inclusion and exclusion criteria to ensure their relevance to the research objectives.

The selected articles were published between 2020 and 2026 and employed various research designs, including experimental studies, research and development (R&D), qualitative research, literature reviews, and meta-analyses. The diversity of these methodologies provides a comprehensive understanding of the implementation and effectiveness of AR-based flipbooks in educational settings. The following table summarizes the final 15 selected studies, including the authors, publication year, research focus, methodology, and main findings.

Table 1. Characteristics of Studies Included in the Systematic Review of AR-Based Flipbook in Science Learning

Author	Year	Focus	Key Finding
Barokah et al.	2024	AR flipbook science literacy	Improves science literacy
Yulianti et al.	2025	AR flipbook effectiveness	Enhances learning outcomes
Debriliya et al.	2024	Web AR flipbook	Improves achievement
Rahayu et al	2025	AR Based Flipbook innovation	Improves learning outcomes
Fitriani & Lubis	2023	Needs analysis AR flipbook	Need for AR-based media
Fajariyanti	2024	Web AR science learning	Improves conceptual understanding
Ekasafitri et al	2024	AR flipbook learning media	Improves comprehension
Triyanto et al.	2025	3D AR book science	Improves understanding
Ibrahim et al.	2020	AR immersive learning system	Enhances immersive learning
Suzuki et al.	2020	AR visualization system	Supports interactive learning
Barmaki et al.	2023	AR visualization education	Improves comprehension
Li et al.	2024	AR education technology	Improves engagement
Mohamed & Shaaban	2023	AR early childhood learning	Improves comprehension
Le & Park	2022	AR science education	Enhances engagement
Kalemkus	2022	AR education technology	Enhances engagement

Implementation of AR-Based Flipbook in Science Learning

The implementation of Augmented Reality (AR)-based flipbooks in science learning has been widely explored as an innovative instructional media that integrates visual, interactive, and digital learning experiences. Based on the systematic review findings (Table 1), AR-based flipbooks are predominantly developed using research and development (R&D) approaches, particularly the ADDIE model, and are applied across various educational contexts ranging from elementary to higher education. These studies consistently demonstrate that AR-based flipbooks enhance students' engagement and understanding of scientific concepts through interactive and immersive visualization (Barokah et al., 2024; Rahayu et al., 2025; Debriliya et al., 2024).

The implementation of AR-based flipbooks allows abstract scientific concepts to be transformed into more concrete and visually engaging learning materials. For example, learners can observe three-dimensional representations of scientific phenomena, which supports conceptual clarity and reduces cognitive load. This aligns with findings from several studies indicating that AR-based learning media significantly improve students' conceptual understanding and comprehension skills (Fajariyanti, 2024). In addition, experimental studies confirm that AR integration fosters better learning achievement and academic performance compared to conventional instructional methods.

Furthermore, the implementation of AR-based flipbooks is strongly associated with increased student engagement and motivation in science learning.

Interactive features such as animation, 3D visualization, and multimedia integration encourage active participation and sustained attention during learning activities. Studies also highlight that AR-based systems provide immersive learning environments that support exploratory learning and enhance students' cognitive involvement (Ibrahim et al., 2020). As a result, learners are more motivated and show higher levels of interaction with learning materials.

The implementation of AR-based flipbooks in science education demonstrates significant pedagogical benefits, particularly in improving science literacy, conceptual understanding, and student engagement. Meta-analytic and review studies further confirm that AR technologies have a positive and consistent effect on learning outcomes across different educational levels (Cheng, 2021).

Therefore, AR-based flipbooks can be considered a promising instructional innovation in 21st-century science education, especially in supporting interactive and technology-enhanced learning environments.

In addition, the implementation of AR-based flipbooks also reflects a shift toward student-centered learning approaches in science education. Teachers are no longer the sole source of information, but rather facilitators who guide students in exploring scientific concepts independently through interactive digital media. This transformation is supported by needs analysis studies that emphasize the importance of integrating technology-based learning resources to meet the demands of 21st-century education (Fitriani & Lubis, 2023). Consequently, AR-based flipbooks not only function as instructional media but also as tools that support active learning and self-directed exploration.

Moreover, the integration of AR technology within flipbooks provides flexibility in learning delivery, allowing students to access learning materials both in classroom and independent learning environments. This aligns with the development studies that highlight the adaptability of AR-based learning media across different platforms, including Android and web-based systems (Fajariyanti, 2024; Rahayu et al., 2025). Such flexibility enhances the accessibility of science learning materials and supports continuous learning outside formal classroom settings, thereby contributing to more sustained learning experiences.

Advantages and Challenges of AR-Based Flipbooks

The use of Augmented Reality (AR)-based flipbooks in science learning offers several significant advantages that enhance the overall learning experience. One of the main benefits is the ability of AR technology to present abstract scientific concepts in a more concrete and visually engaging form. Through 3D visualization and interactive features, learners can better understand complex phenomena that are difficult to observe directly in real-life situations. This improves conceptual clarity and learning effectiveness, as supported by several studies indicating increased engagement and learning outcomes when AR is integrated into instructional media (Le & Park, 2022).

Another important advantage is the increase in student motivation and engagement during learning activities. AR-based flipbooks create immersive learning environments that encourage active participation and curiosity. Students are more interested in exploring scientific content because the learning process becomes more interactive and enjoyable. This aligns with findings that AR-based learning tools significantly improve student engagement and positive learning attitudes. Furthermore, the flexibility of AR flipbooks, which can be accessed through mobile devices or web platforms, allows learning to occur anytime and anywhere, supporting independent and continuous learning (Fajariyanti, 2024; Rahayu et al., 2025).

However, despite its advantages, the implementation of AR-based flipbooks also presents several challenges. One of the main challenges is the need for adequate technological infrastructure, such as smartphones, stable internet access, and compatible software. In some educational contexts, especially in under-resourced schools, these requirements may limit the effective implementation of AR-based learning media. Additionally, teachers may face difficulties in integrating AR technology into classroom instruction due to limited technical skills and lack of training in digital learning tools (Fitriani & Lubis, 2023).

Another challenge is the development cost and time required to design high-quality AR-based flipbooks. Creating interactive 3D content and integrating augmented reality features requires technical expertise and collaboration between educators, designers, and developers. This can be time-consuming and may not always be feasible for all educational institutions. Moreover, there is also a potential risk of cognitive overload if the AR content is not well-designed, which may reduce its effectiveness in supporting learning. Therefore, careful instructional design is essential to ensure that AR-based flipbooks provide meaningful and pedagogically effective learning experiences (Brahim et al., 2020; Mohamed & Shaaban, 2023).

In addition, AR-based flipbooks also provide strong support for differentiated learning, where students with different learning speeds and styles can learn at their own pace. Visual and interactive elements help low-achieving students grasp scientific concepts more easily, while advanced learners can explore deeper explanations through the same learning media. This inclusivity makes AR-based flipbooks a flexible instructional tool that accommodates diverse learner needs in science classrooms (Ekasafitri et al., 2024; Triyanto et al., 2025).

Moreover, the sustainability of AR-based flipbook implementation also depends on institutional support and curriculum integration. Without proper alignment with learning objectives and teacher readiness, the use of AR technology may not achieve optimal results. Therefore, schools need to provide continuous professional development for teachers and ensure that digital learning resources are integrated systematically into science curricula. When these conditions are met, AR-based flipbooks can become an effective long-term innovation in science education rather than just a temporary technological intervention (Li et al., 2024; Rahayu et al., 2025).

Science Skills Developed Through AR-Based Flipbooks

The integration of Augmented Reality (AR)-based flipbooks in science learning plays an important role in developing learners' science process skills. By presenting scientific content through interactive and three-dimensional visualizations, AR-based flipbooks help students engage more actively in observing scientific phenomena. This direct interaction with virtual objects strengthens learners' ability to identify key features, patterns, and relationships within scientific concepts (Siahaan et al., 2024). In addition, AR-based flipbooks support the development of classification and analytical skills. Learners are encouraged to categorize objects, compare scientific properties, and analyze dynamic processes presented in augmented environments. Such activities foster deeper cognitive processing and improve students' ability to construct meaningful scientific understanding rather than simply memorizing facts (Utama & Purwati, 2024; Triyanto et al., 2025).

Furthermore, AR-based flipbooks contribute significantly to the development of learners' skills in interpreting and drawing conclusions from scientific information. Through interactive simulations and augmented visual cues, students are guided to make evidence-based interpretations of observed phenomena. This process enhances their ability to connect theoretical concepts with real-world applications, thereby strengthening higher-order thinking skills in science learning (Ekasafitri et al., 2024). As students engage with dynamic representations, they become more capable of explaining scientific relationships in a structured and logical manner.

In addition, the use of AR-based flipbooks also fosters inquiry and problem-solving skills, which are essential components of science process skills. Students are encouraged to explore scientific scenarios, predict outcomes, and test their understanding through interactive content. This experiential learning approach not only improves conceptual mastery but also nurtures critical thinking and decision-making abilities in scientific contexts. Studies have shown that such immersive learning environments significantly enhance students' motivation and engagement, which in turn supports the development of deeper scientific inquiry skills (Cheng, 2021; Mohamed & Shaaban, 2023).

Furthermore, AR-based learning environments enhance predictive and inferential skills. Through interactive simulations, students can observe cause-and-effect relationships and make predictions based on experimental scenarios. This helps learners develop logical reasoning and scientific thinking, which are essential components of early science education.

Finally, AR-based flipbooks also strengthen students' communication skills in science. After exploring concepts through AR visualization, learners are able to express their findings, explain scientific processes, and communicate their understanding more effectively. Overall, AR-based flipbooks contribute not only to conceptual mastery but also to the holistic development of science process skills in learners.

Conclusion

This systematic literature review demonstrates that the implementation of Augmented Reality (AR)-based flipbooks in science learning provides significant contributions to improving students' learning experiences and outcomes. The integration of AR technology into flipbooks enables the transformation of abstract scientific concepts into interactive and three-dimensional visual representations, which enhances students' conceptual understanding, science literacy, and engagement in learning activities. This finding indicates that AR-based flipbooks have strong potential to support the development of technology-based science learning that is more interactive, student-centered, and relevant to the needs of digital-age learners. Furthermore, the findings indicate that AR-based flipbooks are effective in developing various science process skills, including observation, classification, analysis, interpretation, and problem-solving skills. These learning media encourage active participation and inquiry-based learning, allowing students to construct knowledge more meaningfully. In addition, AR-based flipbooks promote student motivation and engagement through immersive and interactive learning environments. Beyond improving science learning outcomes, the use of AR-based flipbooks also contributes to the development of essential 21st-century skills, such as critical thinking, creativity, collaboration, communication, and digital literacy. Therefore, the integration of AR technology into science learning can help schools prepare students to adapt to rapidly evolving technological and educational environments. Despite these advantages, several challenges were identified, including limited technological infrastructure, teacher readiness, and the need for specialized skills in developing AR-based learning media. Therefore, successful implementation requires adequate institutional support, teacher training, and proper instructional design to maximize its educational potential. In addition, this review also has several limitations that should be considered. The findings may be influenced by potential publication bias, as studies reporting positive results are more likely to be published than those reporting neutral or negative outcomes. Variations in research methodologies, sample characteristics, intervention duration, and assessment instruments across studies may also limit the comparability of findings. Furthermore, most of the reviewed studies were conducted at particular educational levels and within limited contexts, indicating that evidence regarding broader implementation across diverse educational settings remains insufficient. The limited availability of baseline and longitudinal data also restricts deeper understanding of the long-term effectiveness and sustainability of AR-based flipbook implementation. Overall, AR-based flipbooks represent an innovative and promising learning medium for science education in the digital era. Their ability to integrate visualization, interactivity, and immersive learning experiences makes them highly relevant for supporting future-oriented educational practices. Future research is recommended to further explore their long-term impact, scalability, and integration across different educational levels and learning contexts. More importantly, AR-based flipbooks have the potential to become a sustainable and adaptive innovation that supports the global digital transformation of education by creating meaningful, engaging, and technology-enhanced science learning environments for future generations.

Acknowledgments
The authors would like to express their sincere gratitude to all researchers, educators, and institutions whose studies contributed to this systematic literature review. Appreciation is also extended to colleagues and academic peers who provided valuable suggestions and feedback during the preparation of this article.

Author Contributions
Conceptualization: Asyifa Maharani, Yaswinda; Methodology: Asyifa Maharani, Nurhafizah; Data Collection and Analysis: Asyifa Maharani; Writing – Original Draft Preparation: Asyifa Maharani; Writing – Review and Editing: Yaswinda, Nurhafizah, Setiyo Utoyo; Supervision: Setiyo Utoyo. All authors have read and approved the final version of the manuscript.

Funding
This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflicts of Interest
The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

Afriana, J., Permanasari, A., & Fitriani, A. (2016). Project based learning integrated to STEM to enhance elementary school students' scientific literacy. *Jurnal Pendidikan IPA Indonesia, 5*(2), 261–267. https://doi.org/10.15294/jpii.v5i2.5493

Andriani, N., Jamaluddin, J., & Setiadi, D. (2023). Development of augmented reality learning media to improve students' scientific literacy. *Jurnal Penelitian Pendidikan IPA, 9*(7), 5678–5685. https://doi.org/10.29303/jppipa.v9i7.4125

Asyhari, A., Sunarno, W., & Sarwanto, S. (2022). Digital learning media integrated with augmented reality in science education. *Jurnal Penelitian Pendidikan IPA, 8*(5), 2401–2408. https://doi.org/10.29303/jppipa.v8i5.1894

Astuti, F. N., Suranto, S., & Masykuri, M. (2019). Augmented reality for teaching science: Students' problem solving skill, motivation, and learning outcomes. *JPBI (Jurnal Pendidikan Biologi Indonesia), 5*(2), 305–312. https://doi.org/10.22219/jpbi.v5i2.8455

Bond, M., Bedenlier, S., Marín, V. I., & Händel, M. (2020). Emergency remote teaching in higher education: Mapping the first global online semester. *International Journal of Educational Technology in Higher Education, 17*(1), 44. https://doi.org/10.1186/s41239-020-00282-x

Chi, M. T. H., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist, 49*(4), 219–243. https://doi.org/10.1080/00461520.2014.965823

Clinton, V. (2019). Reading from paper compared to screens: A systematic review and meta-analysis. *Journal of Research in Reading, 42*(2), 288–325. https://doi.org/10.1111/1467-9817.12269

Damopolii, I., Bito, G. S., & Resmawan, R. (2021). The effectiveness of problem-based learning to improve students' critical thinking skills. *Journal of Physics: Conference Series, 1764*, 012104. https://doi.org/10.1088/1742-6596/1764/1/012104

Darling-Hammond, L., Flook, L., Cook-Harvey, C., Barron, B., & Osher, D. (2020). Implications for educational practice of the science of learning and development. *Applied Developmental Science, 24*(2), 97–140. https://doi.org/10.1080/10888691.2018.1537791

Delgado, P., Vargas, C., Ackerman, R., & Salmerón, L. (2018). Don't throw away your printed books: A meta-analysis on the effects of reading media on reading comprehension. *Educational Research Review, 25*, 23–38. https://doi.org/10.1016/j.edurev.2018.09.003

Ekasafitri, M., Sismulyasih, N., & Purwati, P. D. (2024). Augmented reality flipbook as a guide to determining main idea in learning. *International Journal of Elementary Education, 8*(2), 218–228. https://doi.org/10.23887/ijee.v8i2.77338.

Fauzi, A., Prayitno, B. A., & Fatmawati, U. (2021). Student engagement in online science learning during the COVID-19 pandemic. *Jurnal Penelitian Pendidikan IPA, 7*(Special Issue), 105–112. https://doi.org/10.29303/jppipa.v7iSpecialIssue.1015

Fitriani, W., Asy'ari, M., Zubaidah, S., & Mahanal, S. (2020). Exploring the prospective teachers' critical thinking and critical analysis skills. *Jurnal Pendidikan IPA Indonesia, 9*(3), 379–390. https://doi.org/10.15294/jpii.v9i3.22988

Fredricks, J. A., Wang, M. T., Schall Linn, J., Hofkens, T., Sung, H., Parr, A., & Allerton, J. (2023). Using qualitative methods to develop a survey measure of math and science engagement. *Learning and Instruction, 83*, 101687. https://doi.org/10.1016/j.learninstruc.2022.101687

Haka, N. B., Anggoro, B. S., & Hamid, A. (2020). Interactive multimedia in science learning to improve critical thinking skills. *Jurnal Penelitian Pendidikan IPA, 6*(2), 219–226. https://doi.org/10.29303/jppipa.v6i2.411

Hiver, P., Al-Hoorie, A. H., Vitta, J. P., & Wu, J. (2021). Engagement in language learning: A systematic review of 20 years of research methods and definitions. *Language Teaching Research, 25*(3), 1–26. https://doi.org/10.1177/13621688211001289

Ibrahim, A., Huynh, B., Downey, J., Höllerer, T., Chun, D., & O'Donovan, J. (2018). ARbis Pictus: A study of language learning with augmented reality. *IEEE Transactions on Visualization and Computer Graphics, 24*(11), 2867–2874. https://doi.org/10.1109/TVCG.2018.2868568

Irwanto, Dianawati, R., & Lukman, I. R. (2022). Trends of augmented reality applications in science education: A systematic review from 2007 to 2022. *International Journal of Emerging Technologies in Learning, 17*(13). https://doi.org/10.3991/ijet.v17i13.30587

Järvelä, S., & Renninger, K. A. (2014). Designing for learning: Interest, motivation, and engagement. In *The Cambridge handbook of the learning sciences* (2nd ed.). Cambridge University Press.

Kalemkuş, J., & Kalemkuş, F. (2022). Effect of the use of augmented reality applications on academic achievement of student in science education: Meta-analysis review. *Interactive Learning Environments*. https://doi.org/10.1080/10494820.2022.2027458

Kurniawan, D. A., Astalini, A., & Darmaji, D. (2019). Mobile learning in science education: Students' attitudes and perceptions. *Jurnal Penelitian Pendidikan IPA, 5*(1), 45–52. https://doi.org/10.29303/jppipa.v5i1.316

Lin, C. Y., Chen, C. H., & Liu, Y. S. (2023). Augmented reality-supported science learning: Effects on motivation and engagement. *Computers & Education: X Reality, 2*, 100024. https://doi.org/10.1016/j.cexr.2023.100024

Mohamed, A. M., & Shaaban, T. S. (2023). Augmented reality technology and reading comprehension in early childhood education. *Education and Information Technologies*. https://doi.org/10.1007/s40692-023-00269-9

Nurhasanah, N., Kusumo, E., & Supartono, S. (2022). STEM-integrated augmented reality media in science learning. *Jurnal Pendidikan IPA Indonesia, 11*(3), 412–421. https://doi.org/10.15294/jpii.v11i3.34567

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., et al. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ, 372*, n71. https://doi.org/10.1136/bmj.n71

Parno, P., Yuliati, L., Munfaridah, N., Ali, M., & Rosyidah, F. U. N. (2020). The impact of project-based learning-STEM on problem-solving skills for students in the topic of electromagnetic induction. *Jurnal Pendidikan IPA Indonesia, 9*(1), 11–21. https://doi.org/10.15294/jpii.v9i1.21080

Putri, D. A., Widodo, W., & Sari, D. P. (2024). Effectiveness of augmented reality flipbook on students' learning outcomes and engagement. *Jurnal Penelitian Pendidikan IPA, 10*(2), 998–1007. https://doi.org/10.29303/jppipa.v10i2.6532

Rahayu, S., Meirawan, D., Muktiarni, M., Ghinaya, Z., Sabitri, Z., & Ismail, A. (2025). Development of an AR-based flipbook as an innovative learning resource. *Jurnal Pendidikan Teknologi Kejuruan, 8*(3), 141–154. https://doi.org/10.24036/jptk.v1i1.46223

Redecker, C. (2017). *European framework for the digital competence of educators: DigCompEdu*. Publications

Office of the European Union.

Ryan, R. M., & Deci, E. L. (2020). Intrinsic and extrinsic motivation from a self-determination theory perspective: Definitions, theory, practices, and future directions. *Contemporary Educational Psychology, 61*, 101860. https://doi.org/10.1016/j.cedpsych.2020.101860

Sari, M. P., Rohman, F., & Lestari, U. (2023). Augmented reality-assisted biology learning and students' conceptual understanding. *JPBI (Jurnal Pendidikan Biologi Indonesia), 9*(3), 455–466. https://doi.org/10.22219/jpbi.v9i3.25478

Schindler, L. A., Burkholder, G. J., Morad, O. A., & Marsh, C. (2021). Computer-based technology and student engagement: A critical review of the literature. *International Journal of Educational Technology in Higher Education, 18*(1), 1–28. https://doi.org/10.1186/s41239-021-00266-3

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

Sung, Y. T., Chang, K. E., & Liu, T. C. (2016). The effects of integrating mobile devices with teaching and learning on students' learning performance: A meta-analysis. *Computers & Education, 94*, 252–275. https://doi.org/10.1016/j.compedu.2015.11.008

Suprapto, N., Prahani, B. K., & Deta, U. A. (2021). The implementation of STEM-based learning to improve scientific literacy. *Jurnal Penelitian Pendidikan IPA, 7*(4), 558–565. https://doi.org/10.29303/jppipa.v7i4.809

Suzuki, R., Kazi, R. H., Wei, L.-Y., DiVerdi, S., Li, W., & Leithinger, D. (2020). RealitySketch: Embedding responsive graphics and visualizations in AR through dynamic sketching. *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology*, 166–181. https://doi.org/10.1145/3379337.3415892

UNESCO. (2021). *Reimagining our futures together: A new social contract for education*. UNESCO Publishing.

Wang, M. T., & Degol, J. L. (2014). Staying engaged: Knowledge and research needs in student engagement. *Child Development Perspectives, 8*(3), 137–143. https://doi.org/10.1111/cdep.12073

Wang, Y. (2022). Effects of augmented reality game-based learning on students' engagement. *International Journal of Science Education, Part B, 12*(3), 254–270. https://doi.org/10.1080/21548455.2022.2072015

Yuliana, I., Rosidi, I., & Hadi, W. P. (2024). Augmented reality in science classrooms: A systematic review of learning effectiveness. *Jurnal Penelitian Pendidikan IPA, 10*(1), 122–133. https://doi.org/10.29303/jppipa.v10i1.6124

Zufahmi, Z., Rohman, F., & Sari, M. S. (2025). Augmented reality in science learning: A systematic literature review. *JPBI (Jurnal Pendidikan Biologi Indonesia), 11*(1). https://doi.org/10.22219/jpbi.v11i1.38570.