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Augmented reality-integrated digital worksheets in science education: research trends, educational outcomes, and future directions from a systematic literature reviews

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ABSTRACT

The demands of digital transformation in the 21st century require continuous innovation in the design of science teaching materials, especially to replace static printed instruments. The integration digital worksheets presented in flipbook format with *Augmented Reality* (AR) technology offers strategic potential in visualizing abstract concepts of Natural Sciences (IPA) into immersive and interactive three-dimensional representations. This *Systematic Literature Review* (SLR) research aims to map research trends, evaluate the level of validity and practicality of media, and identify research *gaps* related to the use of these technologies. This review was limited to 15 peer-reviewed primary articles indexed in academic databases in the 2020 to 2026 publication range. The results of the analysis show that all AR-visualized digital worksheet developed achieve a very valid and practical predicate. Empirically, this fusion of technology has proven to be effective in reducing cognitive burden, shifting the learning paradigm to *student-centered*, and significantly spurring student motivation and learning outcomes. However, the findings reveal that the current research focus is still concentrated at the high school level for abstract materials (Biology and Chemistry) and has not targeted the integration of *Higher Order Thinking Skills* (HOTS) assessments in depth. This SLR concludes that the future development of digital worksheets-AR must go beyond the feasibility of basic media by adopting high-level reasoning instruments and expanding the scale of testing to the higher education level.

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Introduction

Digital transformation demands continuous innovation in the design of teaching materials, where digital worksheet now plays a crucial role in Natural Sciences (IPA) learning in Indonesia to replace static conventional printed instruments (Hidayah et al., 2025; Zahara et al., 2026). Format flipbook Specifically, it offers great potential as a digital medium because it is able to maintain an interactive cognitive schema like reading a physical book, but accommodates the integration of more dynamic and autonomous multimedia elements (Marisda et al., 2024; Siregar, 2025). In addition, the role of technology Augmented Reality (AR) in digital worksheet further disrupts this learning ecosystem by bridging complex and abstract science concepts into three-dimensional object representations in real space, which are empirically proven to reduce excessive cognitive load while deepening students' involvement and conceptual understanding of science (Abdilah & Wulandari, 2024; Sci-fi & Sci-Fi, 2025).

Although the use of digital worksheet is based on flipbook and AR has experienced a rapid surge, findings in the field are still scattered and there are high gaps and complexity in mapping previous studies due to fragmentation in methodological approaches, pedagogical models, and evaluation frameworks (Dyah et al., 2025; Wijayati et al., 2025). Many studies tend to report effectiveness outcomes separately on short-term interventions and miss an in-depth synthesis of implementation consistency and the most effective elements of AR integration (Nurjanah et al., 2024). This condition of fragmentation creates a fundamental urgency and need for study Systematic Literature Review (SLR) to collect, organize, and synthesize research results from these various studies in a coherent and comprehensive manner to strengthen understanding of the effectiveness of the integration of this technology in the field of science (Alfi & Ariyanti, 2026; Susiana & Priyatin, 2025).

Recent review studies have examined the use of Augmented Reality and digital learning resources in science education. For example, Prananta et al. (2024) reviewed the implementation of Augmented Reality in science learning, while Siki and Leba (2025) synthesized evidence regarding AR-based learning media and students' conceptual understanding. In addition, Marisda et al. (2024) reviewed the development trends of interactive flipbooks in educational contexts. However, these reviews focused on Augmented Reality applications and digital learning materials as separate domains. To the best of our knowledge, no systematic review has specifically synthesized studies investigating the integration of Augmented Reality within flipbook-based digital worksheets in science education.

To verify this research gap, a preliminary scoping search was conducted using Google Scholar through the Publish or Perish platform. The initial search identified 410 potentially relevant records published between 2020 and 2026. Preliminary screening revealed substantial variation in educational levels, science topics, instructional models, outcome measures, and implementation approaches. Studies reported diverse outcomes ranging from validity and practicality assessments to learning motivation, critical thinking, scientific literacy, and learning achievement. Such methodological heterogeneity makes it difficult to obtain a comprehensive understanding of current research trends and educational impacts, thereby necessitating a systematic synthesis of existing evidence.

Implementation Systematic Literature Review (SLR) is crucial for tracking and mapping the evolving trends of digital instructional research (Mujakir et al., 2024). A structured literature review is needed to highlight research dynamics such as trends in development method models that are commonly carried out by researchers (such as ADDIE or 4D model R&D), the level of education that is predominantly intervened, the specification of the field of science study explored (biology, physics, or chemistry), and the distribution of the surge trend in the year of publication (Fajarno et al., 2025; Hadi et al., 2025). Through bibliometric mapping and trend analysis, academics can measure how far the integration is flipbook and this AR has been implemented in the curriculum empirically and scientifically as opposed to mere technological innovations (Wicaksono et al., 2025).

Based on this background, this SLR research aims to systematically map the trends of digital worksheet-based research flipbook integrated AR technology in the science learning landscape (Pittanauli et al., 2026). In particular, this study seeks to identify the main findings of the empirical study including the level of validity and practicality of the developed media, its effect on improving learning outcomes, and its effectiveness in encouraging student motivation and engagement (Fitria & Halili, 2023; Maharani & Fathurrahman, 2025). Further, this systematic review aims to point out various gaps (Gap) research that is still minimally explored such as lack of accommodation of questions Higher Order Thinking Skills (HOTS) or the lack of research at the higher education level that needs to be the focus to be further developed (Sunarti & Admoko, 2025).

The scope of this literature review is focused specifically on the study of the development, application, and effectiveness of the formatted digital worksheet instrument flipbook visualize AR specifically in the scope of science learning education. To ensure a state-of-the-art results foundation with modern technological maturity, the SLR limits cover the time span of the publication of the study in the last five years, namely the period 2020 to 2026 (Hayati et al., 2023). In addition to time constraints, this review rigorously limits the type of publication to scientific papers through peer review (Peer-reviewed), which is an article from a journal from google schoolar written and presented within the limits of English (Hidayah et al., 2025).

The results of this comprehensive synthesis of SLR are expected to make a meaningful contribution to various practitioners and experts in the field of science education. For researchers, the findings from SLR provide a fundamental reference in formulating new research designs that can fill the gaps in the literature related to limitations in the field of edutechnology. For educators and digital worksheet developers, this evaluation will provide guidelines based on empirical evidence to design science-based companion media flipbook and AR which is not only technically more captivating, but pedagogically much more relevant, adaptive, and effective in equipping students with essential scientific skills for the 21st century (Saldiana et al., 2025).

Method

This research uses a design Systematic Literature Review (SLR) with a bibliometric and qualitative-descriptive approach that aims to map trends and analyze in depth research findings on digital worksheet-based flipbook Integrated Augmented Reality (AR) in Natural Sciences (IPA) learning. The SLR approach was chosen because it allows researchers to identify, evaluate, and interpret all relevant literature in a systematic, structured manner, and minimize bias in reviewing an educational phenomenon (Kitchenham & Charters, 2007; Snyder, 2019). Integration with bibliometric analysis is used to quantitatively map scientific structures, topic evolutions, and publication trends on a massive data scale (Regolini & Jannès-Ober, 2013). The results of the quantitative mapping are then described through a qualitative approach to obtain a comprehensive understanding of the implementation of these interactive media in science learning (Amanah et al., 2025; Rahmiati et al., 2023).

The literature search strategy is carried out extensively through the database Google Scholar by utilizing software Publish or Perish (PoP) to ensure that data collection runs efficiently and in a targeted manner (Fitri et al., 2025). This search uses a combination of key keywords that include "Augmented Reality", "Flipbook", and "E-LKPD (digital worksheet)". To expand the scope of search in a specific domain, these keywords are combined with synonyms and related terms such as "AR-assisted flipbook-based e-LKPD", "interactive flipbook", "science learning", and "IPA" (Alhusni et al., 2026; Prananta et al., 2024). The search terms were developed based on the main concepts of the study, namely Augmented Reality, digital worksheets, flipbooks, and science education. Keyword combinations were refined through preliminary scoping searches to ensure the retrieval of relevant studies and to minimize the omission of potentially eligible publications. Data collection is limited to a maximum of 1,000 documents according to the standard output configuration in the PoP application. After going through the initial data processing and cleaning stage from the system, 410 articles were obtained that were considered relevant and designated as candidates for initial analysis. To enhance transparency and reproducibility, the inclusion and exclusion criteria applied during the screening process are summarized in Table 1.

Tabel 1 <Inclusion and Exclusion Criteria for Selecting Studies on Augmented Reality-Integrated Digital Worksheets in Science Education>

Aspect	Inclusion Criteria	Exclusion Criteria	Rationale
Publication Year	2020–2026	< 2020	To capture recent developments in AR technology
Language	English, Indonesian	Other languages	Accessibility and accurate interpretation
Document Type	Journals, proceedings	Books, theses, reports	Ensure scientific quality and peer review
Research Focus	AR-integrated digital worksheets/flipbooks	Unrelated AR studies	Align with review objectives
Educational Context	Science education	Non-science subjects	Maintain domain specificity
Accessibility	Full text available	Abstract only	Enable complete analysis
Research Type	Empirical studies	Conceptual/commentary papers	Allow evidence-based synthesis

The screening process for candidate articles is based on the establishment of strict inclusion and exclusion criteria to maintain the quality of the literature. The inclusion criteria set require that articles be written in Indonesian or English, focusing substantially on the development or implementation of digital worksheet-based *flipbook* Integrated *Augmented Reality* in the context of science learning, as well as a form of publication in accredited journals or proceedings whose full text can be accessed (*full-text*). Instead, the exclusion criteria are applied to eliminate articles that do not discuss the digital worksheet instrument, *flipbook*, or *Augmented Reality*, as well as articles that do not focus on the domain of science learning (Sudarmin et al., 2025). In addition, non-research documents such as technical reports, theses or theses that are not published in journals, as well as abstract documents without a complete manuscript, are also excluded from the database (Nurhasnah et al., 2022; Primadianningsih et al., 2023).

Figure 1 presents the PRISMA-based article selection process. From 410 records initially identified, a series of screening and eligibility assessments resulted in 15 studies that met all inclusion criteria and were included in the final review.

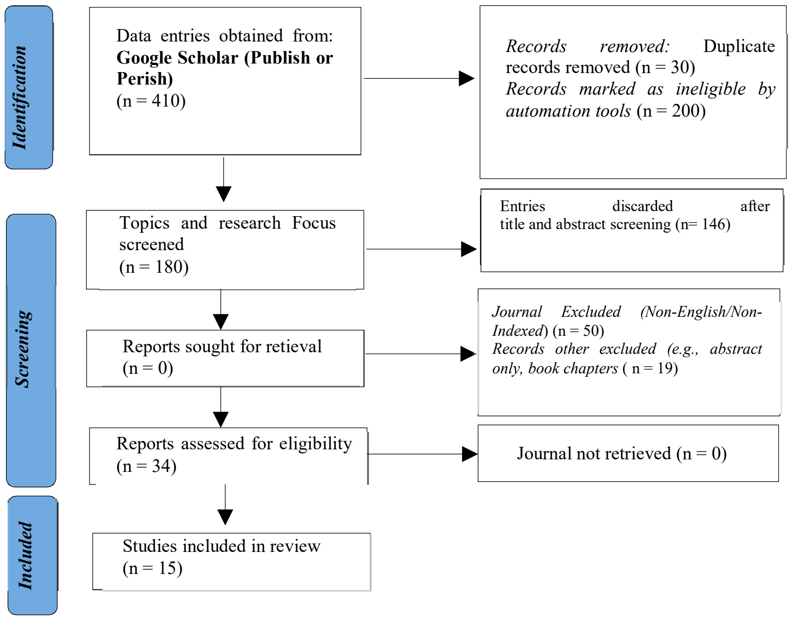

Figure 1 <PRISMA Flowchart>

The selection of articles in this study adopts a flow framework *PRISMA-like* (*Preferred Reporting Items for Systematic Reviews and Meta-Analyses*) to ensure a transparent and replicable selection process (Page et al., 2021). The selection stage consists of four main steps: Stage 1, namely identification, in which 410 candidate articles generated from PoP outputs are collected; Stage 2, i.e. screening (*Screening*), evaluate the suitability of titles and abstracts to the criteria, resulting in a number of articles that pass; Stage 3, i.e. feasibility (*Eligibility*), which involves a full manuscript evaluation (*full-text*) carefully to verify the relevance of the substance (Öztürk Çalık, 2022); and Stage 4, namely inclusion (*Inclusion*), in which articles that meet all criteria are finally determined for bibliometric analysis. The screening and eligibility assessment were conducted by the primary researcher based on predefined inclusion and exclusion criteria.(Miles et al., 2014).

The list of selected final articles is then exported into the RIS metadata format through the application *Publish or Perish* to facilitate data extraction (Setiya Rini et al., 2025). Bibliographic data including title, author, year of publication, journal, affiliation, keywords, and abstracts were analyzed bibliometrically using the VOSviewer software (van Eck & Waltman, 2014). The bibliometric analysis focused on keyword co-occurrence extracted from article metadata. Full counting was applied to identify relationships among keywords. Network visualization, overlay visualization, and density visualization were generated to examine thematic structures, topic evolution, and research concentration patterns. This visualization is used to map publication trends from the number of articles per year, keyword networks and research theme clusters, most productive countries or institutions, as well as the patterns of inter-research relationships related to digital worksheet, *flipbook*, and *Augmented Reality* in science learning. The outputs of VOSviewer are then described qualitatively in order to understand the dominant themes, development trends, and research gaps (*Research gap*) that require further study. Although it is systematically compiled, this SLR study has several limitations, including the focus of the search that only rests on *Google Scholar* via PoP, a maximum limit of 1,000 initial results that generate 410 articles as a candidate base, as well as reliance on metadata from those sources instead of global-scale commercial databases such as *Scopus* or *Web of Science*.

Results and Discussions

Digital Worksheet Flipbook AR Publication Trends (2020-2026)

The attached bar chart visualizes the trend of research publications related to Augmented Reality (AR)-based digital worksheet Flipbook learning media during the period 2020 to 2026. In the range of 2020 to 2022, there is no publication track record for this research topic at all. The topic only began to be explored in 2023 with one publication recorded, which then continued to stagnate at the same number in 2024 (Putri & Yulianti, 2024). This initial phase shows that the integration of AR technology into the digital Worksheet format is still in the early introduction stage and has not yet become a major trend among education researchers.

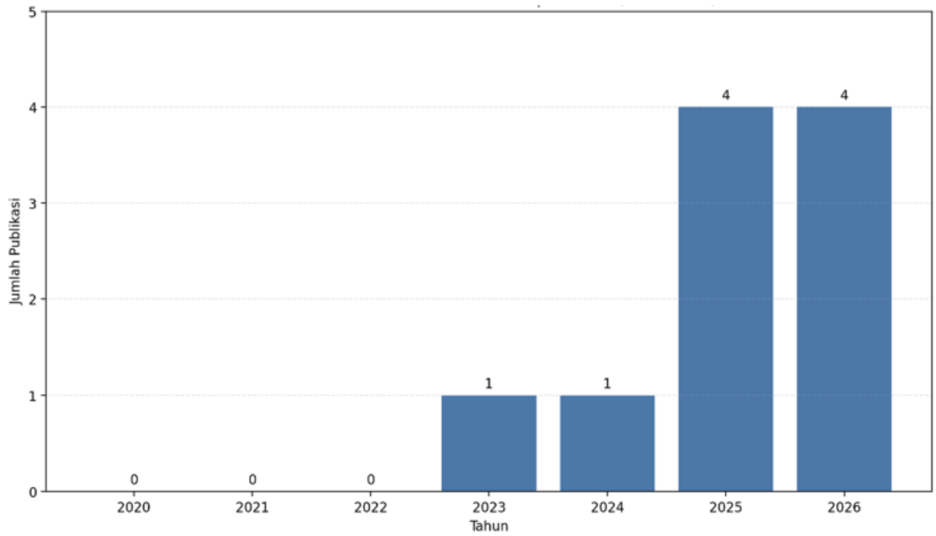

Figure 2 <Trends in Research Publication of Digital Worksheet Flipbook AR (2020-206)>

The publication trend shows a gradual increase in scholarly attention toward AR-integrated digital worksheets in science education. While only one study was identified in both 2023 and 2024, the number increased to four studies in 2025 (Fajarno et al., 2025; Fauni & Isdaryanti, 2025a; Maretha et al., 2025) and remained stable at four publications in 2026 (Amriani et al., 2026; Sartika et al., 2026b). Although the number of studies is still relatively limited, this pattern indicates growing research interest in the integration of Augmented Reality into digital learning resources. The increase observed between 2024 and 2025 may reflect the broader adoption of interactive educational technologies and the increasing demand for innovative science learning media capable of enhancing student engagement and conceptual understanding. Furthermore, the sustained publication output in 2026 suggests that AR-integrated digital worksheets have evolved beyond a temporary research trend and are increasingly recognized as a promising approach for supporting science learning in digital educational environments (Musa et al., 2025; A. D. Rizky & Nuha, 2026). The increase may be associated with the broader adoption of mobile-based AR applications, the acceleration of digital learning transformation following the COVID-19 pandemic, and the increasing demand for interactive science learning environments capable of visualizing abstract scientific concepts.

Distribution of Research Findings Focus

Based on Figure 3 bar chart of the categories of research findings, the highest focus of the analyzed studies led to the aspects of "Validity" and "Critical thinking", which recorded the highest number of findings, which respectively, recorded the highest number of findings, which was 4. This indicates that most studies prioritize the basic due diligence stage to ensure that the developed instrument or medium is expertly and empirically valid (Apmiyanti & Yerimadesi, 2024). In addition, the high findings on the critical thinking aspect show that these studies are very focused on the development of instruments that are not only suitable for use, but also specifically aimed at stimulating and measuring high levels of cognitive ability in students (AlGerafi et al., 2023).

In the middle position, there are three categories of findings that have identical frequency of occurrence, namely "Practicality", "Effectiveness", and "Learning motivation", with a total of 3 findings each. The even distribution in these three aspects shows a continuous pattern of educational research. Once a product is confirmed for validity, researchers consistently evaluate the extent of the practicality of the medium when used directly by teachers and students, as well as how effective it is in supporting the learning process (Darmawan & Suranata, 2025). At the same time, evaluation of learning motivation is also the most frequently observed affective variable to accompany the effectiveness test of the product (Asasiatinnisa & Kurnianto, 2026).

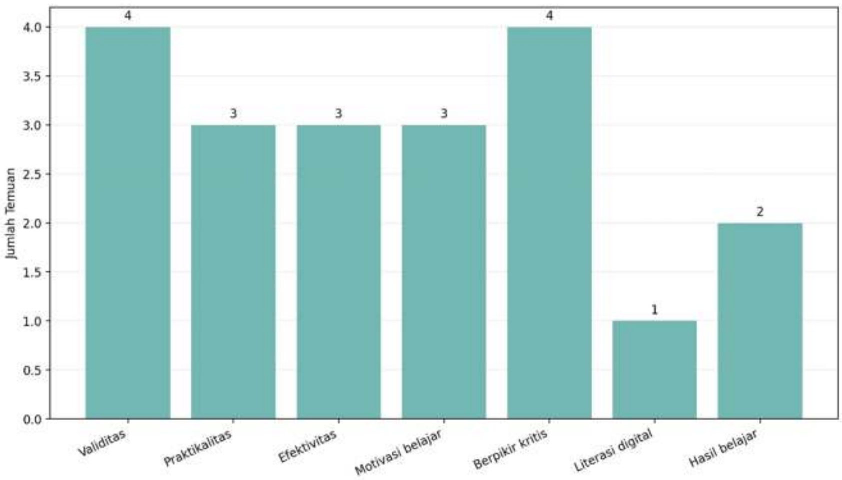

Figure 3 <Bar Chart of Research Findings Categories>

In contrast, the "Learning outcomes" and "Digital literacy" categories occupy the lowest positions on this graph, with the number of findings being 2 and 1 respectively. The most minor number in the digital literacy variable shows findings that are quite contrasting when associated with the current era of education digitalization. This condition also gives rise to *Research gap* or research gaps that have great potential to be filled in future research. In the future, researchers have a great opportunity to shift the focus slightly from conventional learning outcome measurement towards the development of evaluations that specifically measure and improve students' digital literacy skills (Solikha & Shofiyah, 2025).

Distribution Matrix Study Characteristics

The study characteristic distribution matrix provides visualization (*Heatmap*) on mapping literature based on the level of education and subjects studied. Based on the diagram, the highest and dominant research concentration is concentrated at the Senior High School (SMA) level, especially for the subject of Chemistry, which recorded the highest number of studies with 6 publications (Amriani et al., 2026; Sartika et al., 2026b; Utami et al., 2025). The predominance of dark blue in these cells indicates that the characteristics of Chemistry material at the upper secondary level, which are generally rich in abstract and microscopic concepts, are a priority target for researchers to intervene, most likely to facilitate students' visualization and understanding through the media or learning instruments developed (Amriani et al., 2026; Sartika et al., 2026b).

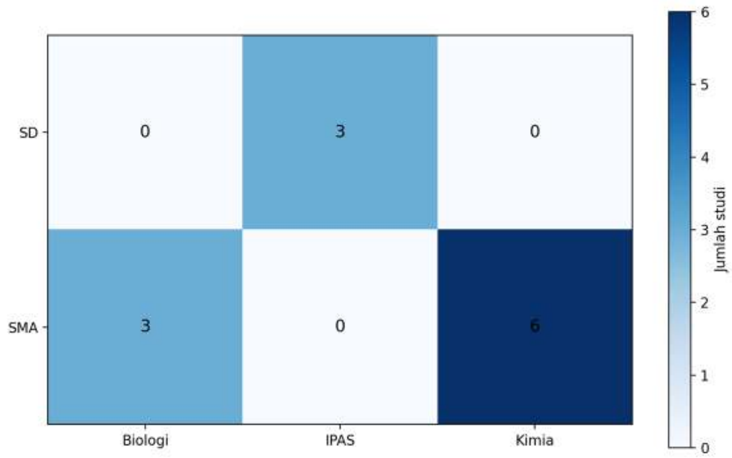

Figure 4 <Distribution Matrix Study Characteristics>

At the medium intensity level (light blue), there are two research clusters that have identical frequency of occurrence, namely 3 studies each. The first cluster focuses on the elementary school (SD) level for science (Natural and Social Sciences) subjects (Cahya & Bektiningsih, 2024; Fauni & Isdaryanti, 2025b; Lestari & Setyasto, 2025), while the second cluster targets the high school level in Biology subjects. The distribution of this data shows that in addition to Chemistry, other scientific disciplines such as Biology at the intermediate level also receive a proportionate portion of research attention. On the other hand, the emergence of 3 science studies at the elementary level shows an active response from researchers to the current basic education curriculum structure that integrates science and social sciences (Cahya & Bektiningsih, 2024; Hermayanti & Setyasto, 2025).

Furthermore, the white matrix area clearly identifies the absence of research findings (value 0) in certain slices of levels and subjects, which at the same time represents the alignment of research trends with the hierarchy of formal curriculum in Indonesia. The absence of specific publications for the branches of Biology and Chemistry separately at the elementary level is very logical, considering that the content of science at the elementary level is merged into a holistic unit in the science subject (Fauni & Isdaryanti, 2025b). On the other hand, the absence of a label of IPAS studies at the high school level also confirms the structure of academic specialization at the upper secondary level, where science has been broken down into more specialized disciplines (Chelly Sonelvia Utami et al., 2025; Musa et al., 2025). This emptiness mapping indirectly validates the limitations of the contextual scope of the literature pool being analyzed.

Bibliometric Mapping Analysis

This section presents an in-depth analysis of bibliometric mapping of digital worksheet research trends based on *flipbook-integrated Augmented Reality* (AR) in science learning using VOSviewer software. Through the integration of data from reputable databases, this analysis was conducted to visualize the conceptual structure, topic evolution, and research density during the period 2020 to 2026. By examining *Network Visualization*, *Overlay Visualization*, and *Density Visualization*, this study aims to uncover the dominant research clusters, shifts in research trends from time to time, and identify research *gaps* that are crucial for the development of science learning in the future. The findings of this mapping are expected to be able to provide a comprehensive overview of *the research roadmap* that has been carried out as well as the strategic direction of developing more innovative and effective digital teaching materials.

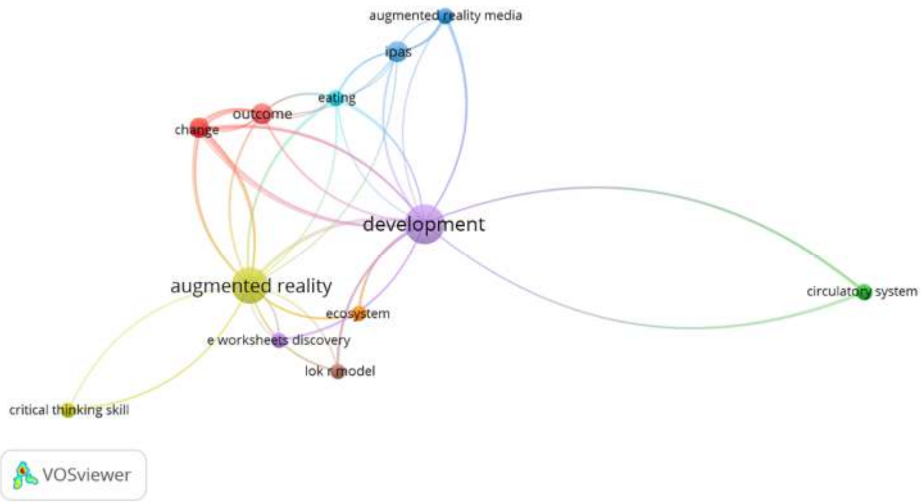

Figure 5 <Network Visualization>

The bibliometric map above shows that the research constellation is dominated by two *node* The most massive centers are "augmented reality" and "development". This confirms that the main trend in the literature is currently centered on research and development (R&D) of AR-based interactive learning media to visualize science materials. Second *node* This main has a line of connection (*edges*) which is very strong with *node* "outcome" and "change", and *node* specific materials such as "IPS", "eating", and "ecosystem". This cluster logically represents the focus of research that proves that the development of AR media is very effective in improving learning outcomes (*Learning outcomes*) and facilitate students' understanding of science subjects (Natural and Social Sciences) at the basic education level, especially to visualize the forms of substances and their changes, the interaction of eating and eating (food chain), to the concept of ecosystems (Cahya & Bektiningsih, 2024; Fauni & Isdaryanti, 2025b; Hermayanti & Setyasto, 2025; Silmi

& Bektiningsih, 2025). The development of interactive media in this cluster is also consistently validated for its feasibility to support more concrete and meaningful learning (Anggreni et al., 2026; Atut et al., 2023).

At the periphery or edge of the network, there is *node* more specific but very essential, such as "Critical Thinking Skill", "E Worksheets Discovery", "LOK R Model", and "Circulatory System". The emergence of this cluster indicates the evolution of the direction of research that has begun to shift from simply improving basic learning outcomes to integrating AR with specific pedagogical models to spur Higher Level Thinking Skills (HOTS). Usage *E-worksheet* (e-LKPD) visualized AR is now strategically combined with approaches such as *Discovery Learning*, *Inquiry*, as well as the LOK-R model to stimulate critical reasoning (*Critical Thinking*São Paulo S (Fajarno et al., 2025; Maretha et al., 2025; Musa et al., 2025; Sartika et al., 2026b). Furthermore, the existence of *node* "circulatory system" that is directly connected to *node* "development" confirms that AR is highly relied upon to dismantle misconceptions in highly complex and microscopic scientific materials, such as the circulatory system, in order to improve health literacy and critical thinking at a higher level (Putri & Yulianti, 2024; Saragih & Pratama, 2026).

This bibliometric pattern is consistent with the findings extracted from the fifteen reviewed studies, in which most publications employed research and development approaches and focused on validating AR-integrated learning media before examining broader educational impacts. The convergence between bibliometric mapping and qualitative synthesis indicates that the field remains predominantly development-oriented rather than outcome-oriented.

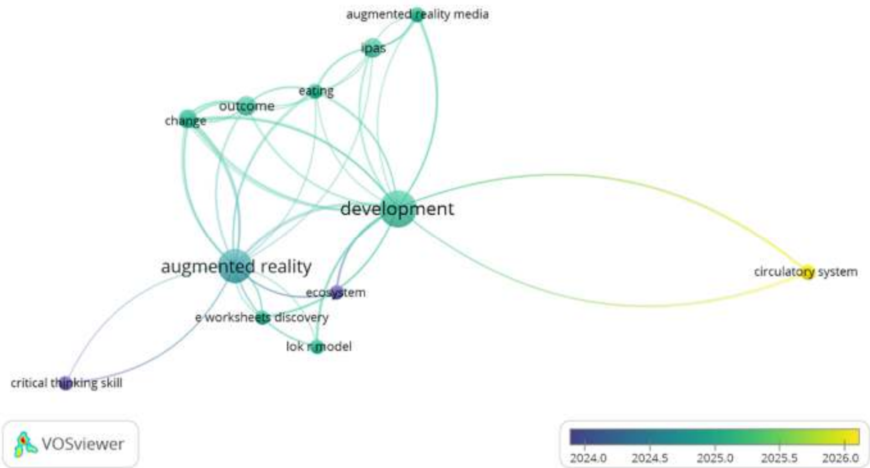

Figure 6 <Overlay Visualization>

Visualization *Overlay* (temporal mapping) of the VOSviewer illustrates the chronological evolution and trend of updating research topics related to learning media *Augmented Reality* (AR) from 2024 to 2026. In the purple to dark blue color spectrum that represents the initial study (around 2024), the focus of the research is still on fundamental variables such as "critical thinking skills" and the basic ecological concept, namely "ecosystem" (Cahya & Bektiningsih, 2024; Putri & Yulianti, 2024). Entering the mid-phase in 2025 marked by dominance *node* Turquoise green, the research landscape has undergone a massive expansion on the keywords "augmented reality" and "development". During this period, researchers began to intensively measure the impact ("outcome" and "change") of the development of AR media integrated with specific modules or instruments such as "lok r model" and "e discovery worksheets" to facilitate "ipas" subjects, especially on the phenomenon of "eating" or food webs (Fajarno et al., 2025; Fauni & Isdaryanti, 2025b; Maretha et al., 2025; Silmi & Bektiningsih, 2025). This shows the existence of methodological maturity where AR technology is beginning to be systematically combined with various literacy instruments and pedagogical models at the secondary and primary education levels.

Furthermore, the trend shift towards the yellow color spectrum represents the limit of novelty (*Frontier*) research in the range of 2025 end to 2026. Emergence *node* The "circulatory system" that lights up in bright yellow indicates that the focus of the exploitation of AR technology is now being directed specifically to solving cognitive barriers to anatomical or scientific materials that are very microscopic and complex (Saragih & Pratama, 2026). This evolutionary trajectory from macroecosystem to microcirculatory systems confirms the latest research trend that is increasingly sharp in testing the effectiveness of AR combined with cutting-edge contextual approaches, in order to unravel misconceptions in advanced science materials

(Amriani et al., 2026; Anggreni et al., 2026; A. D. Rizky & Nuha, 2026; Sartika et al., 2026a). This visualization holistically validates that the direction of the development of digital worksheet and AR-based modules is no longer just a question of media feasibility testing, but has evolved into an essential instrument to facilitate high-level health and science literacy on the most abstract exact topics.

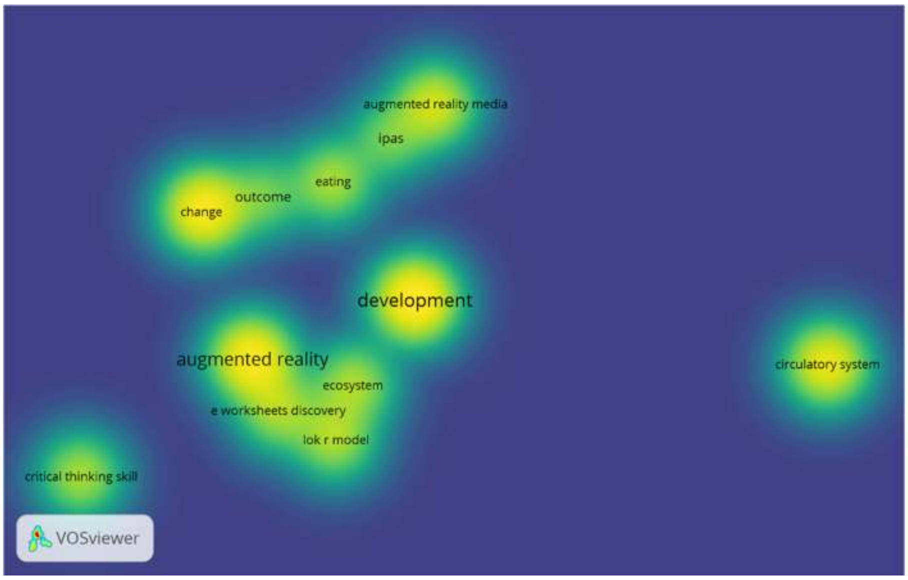

Figure 7 <Density Visualization>

Visualization *Density* The bibliometric mapping above clearly illustrates the main concentration of research centered on bright yellow areas, where *node* "Development" and "augmented reality" dominate the research landscape. The high density at these central points confirms that the current literature trend is heavily focused on the development of media innovations and based learning instruments *Augmented Reality* (AR) to facilitate the visualization of complex materials (Amriani et al., 2026; Anggreni et al., 2026). Densely populated areas that are closely connected to *node* "Outcome" and "change" represent the researchers' dedication to measuring the significant impact and positive change that results from the implementation of such media on student learning outcomes (Hermayanti & Setyasto, 2025; Sartika et al., 2026a; Silmi & Bektiningsih, 2025). These findings are consistently supported by numerous studies that validate the effectiveness of digital worksheet products and *flipbook* visualize AR in creating a more interactive and student-centered learning environment at different levels of education (Atut et al., 2023; Fauni & Isdaryanti, 2025b).

In the peripheral distribution, which also shows prominent density intensity, there is a specialization in the integration of AR technology with certain cognitive variables and pedagogical models. Density on *node* "Critical thinking skills" and the dissemination of specific material concepts such as "circulatory system", "ecosystem", as well as "IPS" and "eating" (food chain) subjects prove that AR is intensively developed to dismantle misconceptions in abstract and microscopic science materials (Cahya & Bektiningsih, 2024; Saragih & Pratama, 2026). Furthermore, the area that houses the "e worksheets discovery" and the "lok r model" marks the evolution of a trend in which AR no longer stands as an additional visual medium, but has been structurally integrated with digital worksheet instruments and scientific learning models to stimulate high-level reasoning (Fajarno et al., 2025; Maretha et al., 2025)The focus on deepening analytical reasoning through this instrument is a strong indicator that science education research is moving progressively towards strengthening literacy and multidimensional problem-solving (Musa et al., 2025; Putri & Yulianti, 2024; A. Rizky & Nuha, 2026).

Findings Based on 15 Articles (2020-2026)

This section presents the results of data extraction and synthesis from 15 primary articles that have met the *inclusion criteria* in this systematic review. Overall, the selected literature was published in the period 2020 to 2026, which represents the latest trend in the use of *Augmented Reality* (AR) technology in digital teaching materials, especially in the format of e-LKPD (digital worksheet), e-Module, and *Flipbook* in the science learning landscape. In order to provide a comprehensive and structured empirical picture, all the characteristics and findings of these studies are summarized into a literature extraction matrix. This table maps specifically the author's reference and year of publication, the integration of pedagogical models, educational and material level targets, and central findings related to the level of validity, practicality, and significance of their effectiveness on learning outcomes and student motivation. The mapping details in the following table will be an essential foundation for thematic analysis and in-depth discussion in the next subchapter:

Table 2 <Trend Matrix and Research Findings of Digital Worksheet(e-LKPD) Based on Flipbook Integrated Augmented Reality in Science Learning>

Author & Year	**Learning Platform & Model**	**Science Subjects & Materials**	**Validity & Practicality**	**Impact (Learning Outcomes, Cognitive, Motivation)**	**Identifying *Research Gaps***
Amriani et al. (2026)	e-Module Flipbook + AR (*Problem Based Learning*)	High School / Chemical Bonding	Very Worth It (98% practicality)	Engagement and interest in learning increased significantly.	Has not touched the high-level evaluation (HOTS); subjects are limited to high school.
Hermayanti & Setyasto (2025)	E-materials + AR	S.S. / Substance	Highly Qualified (91.4% Subject Matter); Practical (97.02%)	Effective in improving learning outcomes with an N-Gain **of 0.62** (Medium Category).	It still focuses on elementary school level with basic cognition; it has not targeted *complex problem-solving*.
Fauni & Isdaryanti (2025)	Flipbook + AR	SD / Respiratory System	Very Feasible (Media 93%); Practical (Students 96.15%)	Improving the learning outcomes of social studies with an N-Gain **of 0.71** (High Category).	It has not been integrated with 21st century learning models (such as STEM/STEAM).
Anggreni et al. (2026)	Flipbook + AR (*Problem Based Learning*)	SMA / Virus	Highly Valid (KVG 1.00); Very Practical (86.9% Students)	Motivate active engagement and visualization of abstract material.	The exploration of the evaluation of HOTS has not been in-depth; has not been tested at the university level.
Silmi & Bektiningsih (2025)	Flipbook + AR	SD/Food Chain	Very Valid (88.75% material); Student Response 92.53%	Improved learning outcomes with an N-Gain **of 0.38** (Medium Category).	Effectiveness is still at a moderate level; need AR interactivity optimization to spur HOTS.
Atut et al. (2023)	Flipbook + AR	SD/Water Cycle	Highly Relevant (Media 90%, Material 91.6%)	Help students visualize the flow of the water cycle in a concrete way.	There has been no quantitative effectiveness testing (such as N-Gain) on learning outcomes.
Lighting & Lighting (2024)	Flipbook + AR	SD/Ecosystem	Very Feasible (90% Media, 94% Material)	Very effective in improving learning outcomes with an N-Gain **of 0.78** (High Category).	The focus of the evaluation is still on the achievement of the KKM, not measuring analytical/synthesis reasoning.

Author & Year	**Learning Platform & Model**	**Science Subjects & Materials**	**Validity & Practicality**	**Impact (Learning Outcomes, Cognitive, Motivation)**	**Identifying *Research Gaps***
Putri & Yulianti (2025)	e-Module + AR	High School / Coordination System	Highly Valid (100%); Practical (95%)	Learning motivation (N-Gain **0.72** / High); Critical thinking (N-Gain **0.31** / Medium).	Critical thinking is still at a moderate level; AR instruments need to further facilitate HOTS case studies.
Saragih & Pratama (2026)	e-Module + AR (*Socio-Scientific Issues*)	High School / Circulation System	Excellent (Material 3.82 / 4.00)	Health literacy (N-Gain **0.41**); Critical Reasoning (N-Gain **0.70** /High).	The SSI approach has great potential for HOTS, but has not yet been implemented at the College level.
Musa et al. (2025)	LKPD + AR (*Inquiry Learning*)	High School / Classification of Living Beings	Very Valid (Material 93%, Medium 86%)	Improve science process skills through direct identification.	There has been no quantitative learning outcome effectiveness test (N-Gain).
Utami et al. (2025)	e-LKPD + AR (*Problem Based Learning*)	High School / Chemical Bonding	Very Decent (Medium 4.8/5); Trial 92.2%	Create self-paced learning and submicroscopic visualization.	The impact on students' advanced logical reasoning/HOTS has not been measured.
Sartika et al. (2026)	e-LKPD + AR (*Contextual Teaching and Learning*)	High School / Atomic Structure	Very Feasible (Material 4.4/5); Student Response 88.72%	It has been proven to significantly foster students' interest in learning.	Focusing on affective (interest); has not targeted high-level HOTS cognitive evaluation.
Maretha et al. (2025)	e-LKPD + AR (Model LOK-R)	SMA / Thermodynamics	Very Feasible (Medium 90.2%); Response 92.5%	Very effective in improving critical thinking skills (N-Gain **0.73** / High).	It has touched critical thinking, but the sample is limited to high school.
Rizky & Nuha (2026)	Module + AR	Junior High School / Digestive System	Very Valid (91.67%); Practicality 87.50%	Increasing science literacy is very effective with an N-Gain **of 0.72** (High Category).	Science literacy focuses on junior high school; Exploration for the high academic level has not been carried out.
Fajarno et al. (2025)	e-Worksheet + AR (*Discovery Learning*)	High School / Renewable Energy	Very Feasible (Material 85%, Media 84%)	Active involvement and ease of understanding abstract concepts of energy.	The evaluation is still limited to *user response*, there is no statistical test of critical reason/HOTS.

Across the fifteen studies included in this review, several recurring patterns were identified. First, all studies reported positive validity and practicality outcomes, indicating that AR-integrated digital worksheets are generally feasible for science learning implementation. Second, the majority of studies demonstrated positive effects on learning outcomes, critical thinking skills, science literacy, learning motivation, or student engagement. However, the reported impacts varied depending on educational level, science topic, and instructional design. Studies integrating inquiry-based, discovery learning, contextual teaching and learning, and problem-based learning approaches tended to report stronger cognitive and affective outcomes than studies focusing solely on media development and validation. These findings suggest that pedagogical integration plays an important role in maximizing the educational potential of AR-based digital worksheets.

A systematic review of the fifteen articles shows the dominance of the *Research and Development* (R&D) with instructional models such as ADDIE and Lee & Owens. This methodological trend indicates that researchers are currently focusing heavily on the rigorous empirical testing stage to ensure the level of validity, practicality, and reliability of the instrument before it is widely implemented (Cahya & Bektiningsih, 2024; Utami et al., 2025). Contextually, the distribution of research is highly concentrated at the primary and secondary education levels, especially in elementary schools (SD) and high schools (SMA) (Hermayanti & Setyasto, 2025; Saragih & Pratama, 2026). Ironically, this mapping reveals a significant scarcity at the higher education level, which suggests that technology adoption *Augmented Reality* (AR) integrated into modules or LKPD is currently still seen as a basic pedagogical tool for school age, rather than as an essential instrument for advanced science exploration in the academic environment of the university.

Across the fifteen studies reviewed, the majority reported validity scores above 85% and practicality scores above 80%, indicating a consistent pattern of high feasibility for implementing AR-integrated digital worksheets in science learning environments. This consistency is not merely coincidental but reflects the complementary strengths of integrating flipbook technology with Augmented Reality (AR). Flipbooks provide structured and user-friendly navigation similar to conventional printed materials, while AR extends learning experiences beyond two-dimensional representations by projecting three-dimensional (3D) visualizations into real-world environments (Fauni & Isdaryanti, 2025b; Putri & Yulianti, 2024). Such integration is particularly valuable in science education, where students often encounter abstract, microscopic, and complex concepts that impose substantial cognitive demands. Several studies highlighted the effectiveness of AR-integrated digital worksheets in visualizing topics such as atomic structures (Sartika et al., 2026b), virus interactions (Anggreni et al., 2026), and the circulatory system (Saragih & Pratama, 2026). These findings suggest that AR-based digital worksheets can effectively bridge the gap between theoretical concepts and concrete visual representations, thereby enhancing the feasibility and instructional value of science learning media.

Furthermore, the integration of this technology has been proven to empirically drive the transformation of learning from the *teacher-centered* be an exploratory experience that *student-centered*. Precise and interactive AR visualizations have proven to be effective in improving students' science literacy and critical reasoning, as evidenced by the spike in scores *N-Gain* in the medium to high category (Maretha et al., 2025; A. D. Rizky & Nuha, 2026). In addition to spurring the cognitive aspect, the spatial immersion presented by AR provides a positive affective impact ; learners show a sharp increase in motivation, interest, and learning engagement (Amriani et al., 2026; Fajarno et al., 2025). When science objects can be manipulated and observed independently in digital worksheet, science learning is no longer reduced to just a rigid text memorization process, but is transformed into a dynamic, relevant, and engaging investigation of natural phenomena.

Despite offering promising effectiveness, this review critically uncovered two loopholes (*Gap*) fundamental research that has not been solved. First, the accommodation of evaluation instruments that specifically target *Higher Order Thinking Skills* (HOTS) is still very superficial. Most studies, although claiming to use innovative approaches such as *Problem Based Learning* or *Inquiry*, in practice, still dwells on mastering basic concepts and does not challenge students to synthesize, evaluate, or create holistic problem-solving (Musa et al., 2025; Silmi & Bektiningsih, 2025). Second, the scarcity of studies at the higher education level has stagnant implications for the maturity of this literature. In fact, exact students in college are faced with much more complex scientific phenomena (bio-chemistry-physics), which are precisely essential and require the support of a high level of spatial visualization from AR. This void signifies that the full potential of AR has not been exploited as a catalyst for advanced science research.

The implications of these findings provide strategic direction for education practitioners and researchers alike. Development of digital worksheet-based *flipbook* Future AR should not be satisfied with just proving the validity of the media or improving the learning outcomes of low cognitive levels. Pedagogical engineering should then explicitly integrate in-depth HOTS assessment designs, for example by bringing together AR with approaches *Socio-Scientific Issues* (SSI) or framework *Science, Technology, Engineering, and Mathematics* (STEM) to spur argumentative reasoning and complex problem solving (Saragih & Pratama, 2026). In addition, the urgency to adapt, research, and elevate this technology to the higher education level must be realized immediately. Through this leap, AR-integrated digital worksheet innovations can evolve from just teaching media in schools to essential analytical instruments for science learners at all levels.

Conclusions

Across the fifteen studies reviewed, AR-integrated digital worksheets consistently demonstrated high levels of validity and practicality, with most studies reporting validation scores above 85% and practicality scores exceeding 80%. In addition, the majority of studies reported positive impacts on learning outcomes, scientific literacy, critical thinking skills, learning motivation, and student engagement. Interpretation of research trends through VOSviewer bibliometric mapping confirms that the current research focus is still very focused on the development cluster. This trend is dominated by efforts to exploit AR features to visualize abstract and microscopic science concepts in integrated Biology, Chemistry, and Science subjects, such as atomic structure, ecosystem interactions, and blood circulation systems.

Nevertheless, gap analysis emphasizes the need for a fundamental shift in focus on future research. The next research must move beyond just a feasibility test and the development of basic media, towards the integration of evaluation instruments that specifically target Higher Order Thinking Skills (HOTS). In addition, there is a high urgency to expand the testing of the effectiveness of this media at the higher education level, as well as to examine its long-term impact on improving digital literacy and critical reasoning of learners. As a practical implication, it is highly recommended for education practitioners (teachers) and developers of digital teaching materials to proactively adapt AR technology in compiling science instructionals. The use of digital worksheet in the format of AR flipbooks not only enriches the variety of visual media, but also plays a crucial role as a catalyst to transform the teacher-*centered* paradigm into a more contextual, immersive, and meaningful science learning experience.

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