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Advancing Scientific Literacy through Digital Learning Media and Learning Management Systems in Online Learning: A Systematic Review

Wersi Handayani* University of Bengkulu, INDONESIA
Mohammad Qais Rezvani Rana University, AFGHANISTAN
Amel Zulfukar Hassan Adlan Nile Valley University, SUDAN

*** Corresponding author:**
Wersi Handayani, University Of Bengkulu, INDONESIA ✉ wersichy77@gmail.com

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Abstract

Background: The rapid development of digital technology has transformed online learning, making digital learning media and Learning Management Systems (LMS) important components in supporting scientific literacy. However, previous studies have reported fragmented findings regarding the effectiveness of integrating digital learning media and LMS in enhancing students' scientific literacy.
Aims: This study aims to systematically review the current literature on the integration of digital learning media and Learning Management Systems in online learning and to identify research trends, implementation strategies, and their contributions to improving scientific literacy.
Methods: This study employed a Systematic Literature Review (SLR) following the PRISMAguidelines. Relevant publications from 2020–2026 were retrieved from the Scopus database using keywords related to scientific literacy, online learning, digital learning, and technology/media/platform. The retrieved data were refined using OpenRefine, analyzed bibliometrically through Biblioshiny and VOSviewer, and synthesized using Elicit AI. After applying the inclusion and exclusion criteria, eight eligible articles were included in the final review.
Results: The review indicates that integrating digital learning media with LMS positively contributes to scientific literacy by improving conceptual understanding, learning outcomes, scientific data interpretation, and student engagement in online learning. Most studies employed Research and Development (50%), followed by quantitative (25%), qualitative (12.5%), and mixed-methods (12.5%) approaches.
Conclusion: Integrating digital learning media and Learning Management Systems has significant potential to enhance scientific literacy in online learning. Future research should expand implementation across diverse educational contexts and strengthen methodological rigor to support sustainable digital learning innovations.

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INTRODUCTION

21st Century Education and Digital Transformation The global view of 21st century education emphasizes the transformation of learning in the digital age and the drive towards the industrial revolution 4.0. This change requires the mastery of critical thinking skills, problem solving, science literacy, and the ability to adapt to technology and information. The abundance of international frameworks emphasizes that 21st century skills, particularly the 4Cs (critical thinking, communication, collaboration, creativity), are prerequisites for competing in the global job market and facing global challenges such as climate change, technological advancements, and health issues. Various studies state that 21st century skills include learning and innovation skills, information, media and technology skills, as well as life and career skills that need to be nurtured from primary to secondary education (Suryawan, 2022; Banila et al., 2021). In addition, science literacy is seen as the key to competence to make evidence-based decisions in the midst of these global challenges (Kahar

et al., 2021; Safitri, 2022). This transformation is also taking place in tandem with an increasing emphasis on a student-centered learning paradigm driven by recommendations from international partnerships such as P21 and 21st century competency definitions that drive resource collection, problem formulation, analysis, and collaboration (Rawung et al., 2021; Suryawan, 2022).

The Urgency of Scientific Literacy in Education Science literacy is defined as a combination of scientific knowledge, processes, contexts, and attitudes that enable students to understand, disseminate, and use scientific information in daily life and evidence-based decision-making. The definition and dimensions of literacy have been discussed in the literature that conveys the linkages between knowledge, scientific processes, social/ecological contexts, and scientific attitudes (e.g., skepticism, proof-reasoning) (Hadrian et al., 2023). International surveys such as PISA show that low literacy levels are the quality of science-based education and assistance in many countries, including Indonesia, hence the need for more effective teaching strategies in improving science literacy comprehensively (Tursinawati & Widodo, 2019; Selamat, 2023; Safitri, 2022). The impact of low science literacy has the potential to weaken citizens' ability to understand issues such as change, public health, and data-driven decision-making, so that science literacy is seen as a key competency that needs to be prioritized in the 21st century curriculum (Safitri, 2022).

Towards Digital and Online Learning The transition from conventional to digital learning has been accelerated by the COVID-19 pandemic, which has accelerated the adoption of online learning and the use of information technology in the teaching and learning process. The learning paradigm is shifting from teacher-centered to student-centered, with an increasing need for learning design that focuses on the 4Cs as well as digital literacy and information technology literacy (Wildan et al., 2022; Putriani & Hudaidah, 2021; Puspa et al., 2023). Digital learning challenges include disruption, uneven accessibility, and interaction between students and teachers that demand adaptive and inclusive pedagogical strategies (Siswati, 2019). Several studies also highlight that the bold learning model needs to be enriched with approaches that maintain the quality of student interaction,

collaboration, and engagement in the context of the digital era 4.0 (Puspa et al., 2023).

The Role of Digital Learning Media in Improving Scientific Literacy Digital learning media includes simulations, interactive videos, virtual labs, and other media that dynamically visualize science concepts. Its strength lies in its ability to visualize abstract science concepts, improve accessibility, and enable interactive exploration of concepts. The results of previous research show that digital media has the potential to improve conceptual understanding and science literacy, although its effects are often partial if not integrated with appropriate learning design and a targeted curricular context, The integration of digital media with a systematic learning framework can strengthen students' science literacy through continuous visualization, interactivity, and feedback (Safitri, 2022; Laksono., 2021).

The role of Learning Management Systems (LMS) in Online Learning LMS is packaged as an important infrastructure for bold online learning with the main functions in the form of content management, evaluation, communication, and monitoring learning progress. The implementation of LMS has been widely applied in the realm of education, with practical examples in case studies of science learning and other areas of education. Key features of the LMS enable the compilation of metrics, progress tracking, and facilitation of communication between teachers and students, thus playing a role in improving the efficiency of online learning management and support for scientific literacy through access to standardized learning resources (Tursinawati & Widodo, 2019; Putriani & Hudaidah, 2021; Puspa et al., 2023).

Integration of Digital Learning Media and LMS Synergy between digital learning media and LMS has the potential to build a more interactive and responsive learning ecosystem. The integration of these two variables can improve interactivity, student involvement, and alignment between learning resources, learning activities, and evaluation. However, its implementation faces technical challenges (infrastructure readiness, accessibility), pedagogy (instructional design relevant to science literacy and the 4Cs), and the readiness of teachers and students to adapt to new technologies (Puspa et al., 2023; Ratri et al., 2023). Various studies on the importance of conceptual frameworks that connect digital media and LMS to support science literacy in an integrated manner, rather than as two separate components (Safitri, 2022).

Recent research trends show that the use of digital media in science learning generally improves understanding of science concepts and literacy, while the use of LMS is effective in online learning

management. However, many studies are still partial because evaluations are often focused on a single component (digital media or LMS) without holistic integration. Widely used methodologies include experiments, quasi-experiments, and case studies (Nurhalizah, 2022; Karomatunnisa et al., 2022). The relationship between educational technology and science literacy shows a positive effect on science understanding, although a more structured synthesis is needed to combine media types, LMS features, and impacts on science literacy simultaneously (Safitri, 2022; Ratri et al., 2023) .

The main gap lies in the lack of studies that examine the simultaneous transmission of digital learning media and LMS and their impact on science literacy, especially through a systematic review approach in the period 2020–2026. Inconsistencies related to the effectiveness of technology in science learning are also obstacles, as is the lack of a comprehensive synthesis that connects media types, LMS features, and science literacy outcomes. A systematic literature reflection is therefore needed to build a conceptual framework that combines digital media, LMS, and science literacy in one bold learning ecosystem (Hadrian et al., 2023; Karomatunnisa et al., 2022). The proposed research offers a systematic analysis of the literature 2020–2026 with a focus on the integration of two main variables: digital learning media and LMS, specifically on improving science literacy. This research will develop a new conceptual framework linking digital media, LMS, and science literacy, and provide evidence-based recommendations for the development of 21st century learning. The novelty lies in the effort to unite its two dimensions in an integrated perspective in one perspective oriented to science literacy, so that it can become a practical basis for classroom practice and policy (Ratri et al., 2023; Afifah et al., 2022; Banila et al., 2021).

The research includes identifying research trends related to the topic, analyzing the effectiveness of technology integration in improving science literacy, and identifying patterns, strengths, and weaknesses of previous studies. The goal is to build a scientific basis for further research and more effective learning practices, as well as provide evidence-based recommendations for curriculum developers, educators, and policymakers on how to synergistically integrate digital learning media and LMS to improve science literacy in the digital age (Hadrian et al., 2023; Afifah et al., 2022). 21st century literacy and science literacy are no longer considered complementary, but have become a core component that must be mastered by every student. 21st century literacy includes four main competencies known as the 4Cs, namely Critical Thinking, Creativity, Collaboration, and Communication. Meanwhile, science literacy equips students with the ability to understand and evaluate scientific information objectively and responsibly. Both forms of literacy are becoming increasingly relevant considering the real challenges facing the world today. Strong analytical skills are needed so that the younger generation is able to understand the issue of climate change based on data, keep up with rapid technological developments, and respond to information in the health sector critically and not easily get lost by wrong information. Thus, modern education is not enough to just impart knowledge, but must also form individuals who are able to think, analyze, and act intelligently in the face of the complexities of the global world (Aji, 2019; Rawung et al., 2021).

The pandemic that occurred a few years ago has become a point of acceleration of learning transformation towards the digital era. This situation forces the world of education to quickly switch from conventional face-to-face methods to online learning systems. This change is not just a media shift, but a fundamental shift in the way teachers teach and students learn. Digital technology is the backbone of the sustainability of the educational process in the midst of the unavoidable limitations of space and time. However, the implementation of online learning alone is not enough without the design of effective learning interactions in a digital environment. Meaningful interaction between teachers and students, as well as between fellow students, must be maintained even though it takes place virtually. This requires educators to be able to design learning experiences that not only deliver the material, but also encourage active engagement, discussion, collaboration, and constructive feedback. Thus, digital transformation in learning must be interpreted as an opportunity to create a learning ecosystem that is more innovative, inclusive, and relevant to the needs of the times (Wildan et al., 2022; Putriani & Hudaidah, 2021; Puspa et al., 2023).

Digital learning media and Learning Management System (LMS) are two components that complement each other in an effort to improve students' science literacy. Digital learning media plays a role in presenting abstract science concepts that are easier to understand through visualizations such as animations, simulations, and interactive infographics, thereby encouraging active student involvement and interaction in the learning process. On the other hand, an LMS serves as a platform

that organizes and manages all learning content, while providing features for evaluating and monitoring student learning progress in a systematic and structured manner. However, the success of the integration of the two will not be optimal if it is not supported by a mature and integrated instructional design, which is able to align each digital component with the learning objectives to be achieved. In addition, a clear curricular context is also an important requirement so that the use of digital media and LMS does not run separately, but is truly aligned with the achievement of science literacy competencies that have been set out in the curriculum (Safitri, 2022; Nurhalizah, 2022).

METHOD

Research Design

The method used in this study is Systematic Literature Review (SLR), which is a systematic, structured, and replicable literature review approach to produce a synthesis of valid and comprehensive scientific evidence. This research is titled "Advancing Scientific Literacy through Digital Learning Media and Learning Management Systems in Online Learning: A Systematic Review". In the data collection process, three main keywords were used designed to capture the widely relevant literature. The first keyword is ("scientific literacy"), which serves as the main focus of the study. The second keyword is ("online learning" OR "digital learning"), which represents the context of the learning environment being studied. The third keyword is ("technology OR media OR platform"), which includes various technological instruments and means used in the digital learning process. All scientific article data is obtained from the Scopus database, one of the world's leading and trusted academic databases, with a publication time span limited to 2020 to 2026. The time span was chosen deliberately because the topics studied are relatively new and rapidly evolving, so the most relevant and up-to-date literature tends to be concentrated in that period. However, it should be admitted that the limited number of articles with very recent and directly relevant publication years is one of the challenges in the data collection process of this research. All articles found based on these three keywords are then downloaded from Scopus in CSV format to facilitate the process of digital data management. To simplify file management, the three CSV documents are combined into one ZIP file using files2zip.com online services, so that all data can be managed in one more efficient unit. The ZIP files that have been formed are then extracted and processed using the OpenRefine application, which is an open-source software specifically designed to clean, transform, and standardize data. At this stage, the deduplication process is carried out to remove articles that appear more than once due to overlap between keywords, while reducing the potential for bias in the analysis. The cleaned and standardized data is then analyzed in depth using the Biblioshiny application, which is a web-based visual interface of the bibliometrix bibliometric package that runs on the RStudio platform. Through Biblioshiny, a comprehensive bibliometric interpretation is carried out, including the analysis of the author's keyword metadata (DE), data set summary information, publication growth graphs and tables per year, annual citations, Three-Fields Plot diagram, the most relevant journal sources, the local impact of the source, the application of Bradford's Law to identify core sources, the cumulative occurrence of keywords, the productivity of the author over time, as well as maps of scientific production by country of origin. In addition, the data is also visualized using the VOSviewer application, a software specifically designed to create and explore bibliometric maps. Through VOSviewer, two main types of visualization are produced, namely Density Visualization which describes the level of concentration and dominance of certain topics in the literature, and Network Visualization which displays the relationship and relationship between keywords, authors, and documents in an interactive and intuitive manner. The next step in the flow of this research methodology involves the use of Elicit AI, an artificial intelligence-based literature review platform that can be accessed through web browsers such as Google Chrome. Elicit AI is designed to assist researchers in conducting literature reviews more efficiently, including in terms of formulating research questions, extracting key information from scientific articles, and making decisions based on empirical evidence. Before the data is fed into Elicit AI, the pre-generated combined CSV files are first filtered and re-selected to ensure the article's relevance and relevance to the research focus. Articles that have passed the selection stage are then downloaded in PDF format for further processing. The PDF documents are then uploaded into the Elicit AI platform, where the artificial intelligence system automatically extracts important data from each document, such as the research

objectives, methods used, key findings, as well as relevant conclusions. This extraction process allows researchers to synthesize literature more systematically, accurately, and efficiently, resulting in a comprehensive and scientifically accountable review.

Here is a drawing of the Research Method Flow Chart

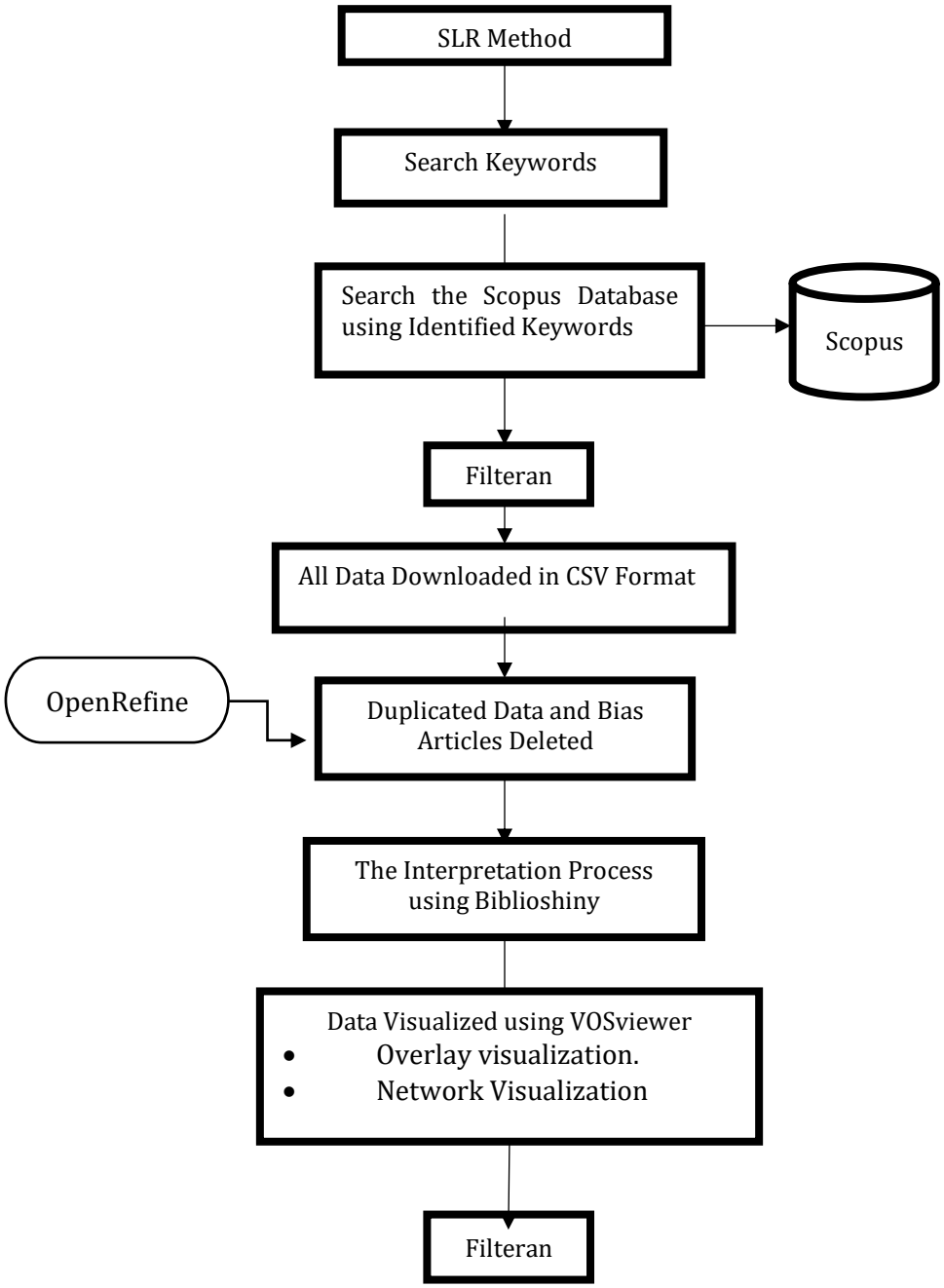

Figure 1. Research Method Flow Chart

Prism Method

This study applies the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol to ensure a systematic, transparent, and structured article selection flow. Through the stages of identification, screening, and determination of study inclusion, this method ensures that the literature selection process is carried out validly and free from duplication. The use of this diagram not only strengthens the research methodology, but also makes it easier for the reader to trace each phase of selection chronologically, as presented in the following Figure 2:

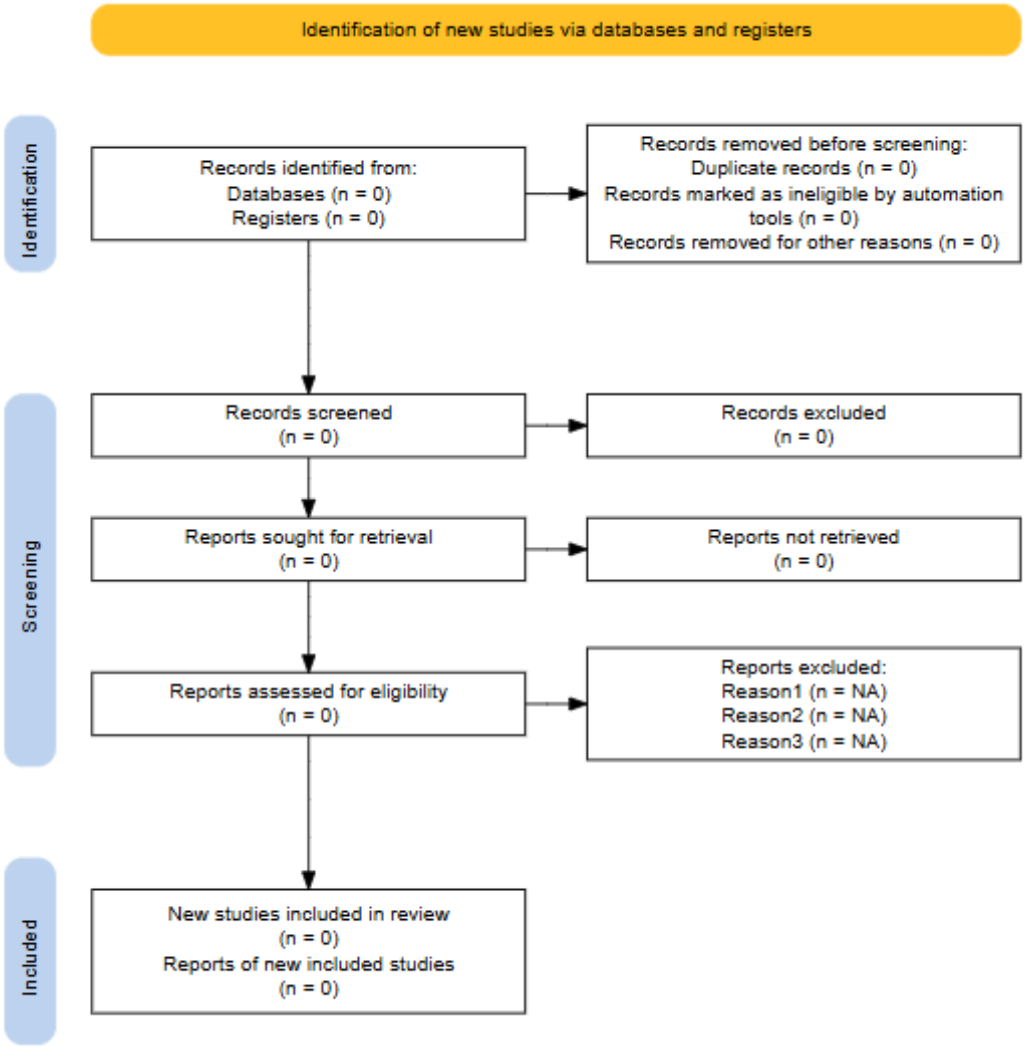

Figure 2 Prism Method Diagram

Figure 2 is a Prism Method Diagram that describes a systematic protocol in selecting literature for a study. This process is divided into three main phases, starting from the identification phase where the researcher calculates the total records found from the database and removes duplicate or ineligible documents. The stage continues to the screening phase, where articles are examined in depth through titles, abstracts, and complete manuscripts to assess their eligibility based on strict inclusion and exclusion criteria. This entire series ends with the inclusion phase, which is the determination of the final number of studies that are really quality and relevant to then be analyzed and further processed in the literature review.

RESULT AND DISCUSSION

Result

Bibiometric Studies

In this bibliometric analysis, the data search strategy is carried out through the Scopus database as the main reference source relevant to the research theme. From a set of available terminology, three core keywords were selected that were designed to cover a broad spectrum of *AI-resistant assessment* strategies. The keywords specifically highlight aspects of academic integrity in the AI era, as well as testing the validity and reliability of the use of artificial intelligence technology in learning evaluation." For a broad search on AI-resilient scoring strategies Through the use of *strings*

("scientific literacy")

As a competency target, to capture studies that focus on critical thinking skills and in-depth concept understanding

("online learning" OR "digital learning")

As an environmental context, to limit the scope of the digital education ecosystem that is vulnerable to AI challenges.

("technology" OR "media" OR "platform"),

As a supporting instrument, to identify the infrastructure facilities used in securing or facilitating assessments.

Of the 3 keywords above, the initial data obtained was 24 documents, after data filtering was obtained, 11 documents were obtained from 2020-2026. Then the data is exported to CSV and then from the 3 keywords, the CSV file is zipped to make 1 and entered into the Open refine data to filter out duplicate data

Reduce duplicate data

With the use of the above keyword search result data that is exported then decompressed to zip and then put into open refine. This application is used to filter data, especially to see whether or not there is data obtained from search results. In addition, this application can also be used to eliminate keyword bias contained in the data obtained where initially the data was obtained as many as 11 articles, When entered into open refine it remains 11 articles because there are no duplicates.

The following is a picture of Meta data on DE/Keword is Good

Completeness of metadata -- **11** docs from **Scopus**

Metadata	Description	Missing Counts	Missing %	Status
AB	Abstract	0	0.00	Excellent
C1	Affiliation	0	0.00	Excellent
AU	Author	0	0.00	Excellent
CR	Cited References	0	0.00	Excellent
DI	DOI	0	0.00	Excellent
DT	Document Type	0	0.00	Excellent
SO	Journal	0	0.00	Excellent
DE	Keywords	0	0.00	Excellent
PY	Publication Year	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
RP	Corresponding Author	11	100.00	Completely missing
ID	Keywords Plus	11	100.00	Completely missing
LA	Language	11	100.00	Completely missing
WC	Science Categories	11	100.00	Completely missing

Advice Report Save Close

Figure 3 Meta data on DE/Keword is Good

Based on the data "Completeness of metadata 11 docs from Scopus", Figure 3 shows that core metadata such as abstract (AB), author (AU), DOI (DI), keywords (DE), and title (TI) all have a missing percentage of 0% with the *Excellent* category. Table 1 reveals that the dataset includes 11 documents from 8 sources, with a range of 2020–2026, an annual growth rate of 30.77%, an average of 3,091 document citations, and a total of 1,581 references. All documents are collaborative scientific articles with an average of 4.18 authors per document and there is no international collaboration. The completeness of this metadata occurs because the data is downloaded from reputable databases with strict indexing standards, so that every indexed article must have a complete abstract, DOI, and author information. The high *Annual Growth Rate* of 30.77% reflects the acceleration of research triggered by the COVID-19 pandemic which encourages the massive use of technology in digital learning. The relatively young average age of the document (1.36 years) shows that this topic is a rapidly developing field of study. Meanwhile, the absence of international collaboration (0%) indicates that research is still centered in the domestic academic community and is not widely connected to global research networks. These findings are in line with the research of Hadrian et al. (2023) which emphasizes the importance of technology-based data management in modern education research. The rapid growth of publications is also consistent with the observation (Wildan et al., 2022) that the pandemic is a catalyst for accelerating the adoption of learning technology, especially in Indonesia. The high number of references per document (average 143.7) reflects a strong tradition of literature review in the meta-analysis of learning models. In addition, the low level of international collaboration is also in line with research trends that are still dominated by local or national contexts.

After the data is clean from duplicates and is free of bias, the bilometric data interpretation process is carried out using the Bibliosiny application as follows. The main information data obtained as a whole is seen in the Table below

Table 1. Main information on the data sheet.

Description	**Results**
Main information about data	
Timespan	2020:2026
Sources (journals, books, etc)	8
Documents	11
Annual growth rate %	30,77
Document average age	1,36
Average citations per doc	3,091
References	1581
Document contents	
Keywords plus (id)	0
Author's keywords (de)	52
Authors	
Authors	43
Authors of single-authored docs	0
Authors collaboration	
Single-authored docs	0
Co-authors per doc	4,18
International co-authorships %	0
Document types	
Article	11

Based on the descriptive table, the main characteristics of scientific publication data show that the research time span is in the period 2020 to 2026 with a total of 11 documents coming from 8 sources, including journals and other forms of publication. The Annual *Growth Rate* of 30.77%

indicates a significant increase in publications during this period. The average age of the document of 1.36 years shows that the data analyzed is dominated by the latest publications. Meanwhile, the average citation per document of 3,091 reflects that the scientific impact is still in the developing stage. The number of references reaching 1,581 shows that each document has a broad basis for literature review. In terms of content, no *Keywords Plus* (ID) were found, while *Author's Keywords* (DE) amounted to 52, which indicates that topic identification is more dependent on the keywords provided by the author. In terms of authorship, there are 43 authors who are all involved in collaborative publications without a single written document, with an average of 4.18 authors per document. In addition, there is no international collaboration (*international co-authorships* of 0%), and all the documents analyzed are scientific articles. In terms of document content, no *Keywords Plus* (ID) were found, while *Author's Keywords* (DE) totaled 52. This indicates that topic analysis relies more on keywords provided directly by the author, rather than on additional indexes that are usually automatically generated by databases. In terms of authorship, there are 43 contributing authors, and none of the documents are single-authored, which means that all publications are the result of collaboration. This is reinforced by the average value of the number of authors per document of 4.18, which indicates a fairly high level of collaboration between researchers. However, such collaboration does not involve international cooperation, as shown by the percentage of *international co-authorships* of 0%. This indicates that all collaborations take place within the same domestic or institutional scope. In terms of document type, all publications (11 documents) are scientific articles, so the data analyzed has consistency in the form of publications. Overall, this table illustrates that the dataset is dominated by recent articles with high levels of author collaboration, but is still limited in the scope of international collaborations and the variety of document types. This condition occurs because the data is taken from reputable scientific databases that have high indexing standards, so that key information such as the number of documents, references, and authors can be fully identified. The high rate of publication growth shows that there is an increase in attention to the topic of digital learning and science literacy, especially in the context of post-pandemic education transformation. The relatively young age of the document reflects that this field of study is still developing and is the focus of current research. The large number of references shows that the research conducted is based on a strong literature review. The dominance of author collaboration is due to the complexity of research that requires a multidisciplinary approach. However, the absence of international collaboration shows the limitations of the global research network that still focuses on the domestic scope. These findings are in line with research (Tursinawati and Widodo 2019) which highlights that the global research network of science education researchers in Indonesia is still limited, so international collaboration has not developed optimally. In addition, the increase in the number of publications is also consistent with the findings (Puspa et al., 2023) which show that there is an acceleration of educational research in the digital era (Safitri et al2022) also emphasized that the development of learning technology has encouraged the increase of digital-based research, especially in the context of science literacy and the use of LMS. The implications of these findings show that although the quality of the data and the strength of the literature review are quite good, there are still several aspects that need to be improved, especially in terms of completeness of metadata such as *Keywords Plus* and the expansion of international collaborations. Academic institutions need to encourage researchers to increase cross-border cooperation to expand the impact and visibility of research at the global level. In addition, efforts are needed to improve the quality of research through strengthening methodologies and theoretical contributions so that they focus not only on the quantity of publications, but also on the quality and relevance of science in the long term.

The following is an Annual Scientific Production Graph that shows the development of the number of scientific publications per year in the period 2020–2026. At the beginning of the period, the number of articles was relatively low and fluctuating, with a decline to zero in any given year. After that, there will be a gradual increase starting in 2024. A significant surge is seen in 2025 until it peaks in 2026 with the highest number of publications. Overall, this trend reflects the increasing growth in scientific productivity at the end of the observation period.

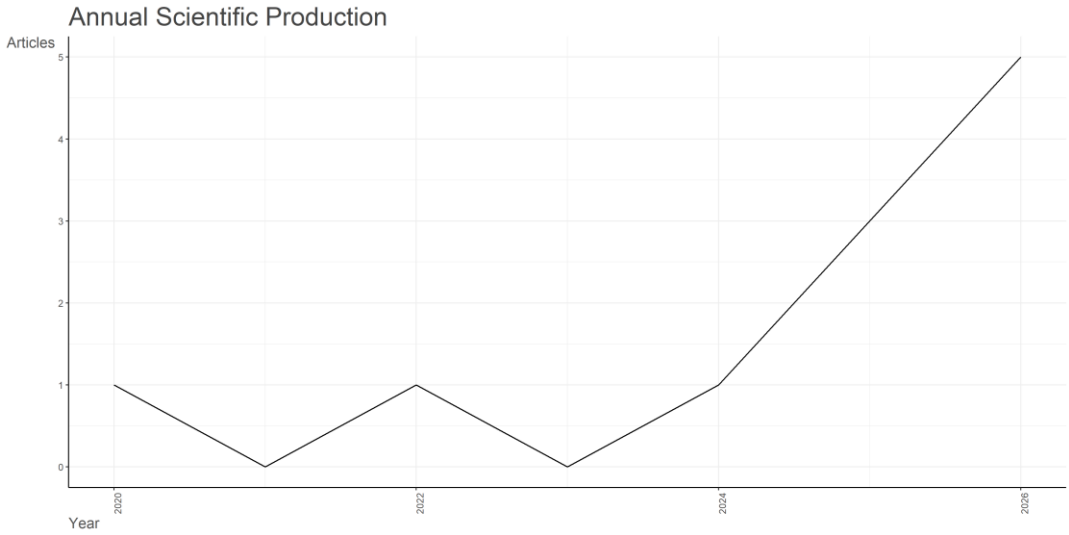

Figure 4. Year-over-year growth chart.

Based on Figure 4 representing *the Annual Scientific Production*, it can be seen that the number of scientific publications in the period 2020 to 2026 experienced a fluctuating pattern in the initial period and a significant increase in the final period. In 2020 there were 1 article, then it decreased to 0 in 2021, increased again to 1 in 2022, and again dropped to 0 in 2023. This condition shows that scientific productivity in the early phase is still unstable and sporadic. However in 2024 there is a more consistent trend of improvement, i.e. 1 article in 2024, increasing to 3 articles in 2025, and reaching its peak with 5 articles in 2026. Overall, this graph shows a fairly rapid growth in scientific productivity in recent years. The fluctuations in the early period were caused by the limited exploration of research in the field of integration of digital learning media and Learning Management System (LMS), so that the number of publications was not stable. In addition, the research process to publication which takes a relatively long time also contributes to the existence of a year without publication. The significant increase in the final period can be explained by the increasing academic awareness of the importance of science literacy in the digital era, especially after the COVID-19 pandemic which has driven the transformation of technology-based learning. In addition, increasing access to internationally reputable journals and increasing the capacity of researchers also contributed to the increase in the number of publications. These findings are in line with research (Puspa et al.2023) which shows that there is an acceleration of digital education transformation in the 21st century, especially after the pandemic (Safitri 2022) also emphasized that the development of learning technology has encouraged an increase in the number of research focusing on digital innovation in education. In addition, (Nurhalizah, 2022) stated that the increase in scientific publications in the field of digital education is an indication of the growing academic attention to the integration of technology in learning. The implications of these findings suggest that although in the early stages scientific productivity is still low and unstable, there is strong growth potential in the later period. This indicates that the field of research related to digital learning and science literacy is growing and has high prospects in the future. Therefore, efforts are needed to maintain the consistency of research productivity through increasing collaboration, both at the national and international levels, as well as strengthening the quality of research in order to make a more significant contribution to the development of science and educational practice. The table below shows the number of scientific article publications per year in the period 2020–2026.

Table 2. Annual Growth

Year	Articles
2020	1
2021	0
2022	1
2023	0
2024	1

2025	3
2026	5

Annual growth data on the number of articles in the period 2020–2026 shows a pattern that was initially volatile, then developed significantly by the end of the year. In 2020 there was 1 article, but it decreased to 0 in 2021. This condition increased again to 1 article in 2022, but dropped back to 0 in 2023. Entering 2024, the number of publications again increased to 1 article, which was then followed by a fairly sharp spike in 2025 with 3 articles, and reached its peak in 2026 with 5 articles. This pattern shows that although there was a fluctuation in the number of publications in the early period due to the limited exploration of research in the field studied, especially related to the integration of digital learning media and Learning Management System (LMS) in improving science literacy. In addition, the research process that takes time from design to publication also causes years without publication output. The significant increase in the 2025–2026 period can be explained by increasing academic awareness of the importance of digital transformation in education, especially post-COVID-19 pandemic. In addition, the growing access to internationally reputable journals and the increasing capacity of researchers to produce scientific papers have also encouraged an increase in the number of publications. These findings are in line with the results of research (Puspa et al., 2023) which shows that there is an acceleration of digital-based education research in the 21st century (Safitri 2022) also stated that the development of learning technology has encouraged an increase in the number of scientific publications, especially in the field of science literacy and the use of digital technology in education. In addition, (Nurhalizah 2022) emphasized that increasing scientific productivity is an indicator of growing academic attention to technology-based learning innovation. The implications of this growth pattern suggest that although in the early stages scientific productivity is still low and unstable, there is significant potential for development in the later period. This indicates that the field of research related to digital learning and science literacy has growing prospects. Therefore, efforts are needed to maintain the consistency of research productivity through increasing collaboration, both nationally and internationally, as well as strengthening the quality of research in order to be able to make a broader contribution to the development of educational science and learning practices.

The graph below presents data on the trend of Average Citations per Year from 2020 to early 2026. In general, this graph shows quite sharp fluctuations in the number of citations of scientific papers or articles.

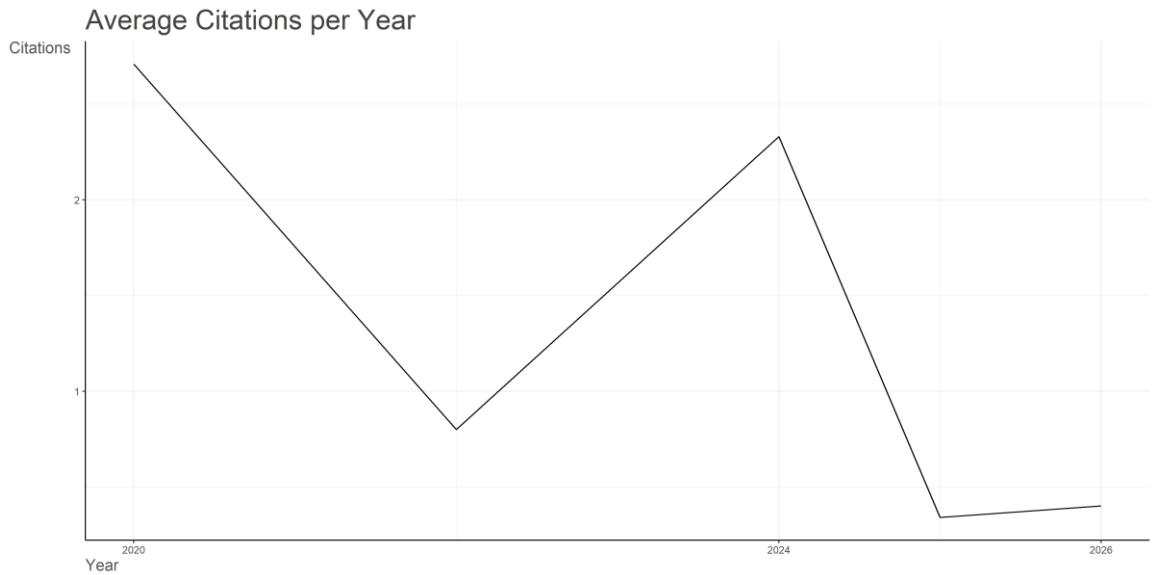

Figure 5 Annual Quotes Chart

Based on Figure 5, the line graph shows that the average article citations in the time range of 2020 to early 2026 have fluctuated quite significantly. In 2020, the average value of citations was at an all-time high, approaching triple digits. After that, there was a sharp decline over the next two years until it reached a low point below the single digits around 2022. Entering 2024, there will be a

resurgence with the average citations exceeding the number two, before experiencing another drastic decline in 2025 to reach a range of around 0.5, which is the lowest point in the period. At the end of the period, i.e. from 2025 to early 2026, the chart shows a downward trend with a slight increase. Overall, this pattern reflects volatile citation dynamics with two phases of upward separated by sharp declines. This fluctuation in the average citation is mainly influenced by the age factor of publication, where older articles have a greater chance of obtaining citations than newly published articles. The sharp decline after 2020 can be caused by the limited number of articles published in that period, so the distribution of citations becomes uneven. The increase again in 2024 reflects the beginning of the recognition of more relevant and quality publications by the scientific community. Meanwhile, the decline again in 2025 to early 2026 is a common phenomenon because newly published articles take time to be cited. In addition, these dynamics can also be influenced by changes in the focus of research and the level of relevance of the topic to academic needs at that time. These findings are in line with the principle in bibliometric analysis that citations are cumulative and time-dependent on publication, where longer articles tend to have a higher number of citations. This is also supported by (Tursinawati and Widodo 2019) who emphasize that the dynamics of citation in educational research are greatly influenced by the visibility of publications and scientific collaboration networks. In addition, (Safitri 2022) stated that the relevance of research topics to the development of educational technology also affects the citation rate of an article, especially in the field of digital learning that continues to develop. The implications of these findings suggest that the interpretation of the number of citations must take into account the time factor and the context of the publication, so that it cannot be used as the only indicator of research quality. Researchers need to increase the visibility of scientific papers through publication in reputable journals and expand collaboration, including at the international level, to increase the chances of citation. In addition, the selection of relevant and actual topics is also an important factor in increasing the scientific impact of a research. Thus, a planned and sustainable publication strategy is needed to increase research contributions in the global academic community.

The table presents article citation performance data from 2020 to 2026 measured through several key bibliometric indicators.

Table 3 Annual Quotation

Year	MeanTCperArt	N	MeanTCperYear	CitableYears
2020	19,00	1	2,71	7
2022	4,00	1	0,80	5
2024	7,00	1	2,33	3
2025	0,67	3	0,34	2
2026	0,40	5	0,40	1

The data shows that in 2020, even though there was only one article (N = 1), the article had a very high citation impact with *a MeanTCperArt* of 19.00 and *a MeanTCperYear* of 2.71, while in 2022 there was a significant decrease with the average citation per article of 4.00 and the annual average of 0.80; then in 2024 there was a re-increase with the average citation value per article of 7.00 and annual average of 2.33. However, in 2025 and 2026, although the number of publications increased to 3 and 5 articles respectively, the average value of citations decreased drastically to 0.67 and 0.40 respectively. This phenomenon occurs due to the difference in *citable years*, where older articles have a longer time to obtain citations than newly published articles, so citations are cumulative and depend on the age of the document. This finding is in line with Tursinawati and Widodo (2019) who stated that visibility and publication time greatly affect the number of citations of a study. Therefore, the low number of citations in the latest publication cannot be directly interpreted as a low quality of research, but needs to be understood in the context of the publication time and the cycle of citation development, so that the evaluation of scientific impact must consider temporal factors as well as strategies to increase the visibility of the publication.

The figure below is a Three-Field Plot (often called a Sankey diagram) used in bibliometric analysis to visualize the relationships between three major elements in the scientific literature. In

this graph, the three elements are connected are CR (*Cited References*) on the left side, AU (*Authors*) in the middle, and KW_Merged (*Keywords* or keywords) on the right side.

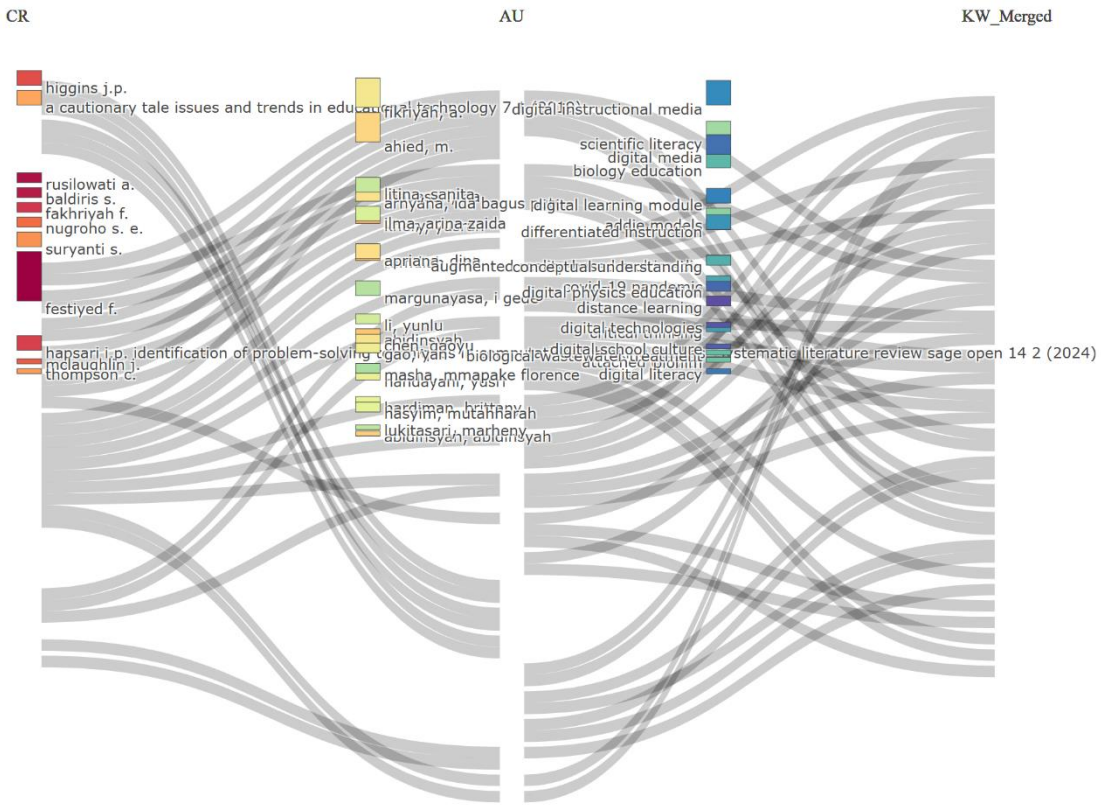

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Figure 6. diagram Three-Field Plot

Based on Figure 6, it can be seen that the relationship between references, authors, and keywords forms an integrated research network, where references on the left side such as Rusilowati A., Festiyed F., and Higgins J.P. are the main references that affect the author in the middle column, which is indicated by the thickness of the line as an indicator of the intensity of use of the reference. Furthermore, prolific authors such as Fikriyan, A., Ahied, M., and Arnyana, Ida Bagus are connected to various keywords on the right side such as *Digital Learning Module*, *Scientific Literacy*, *Biology Education*, and *Digital Instructional Media*, which show the research focus on the integration of technology in learning and science literacy. The dominance of keywords such as *Digital Technologies*, *Digital Literacy*, *Distance Learning*, and *Covid-19 Pandemic* indicates that research is developing in the context of digital education transformation, especially during the pandemic. This pattern occurs because researchers tend to use established references as a theoretical foundation, then develop them into the context of technology-based learning innovations that are relevant to the needs of the times. These findings are in line with Tursinawati and Widodo (2019) who stated that the structure of scientific research is shaped by the linkage between reference sources, the community of authors, and the development of research topics. Implicitly, this pattern of interconnectedness indicates the existence of a strong and directed research ecosystem, so it is important for researchers to not only strengthen the theoretical foundation, but also expand collaboration and exploration of topics in order to be able to produce more innovative and far-reaching scientific contributions.

The image below is a horizontal bar graph (often called *the Cleveland dot plot*) that shows the Most Relevant Sources in a research data set. This graph maps the productivity of various journals based on the number of papers published.

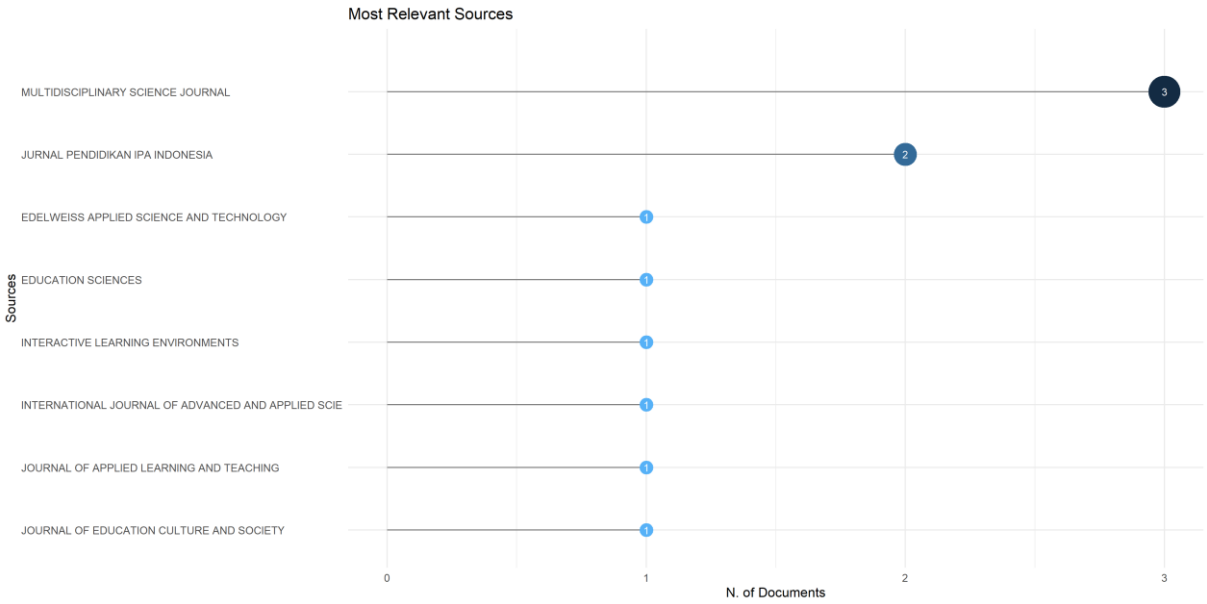

Figure 7. Most relevan Source

The figure shows that the most relevant publication sources are dominated by *the Multidisciplinary Science Journal* with a total of three documents, followed by *the Indonesian Journal of Science Education* with two documents, while other journals such as *Edelweiss Applied Science and Technology*, *Education Sciences*, *Interactive Learning Environments*, *International Journal of Advanced and Applied Science*, *the Journal of Applied Learning and Teaching*, and *the Journal of Education Culture and Society* each contributed only one document, so that in general there is a concentration of publications in multidisciplinary journals and science education. This condition occurs because multidisciplinary journals tend to have a wider and more flexible coverage of topics, so that they are able to accommodate a wide range of cross-field research, including the integration of technology in education, while science education journals are the main forum for research focusing on science literacy and learning. This finding is in line with the study of Tursinawati and Widodo (2019) which states that science education research publications tend to be concentrated in certain journals that have high relevance to the field of study, and are supported by the trend of increasing publications in reputable journals as revealed by Puspa et al. (2023). Therefore, this information has important implications for researchers in determining publication strategies, namely by targeting journals that have a multidisciplinary focus and science education as the main dissemination medium, as well as as as a reference in tracing relevant references to support future research.

Here's an explanation of **the Sources' Local Impact table**

Table 4. Sources' Local Impact

Source	h_index	g_index	m_index	TC	NP	PY_start
Edelweiss applied science and technology	1	1	0,5	1	1	2025
Journal of applied learning and teaching	1	1	0,2	4	1	2022
Journal of education culture and society	1	1	0,333	7	1	2024
Indonesian science education journal	1	2	0,143	20	2	2020
Multidisciplinary science journal	1	1	1	2	3	2026

Based on the table presented, the data shows that all journals have an h-index value of 1, which indicates that each journal has at least one article that has received citations, but there are significant differences in other indicators such as total citations (TC), number of publications (NP), as well as g-index and m-index. The Indonesian Journal of Science Education stands out with a total of 20 citations from 2 articles since 2020 and a g-index of 2, which shows a strong distribution of citations, while the Multidisciplinary Science Journal has the highest productivity with 3 articles and an m-index of 1 despite only starting in 2026, which reflects the rapid growth of impact in a short period of time. This difference occurs due to the influence of *citable years* or the length of publication time, where older

journals have a greater chance of accumulating citations, while newer journals show a rapid rate of impact growth even though the total citations are still low. These findings are in line with bibliometric principles that state that indicators such as h-index, g-index, and m-index not only reflect the number of publications, but also the quality of citation distribution and time efficiency, as also affirmed by Tursinawati and Widodo (2019) regarding the influence of visibility and time on scientific impact. Therefore, the implication is that the evaluation of journal performance cannot be based on just one indicator, but it is necessary to consider a combination of productivity, citation distribution, and publication age, so that the assessment of scientific impact becomes more comprehensive and accurate.

Based on Bradford's Law's analysis, the graph below visualizes the distribution of article productivity from various journals, highlighting what are referred to as 'Core Sources'. Journals classified as Core Sources contribute the most articles, which is indicated by their highest position on the y-axis. The journal 'Multidisciplinary Science' ranks at the top as the most productive journal, followed by the journal 'Indonesian Science Education' which is also included in the core category. This analysis is very useful for identifying the main journals that are pillars in a particular field of study.

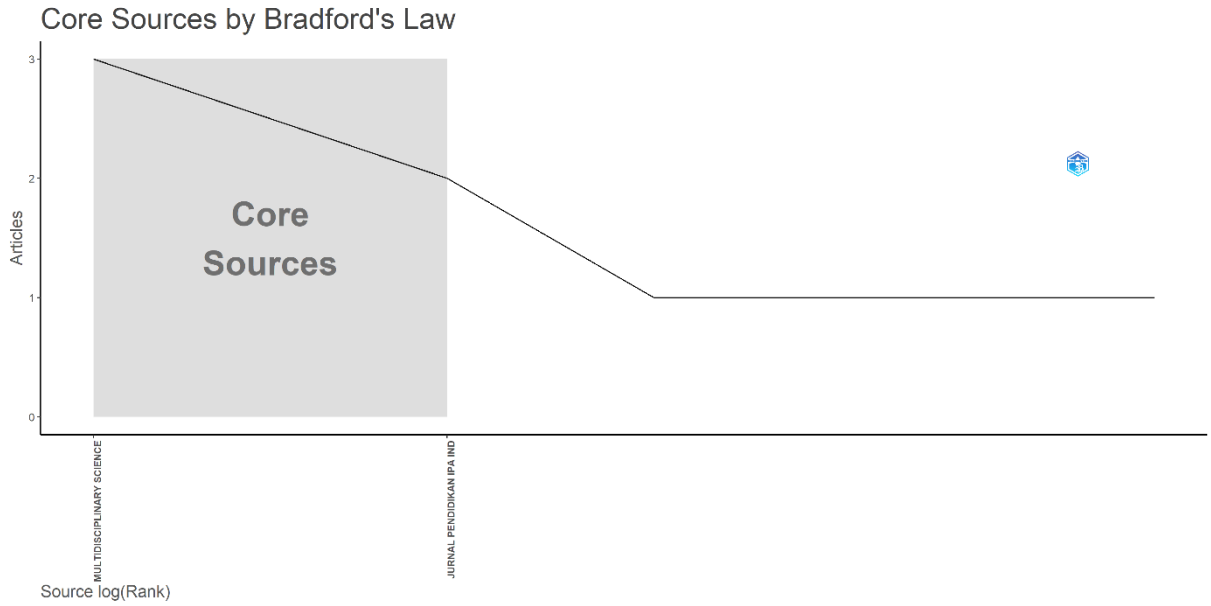

Figure 8. Core Sources by Bradford'd Law

Based on the image representing *Bradford's Law*, it can be seen that the productivity distribution of journal sources follows a certain concentration pattern, where the two main journals, namely *the Multidisciplinary Science Journal* with 3 articles and *the Indonesian Journal of Science Education* with 2 articles, are included in the *Core Sources* category. as the most productive and relevant source, while other sources contribute only 1 article each thus forming a peripheral zone . This pattern occurs because in a field of science, only a small number of journals consistently produce a large number of publications, while most other journals have a more limited contribution, thus forming an uneven distribution according to the principle of information concentration. These findings are in line with Bradford's Law theory in Bibliometric studies which states that scientific literature tends to be distributed in three zones, namely core sources, intermediate zones, and peripheral zones, where core sources become the main reference center in a field of research. Therefore, the implication is that researchers can use this information to optimize the literature search strategy by prioritizing core journals that have high productivity and relevance, so that the literature review process becomes more efficient and directed.

The image below is a line graph showing the cumulative frequency trends of several research terms (keywords) from 2020 to 2026. These graphs are commonly used in bibliometric studies to see the development of a research topic over time.

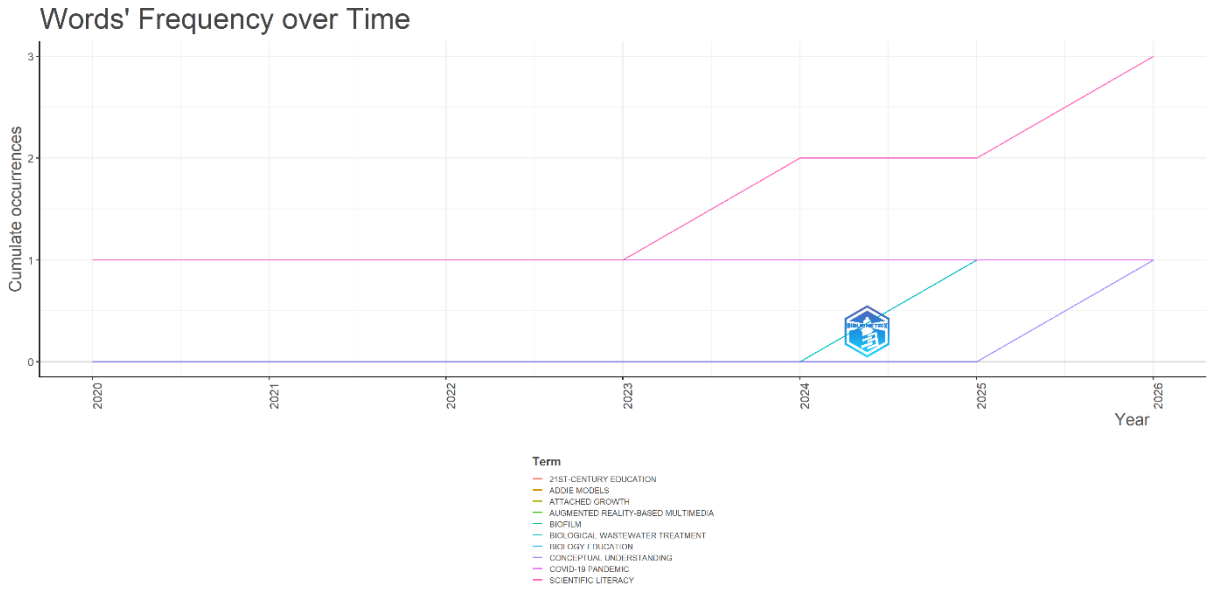

Figure 9. Grafik Cumulate Occurrences

The graph shows that the trend of keyword frequency cumulatively in the period 2020 to early 2026 experienced diverse dynamics, where the term Scientific Literacy experienced the most significant and consistent increase from 2023 to reaching a peak in 2026, while the term COVID-19 Pandemic tended to stagnate without a significant increase, and several terms such as Biological Wastewater Treatment and Conceptual Understanding began to appear in the 2024–2025 period. This condition occurs because the focus of research has shifted from temporary global issues such as the pandemic to strengthening core competencies such as science literacy and the development of specific topics that are more applicable, so that new keywords begin to develop in line with the latest research needs. These findings are in line with the research of Safitri (2022) and Puspa et al. (2023) which stated that after the pandemic, there has been a shift in research focus towards strengthening literacy and science- and technology-based learning innovation. Therefore, the implication suggests that the development of keywords can be used as an indicator of the direction of research trends, so researchers need to adapt the topic of study to the development of strategic issues in order to remain relevant and contribute significantly to the development of science. Here is a table of the most relevant authors.

Table 5. Most Relevant Authors

Author	Articles	Articles Fractionalized
Khery, Yusran	2	0,37
Mayasari, Ria	2	0,37
Ramdiah, Siti	2	0,37
Abidinsyah	1	0,17
Abidinsyah, Abidinsyah	1	0,20
Ahied, M.	1	0,25
Adriana, Dina.	1	0,25
Arnyana, Ida Bagus Putu	1	0,25
Chen, Gaoyu	1	0,17
Fikriyah, A.	1	0,25

Based on the bibliometric table presented, author productivity is measured through the number of articles and the value of fractionalized articles, where authors such as Yusran Khery, Ria Mayasari, and Siti Ramdiah occupy the top position with two articles each and a fractional value of 0.37, while other authors such as Abidinsyah, M. Ahied, and A. Fikriyah have one article with a variation of fractional values such as 0.25 and 0.17. This difference between the number of articles and fractional

values occurs due to collaboration in writing, where the contribution of each author is divided proportionally according to the number of team members; The more authors in an article, the smaller the fractional value obtained by each individual. These findings are in line with the concept of bibliometric analysis which states that scientific productivity is not only measured from the quantity of publications, but also from the relative contribution in collaboration, as explained by Tursinawati and Widodo (2019) regarding the importance of cooperation patterns in determining research impact and contribution. Therefore, the implication is that the performance evaluation of the author needs to consider fractional indicators to provide a fairer and more proportionate picture of individual contributions, especially in the context of collaborative research that is increasingly dominant in the academic world. The following is a picture of the Author's Production From Time which shows the development of the number of publication contributions by the author in a certain time span.

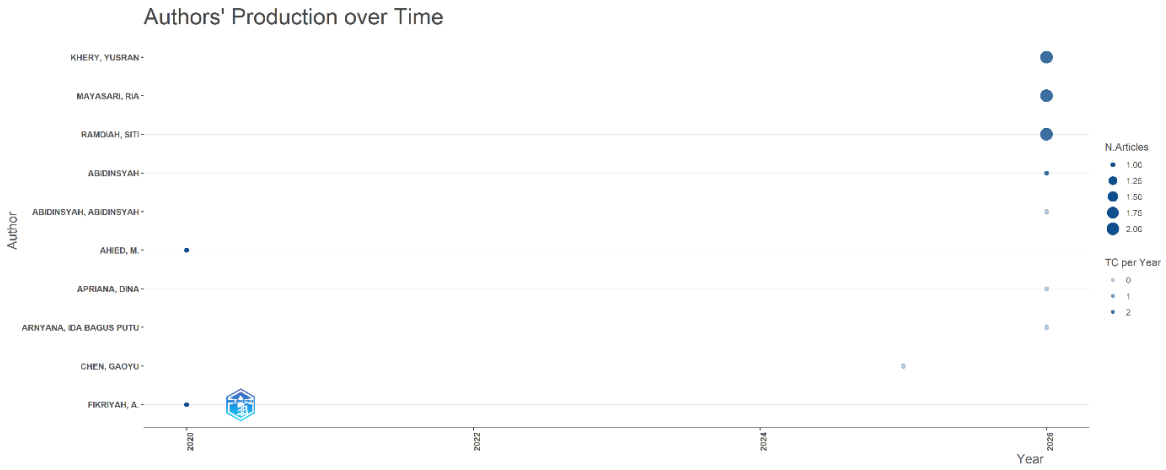

Figure 10. Authors Production Over Time.

Based on a graph that visualizes the dynamics of author productivity in the period 2020 to early 2026, it can be seen that the circle size represents the number of articles (N. Articles) and the color intensity shows the total citations per year (TC per Year), where there will be a significant spike in 2026 with writers such as Yusran Khery, Ria Mayasari, and Siti Ramdiah recording the highest productivity (2 articles each), while the initial contribution was recorded in 2020 by M. Ahied and A. Fikriyah, as well as the publication activity by Gaoyu Chen in 2025. This pattern occurs because most authors reach the peak of their productivity in the final period, which is likely influenced by increasing research trends on certain topics, the existence of large-scale research collaborations, and the concomitant publication time after a relatively long research process. These findings are in line with bibliometric studies that show that scientific productivity is often clustered and increases in certain periods due to the encouragement of research and collaboration trends, as explained by Tursinawati and Widodo (2019) regarding the dynamics of research networks and scientific contributions. Therefore, the implication is that the increase in author productivity not only reflects individual abilities, but also demonstrates the importance of research momentum, team collaboration, as well as a coordinated publication strategy to significantly increase scientific impact.

The following are the top 6 Countries' Scientific Production data.

Table 6. TOP 6 Countries' Scientific Production.

Country	Freq
Indonesia	15
China	4
Australia	2
Philippines	2
Latvia	1
South Africa	1

Based on the Top 6 Countries' Scientific Production table, it can be seen that Indonesia occupies the top position with a very dominant number of publications, which is as many as 15 articles, followed by China with 4 publications, and Australia and the Philippines which each contribute 2 publications, while Latvia and South Africa are in the last position with 1 publication each. Indonesia's dominance occurs due to the high level of research activities in the field studied, as well as the increasing need for the development of technology-based learning and science literacy at the national level, which drives scientific productivity significantly compared to other countries. These findings are in line with Tursinawati and Widodo (2019) who stated that the contribution of science education research in Indonesia tends to be high in the local context, although it is still limited in global reach, resulting in a strong concentration of publications within . Therefore, the implication is that although Indonesia's scientific productivity is relatively high, there is a need for increased international collaboration and diversification of global contributions so that research impacts are not only focused on a national scale, but also have a wider influence in the international scientific community. The following is the data on Countries' Production over Time. The data can be seen in the graph below.

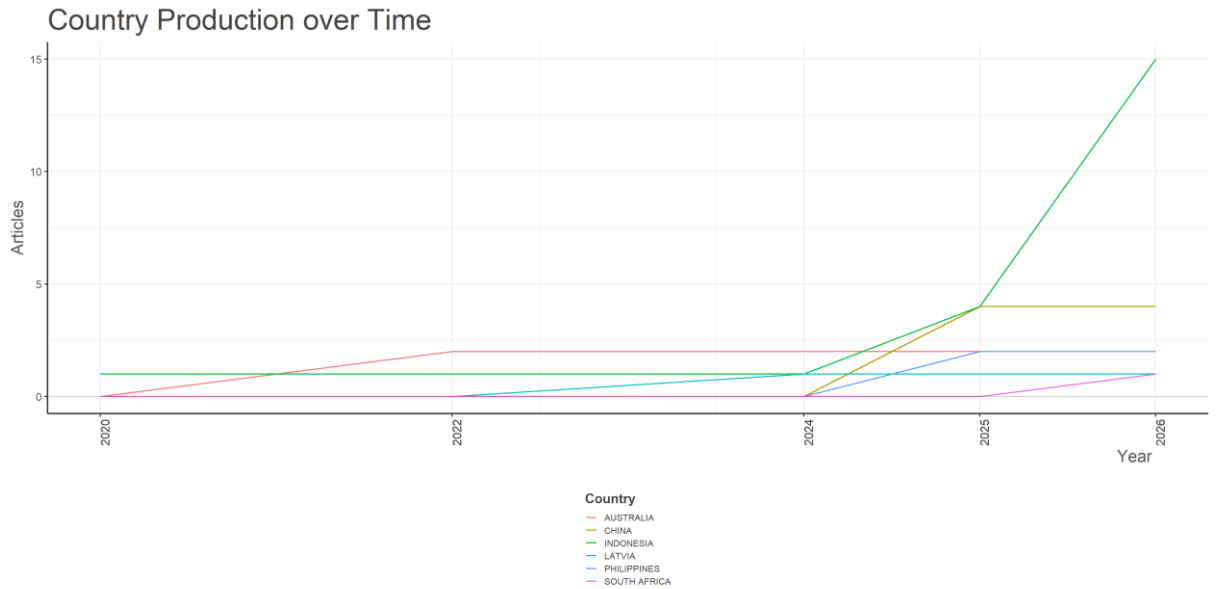

Figure 11. Grafik Countries' Production over Time

Based on the graph of scientific article production by country in the period 2020 to early 2026, it can be seen that the contribution of publications shows quite significant variation between countries, where Indonesia is the most dominant contributor with a sharp spike to reach around 15 articles in 2026, while other countries such as China, Australia, and the Philippines show more moderate growth, as well as Latvia and South Africa are still at low production levels and only appeared in the final period. This pattern occurs due to differences in the level of research needs, the capacity of research resources, and the encouragement of national policies in the development of scientific publications, where Indonesia shows high acceleration due to the increasing focus on digital education research and science literacy, while other countries tend to be stable or develop gradually. These findings are in line with Tursinawati and Widodo (2019) who stated that the dominance of a country's scientific production is influenced by the strength of academic communities and research networks, as well as by Puspa et al. (2023) who affirm the increasing contribution of developing countries in scientific publications in the digital era. Therefore, the implication is that efforts are needed to increase international collaboration and equitable distribution of research capacity between countries so that the distribution of scientific contributions becomes more balanced, as well as to strengthen the position of research on a global scale.

Overlay visualization

The image below is an Overlay Visualization generated through bibliometric analysis software (such as VOSviewer). This visualization maps the relationship between keywords or research topics while showing the evolution of the trend over time.

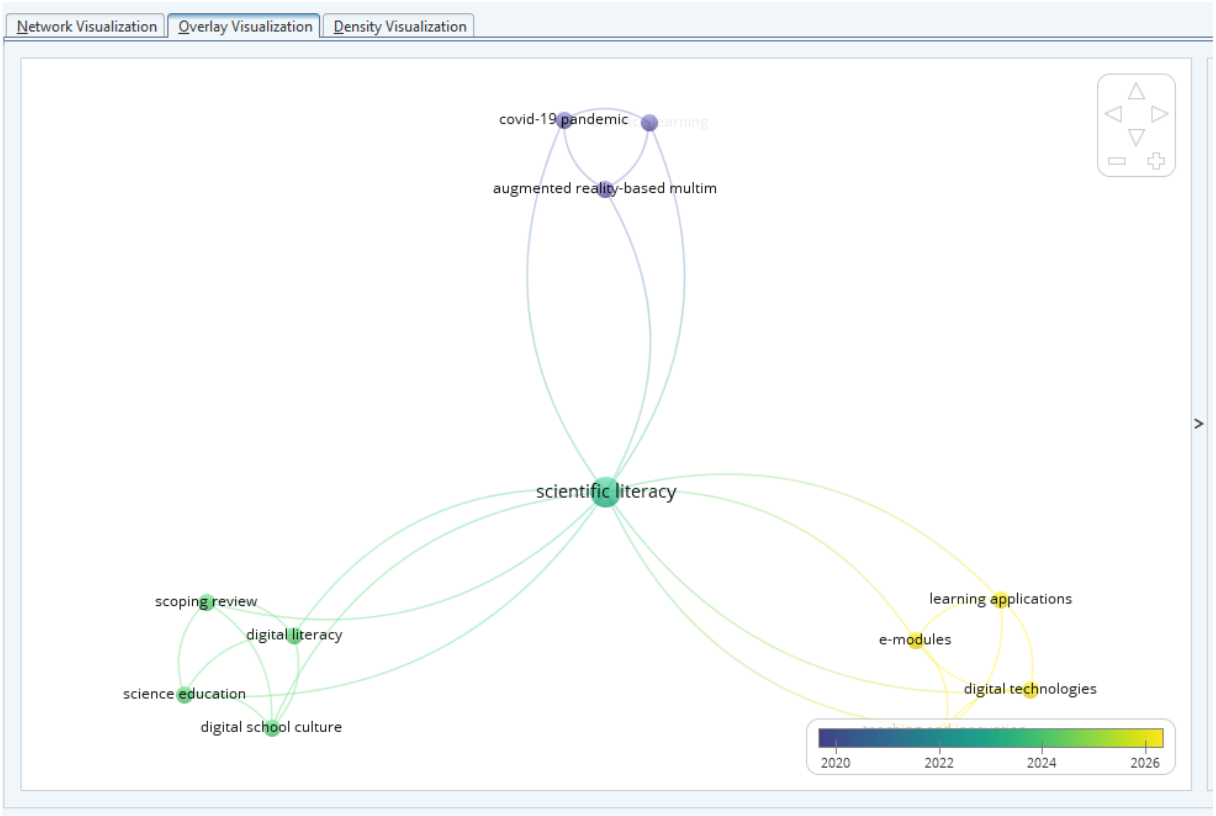

Figure 12. Overlay visualization.

Based on Figure 12 showing Overlay Visualization using VOSviewer, it can be seen that the keyword "scientific literacy" is the most dominant node and acts as the center of interconnectedness of various research topics, with the largest circle size showing the highest frequency of occurrences as well as wide connectivity between clusters. Color visualization shows a temporal evolution, where early topics such as "covid-19 pandemic" and "augmented reality-based multimedia" (2020–2021) progressed towards "digital literacy" and "science education" (2023–2024), to recent trends such as "e-modules", "learning applications", and "digital technologies" in the period 2025–2026. This shift occurred due to the change in educational needs from pandemic emergencies to the strengthening of a more structured and applicable digital learning system, along with technological advances and the increasing integration of LMS in the learning process. These findings are in line with Safitri (2022) who stated that the focus of educational research continues to grow following digital transformation, and Puspa et al. (2023) who emphasized the acceleration of technology-based learning innovation after the pandemic. Therefore, the implication is that future research needs to be more directed at the development of learning technologies that are adaptive, interactive, and based on user needs, as well as strengthening the integration between science literacy and digital literacy to support the quality of education in the digital era.

Network Visualization

The image displays the Network Visualization generated through VOSviewer, which represents the structural relationships between research topics through cluster mapping.

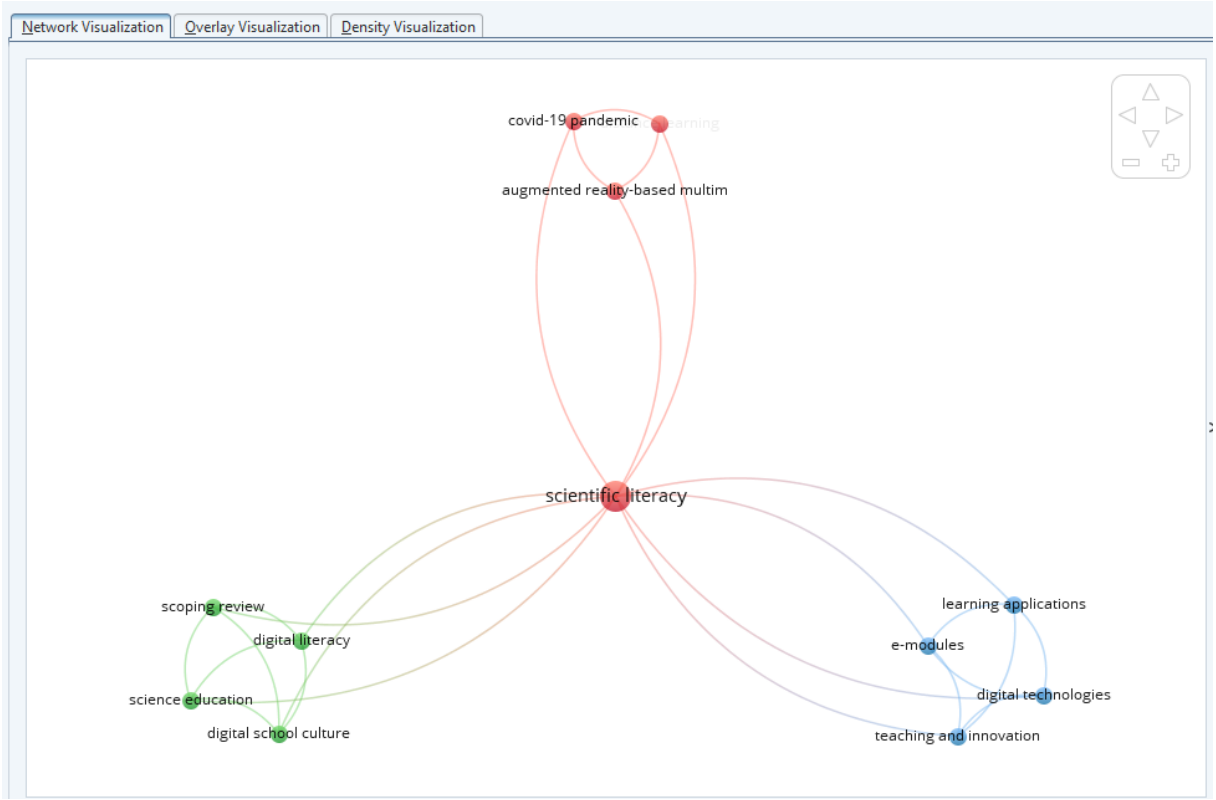

Figure 13. Network Visualization.

Based on *the Network Visualization* image showing the co-occurrence *relationship* of keywords, it can be seen that the research network is divided into three main clusters with "scientific literacy" as the most dominant central node, indicated by the largest circle size and the highest connectivity with various other terms. The red cluster focuses on science literacy in the context of the COVID-19 pandemic and the use of technologies such as *augmented reality*, the green cluster covers broader aspects of education such as digital literacy, science education, and *scoping review*, while the blue cluster emphasizes practical implementation through e-modules, learning applications, and educational technology innovations. This pattern of connectivity occurs because science literacy acts as an integrative concept that connects various fields, ranging from global health issues to learning technology innovations, so that these keywords often appear at the same time as various related topics. This finding is in line with Tursinawati and Widodo (2019) who affirm that science literacy is a key competency in modern education that is integrated with technology and social contexts, and supported by Safitri (2022) who states that the development of digital technology expands the linkage between research topics in education. Therefore, the implication is that research in this field needs to continue to develop an interdisciplinary approach by placing science literacy as the center of integration between technology, education, and global issues, so as to be able to produce learning innovations that are relevant and adaptive to the development of the times.

SLR review

Of the 24 data obtained, 8 will be focused on the type of article.

Table 7. Data Kajian SLR

No	Jenis	Quantity
1	Article	8
2	Conference Paper	12
3	Review	3
4	Book Chapter	1
Total		24

Here is a picture of the Prism Method Result Diagram

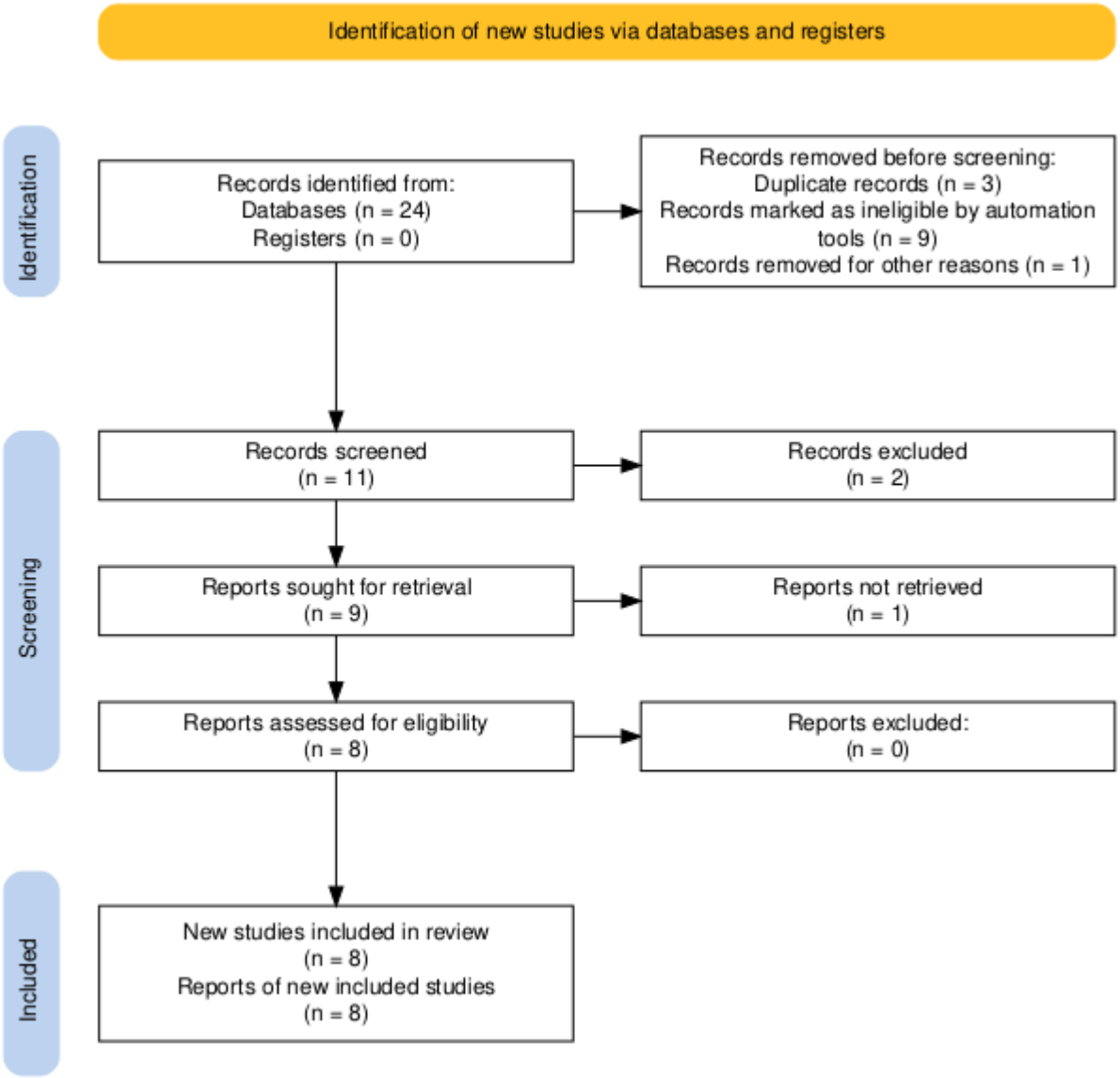

Figure 14 Prism Method Result Diagram

The PRISMA diagram shows that out of a total of 24 articles identified in the initial stage, as many as 13 articles were eliminated before screening due to duplication, inconsistencies based on automated tools, and other reasons, leaving 11 articles for the screening stage, then reduced to 9 full-text sought-after articles, with 8 articles successfully accessed and all of them declared viable until finally 8 studies were included in the final SLR analysis. This process occurs due to the application of strict inclusion and exclusion criteria and layered selection stages designed to ensure the quality and relevance of the literature used in the research (Mayadesti et al., 2025; Sundeyani et al., 2026). This procedure is in line with the Systematic Literature Review methodological standards recommended by PRISMA, which emphasizes transparency and systematization in the literature selection process (Ardern et al., 2021), as well as supported by the Kitchenham guidelines in SLR which emphasize the importance of a gradual process of identification, screening, and feasibility assessment to produce a valid synthesis. Therefore, the implication is that the use of the PRISMA method in this study increases the credibility and reliability of the study results, since only relevant and high-quality articles are used as the basis of the analysis, so that the resulting findings are more scientifically accountable. The following is the classification of the Main findings of the 8 studies in the form of a table with categories, number of papers, and percentages:

Table 8. Key Classifications in the Elicit AI Methodology Table

Category Methodology	Number of Papers	Percentage
Research and Development (R&D)	4	50%
Quantitative	2	25%
Qualitative	1	12.5%
Mixed Methods	1	12.5%
Total	**8**	**100%**

Based on the data in the table, the research methodology in the article collection is dominated by the *Research and Development* (R&D) approach of 50% (4 articles) which focuses on the development and validation of products such as digital learning media and modules based on local wisdom, followed by quantitative/experimental methods of 25% (2 articles), as well as qualitative/descriptive methods and *mixed methods* each of 12.5% (1 article), so as a whole it reflects a research cycle that includes development, testing, and in-depth evaluation. The dominance of the R&D approach occurs due to the need in biology education to produce learning innovations that are adaptive to technological developments as well as contextual to local cultures, while quantitative methods are used to test the effectiveness of products empirically, and qualitative and mixed approaches are used to understand user experience and implementation constraints in the field. These findings are in line with instructional development models such as ADDIE which emphasizes the stages of analysis, design, development, implementation, and evaluation in educational research, as well as educational research design approaches that integrate product development with empirical testing as described by Walter R. Borg and Meredith D. Gall in the R&D framework, and also supported by John W. Creswell who affirms the importance of using mixed methods to obtain comprehensive understanding in educational research (Creswell et al 2024). Therefore, the implication is that researchers need to maintain a balance between the development of innovation and empirical testing and strengthen the integration of qualitative methods to obtain a more holistic understanding, so that the results of the research not only produce products, but also make a deeper theoretical and practical contribution in the field of education. The following is the classification of the Main findings of the 8 studies in the form of a table with categories, number of papers, and keywords:

Table 9. Key Classifications in the Main Table of Elicit AI findings

Category	Number of Papers	Key Examples
Improved Learning & Cognitive Outcomes	3	Digital media significantly improves students' N-gain scores and classical completeness on biology material.
Media Validity & Practicality	2	Learning tools (such as Sasirangan Verse) are declared very valid by experts and are practically used in KBM.
Integration of Local Wisdom	1	Incorporating local cultural content into digital media effectively increases interest in and understanding of contextual science concepts.
Science & Data Literacy	1	The use of apps (such as Binogi) assists students in interpreting graphs and improving scientific data literacy skills.
Digital Accessibility & Inclusion	1	The use of online platforms and electronic modules supports independent learning but requires adequate infrastructure support.
Total	**8**	

Based on the classification of key findings from the analyzed articles, the integration of digital innovation in education has been shown to have a significant positive impact on students' cognitive achievement and learning outcomes, which is demonstrated through measurable score improvement as well as the ability of interactive media to simplify complex biological concepts into easier to understand. This effectiveness occurs because digital learning media such as electronic modules and interactive applications are systematically designed by paying attention to aspects of validity and practicality, thus making it easier for teachers and students in the learning process and increasing learning engagement . This finding is in line with the OECD report (2019) which emphasizes that the integration of digital technology can improve the quality of learning and science literacy, and is supported by Neil Selwyn (2016) who states that educational technology plays an important role in increasing the effectiveness of learning through pedagogical innovation. In addition, the integration of local wisdom in digital content has been shown to increase students' emotional attachment, while the use of technology also helps develop science literacy skills, particularly in the interpretation of scientific data. However, an important implication of these findings is the need to pay attention to the accessibility and inclusion aspects of digital, as the successful implementation of learning innovations is highly dependent on the availability of infrastructure and equitable support of devices for all students. The following is a summary classification of 8 studies in the form of a table with categories, number of papers, percentages and keywords.

Table 10. Key Classifications in the Elicit AI Summary Table

Category	Number of Papers	Percentage	Key Examples
Media Innovation & Development	4	50%	Development of digital media based on local wisdom (*Sasirangan Verse*) and interactive applications.
Implementation & Learning Effectiveness	2	25%	Evaluate the use of *e-modules* and digital tools to improve students' cognitive outcomes.
Science Literacy & Ability	1	12.5%	Focus on improving students' scientific data literacy and graph interpretation skills.
Accessibility & Digital Transformation	1	12.5%	Challenges of infrastructure, digital equity, and the use of multilingual platforms (*Binogi*).
Total	**8**	**100%**	

Based on the summary classification table, it can be seen that the main focus of research in this dataset is dominated by the category of media innovation and development of 50% (4 articles), which is oriented towards the creation of new teaching tools such as digital media based on local wisdom, followed by the category of implementation and learning effectiveness of 25% (2 articles) which tests the impact of the use of electronic modules on students' cognitive outcomes, and 12.5% each (1 article) for the categories of science literacy and ability as well as accessibility and digital transformation which highlights mastery of scientific data and infrastructure challenges. The dominance in the media development aspect occurs because technology-based educational research generally begins with the product design and development stage before conducting effectiveness and implementation tests widely. These findings are in line with the OECD report (2019) which emphasizes the importance of digital innovation in improving the quality of learning, and supported by Neil Selwyn (2016) who states that modern education transformation focuses on the integration of technology as the basis for pedagogical innovation. Therefore, the implication is that research in this field needs to develop a balance between media innovation, effectiveness testing, and accessibility aspects so that the implementation of learning technology is not only innovative, but also inclusive and sustainable in various educational contexts. The following is the classification of Study Design from 81 studies in the form of a table with categories, number of papers, and percentages:

Table 11. Key Classifications in the Elicit AI Design Study Table

Study Design	Number of Papers	Percentage	Unique Feature
Development Model (ADDIE/4D)	4	50%	Focus on design cycles, expert validation, and limited testing of digital products.
Pre-Experimental/ Quasi-Experimental	2	25%	Use *pre-test* and *post-test designs* to measure the effectiveness of interventions in the classroom.
Qualitative Descriptive	1	12.5%	Focusing on in-depth observation and narrative analysis of educational phenomena.
Case Study (Studi Kasus)	1	12.5%	In-depth investigation into a specific context (e.g. one school or one specific platform).
Total	8	100%	

Based on the study design classification table, it can be seen that the majority of research, which is 50% (4 papers), uses development models such as ADDIE or 4D which focus on systematic processes starting from design, expert validation, to practicality tests to produce learning media that is suitable for use. The dominance of this model occurs because the main goal of research is to produce learning technology innovations that are not only new, but also tested for quality before being widely implemented, so a structured development approach is needed. Meanwhile, other methods such as *pre-experimental* or *quasi-experimental* (25%) were used to test the effectiveness of interventions through pre- and post-treatment comparisons, while qualitative descriptive approaches and case studies (12.5% each) provided an in-depth understanding of the field context, social interactions, and implementation constraints. These findings are in line with the views of Walter Dick and Lou Carey in the systematic learning design model as well as reinforced by Thomas Reeves who emphasized the importance of a balance between product development and empirical evaluation in educational technology research. Therefore, the implication is that modern educational research needs to integrate development and evaluation approaches simultaneously so that the resulting innovations are not only theoretically valid, but also effective and relevant in real learning practice. The following is the classification of Future Research Recommendations based on the type of research methodology (Research and Development (R&D), Quantitative, Qualitative, Mixed Methods).

Table 12. Key Classifications in the Future Research Table Elicit AI

Category	Frequency	Urgency Levels	Representative Examples
Scale Expansion	3	High	Multi-site trials in various area schools.
Methodology	2	High	Use of *Cluster-Randomised design*.
Digital Equity	1	Critical	*Zero-rated* platform (data free).
Data Literacy	1	Medium	Specialized intervention of science graph interpretation.
Multilingual	1	High	Language-switching *feature* in concept comprehension.
Longitudinal	1	Medium	Continuous impact until the final exam.

Based on the classification table of *future research*, it can be seen that the main priority lies in expanding the scale of research that has the highest frequency, namely the three recommendations, which shows the need to test the effectiveness of digital media in a broader context so that the research results have strong generalizations. In addition, the methodological aspect is also of high urgency through the proposed use of more robust experimental designs such as *cluster-randomised*, while the issue of digital equality emerges as a very critical aspect despite its lower frequency, followed by the need for the development of multilingual features, data literacy, and longitudinal

studies as a medium-term agenda. This condition occurs because previous research is still limited to small scale and local contexts, so it is necessary to strengthen research design and expand implementation to increase external validity and ensure equitable access to educational technology. These findings are in line with the recommendations of the OECD (2019) which emphasizes the importance of equitable access to technology and improving the quality of methodologies in educational research, and supported by Neil Selwyn (2016) who highlights that the success of digital innovation is highly dependent on the aspects of inclusion, accessibility, and long-term evaluation. Therefore, the implication is that future research needs to be directed at strengthening methodological design, expanding cross-contextual implementation, and developing policies that support equal access to technology, so that digital innovation is not only limited in its effectiveness but also inclusive and sustainable in the education system.

Discussion

The synthesis of bibliometric data and the Systematic Literature Review (SLR) conducted in this study reveals that the integration of digital learning media and Learning Management Systems (LMS) plays a crucial role in transforming the online learning ecosystem toward enhancing scientific literacy and 21st-century skills (Risdianto et al., 2022). The findings on the significant surge in publication productivity between 2024 and 2026 confirm a paradigm shift in education following the COVID-19 pandemic, in which the use of technology no longer serves merely as an emergency tool to support virtual interactions but has become a fundamental pillar of well-planned and sustainable digital pedagogy (Cambeses-Franco & Cambeses-Franco, 2026). The integration of interactive learning media, such as virtual laboratories, simulations, locally grounded electronic modules, and educational applications, into Learning Management System (LMS) platforms has been shown to significantly enhance students' conceptual understanding, visual data analysis skills, and N-gain scores. The visualization of abstract scientific concepts through digital media facilitates knowledge acquisition, while LMS platforms provide an infrastructure that systematically integrates content management, assessment, and the monitoring of students' learning progress. However, the success of this integration largely depends on the quality of instructional design, educators' pedagogical readiness, and equitable access to digital infrastructure (Sarhindi & Rostini, 2026; Sholihah Hasna Inas Nashofa, 2025).

Implications

Based on a comprehensive assessment, the findings of this study have strategic implications from both theoretical and practical perspectives. Theoretically, this study reinforces the digital constructivist framework by demonstrating that scientific literacy does not emerge from the use of a single learning medium in isolation, but rather through the synergy between interactive visual media and well-structured Learning Management Systems (LMS). Furthermore, the findings reshape perspectives on learning assessment in the era of generative AI by introducing the concept of AI-resilient assessment. In this context, the evaluation of scientific literacy shifts from merely assessing the reproduction of scientific information to measuring higher-order thinking, authentic data analysis, contextual problem-solving, and reflective reasoning that cannot be easily replicated by AI systems.

From a practical perspective, these findings encourage educators and educational practitioners not only to develop technical proficiency in using LMS platforms but also to design contextually relevant digital learning modules that incorporate local wisdom and utilize learning analytics to provide timely and personalized feedback. For curriculum developers and policymakers, the results offer an empirical foundation for developing curriculum standards that emphasize inclusive digital and scientific literacy. Educational policies should also prioritize equitable investment in internet infrastructure and digital learning platforms, including the provision of affordable or free internet access for underserved and digitally disadvantaged regions.

Research contribution

This study makes several important contributions to the advancement of knowledge and educational practice. First, it provides a comprehensive synthesis of research trends from 2020 to 2026 by systematically linking the types of digital learning media, LMS features, and their impact on

scientific literacy. This distinguishes the study from previous research, which has often examined digital learning media and Learning Management Systems (LMS) separately. Second, the study presents empirical evidence using contemporary methodological approaches, highlighting that the majority of the literature employs Research and Development (50%) and quasi-experimental designs (25%). This provides an accurate overview of how digital learning media and LMS platforms are developed and evaluated in real-world educational settings. Third, the study proposes a strategic framework for contextual learning grounded in local wisdom, emphasizing innovations such as culturally based digital modules that have been shown not only to enhance scientific literacy but also to strengthen students' emotional engagement and character development.

Limitations

Although this study employed a rigorous methodological approach in accordance with the PRISMA protocol and utilized advanced analytical tools such as OpenRefine, Biblioshiny, VOSviewer, and Elicit AI, several limitations should be acknowledged. First, the literature search was primarily confined to the Scopus database, which may have excluded relevant studies indexed in other international databases, such as Web of Science, IEEE Xplore, or reputable national databases. Second, after applying stringent inclusion and exclusion criteria, the Systematic Literature Review (SLR) was limited to eight core articles, most of which were based on local research contexts. Furthermore, the bibliometric analysis revealed that international collaboration among authors remained absent (0%), with publications predominantly produced by local researchers. Consequently, the generalizability of the findings to broader global contexts should be interpreted with caution and warrants further investigation.

Suggestions

To address the existing limitations and broaden the scope of knowledge in the future, several strategic recommendations are proposed for subsequent research. Future researchers are encouraged to expand the scale of their studies by adopting more advanced methodologies, including conducting multi-center evaluations of digital learning media and Learning Management Systems (LMS) using robust experimental designs such as Cluster Randomized Controlled Trials to enhance external validity. In addition, longitudinal studies are needed to examine the sustained impact of digital learning media and LMS on students' scientific literacy across successive educational levels. Future e-learning platform development should also incorporate multilingual features to reduce language barriers in understanding scientific concepts, while being designed from the outset to be data-efficient in order to support inclusive learning in remote, underserved, and disadvantaged regions. Finally, greater international and interdisciplinary research collaboration is strongly recommended to expand global academic networks and enable cross-cultural comparisons of the effectiveness of e-learning in promoting scientific literacy.

CONCLUSION

This research reveals a significant connection between the initial goals presented in the Introduction and the empirical findings detailed in the Results and Discussion section. The main objective of addressing significant gaps in the incorporation of digital learning environments to foster scientific literacy and uphold academic integrity has been achieved through a Systematic Literature Review (SLR) and bibliometric study. The results indicate that the integration of tailored digital learning resources with organized online platforms improves students' conceptual comprehension, critical analysis, and involvement. In addition, evolving assessment methodologies towards contextually rich and advanced cognitive aspects directly aids in the creation of assessment strategies in contemporary education that can withstand AI influences. The knowledge acquired from this research provides promising avenues for upcoming studies and practice. Future investigations should move away from limited frameworks to longitudinal and multi-contextual approaches to evaluate the enduring effects of digital literacy programs. From a practical standpoint, educational organizations and policymakers can utilize these insights to create flexible, technology-integrated curricula and equitable digital platforms, thereby ensuring effective educational strategies for learners in the 21st century.

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AUTHOR CONTRIBUTION STATEMENT

WH originated the research and created the study framework. WH and MQ carried out the process of gathering data, extracting bibliometric information, and screening the literature. AZ examined the combined data and participated in the discussion. WH composed the initial version of the manuscript. MQ and AZ assessed, revised, and offered significant intellectual contributions. Each author reviewed and agreed upon the completed manuscript.

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