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Mapping the Global Research Landscape of Problem-Based Learning in Digital Learning Environments: A Bibliometric Analysis Toward Achieving SDG 4

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ABSTRACT

Objective: *The study aims to map the global research landscape of Problem-Based Learning (PBL) in Digital Learning Environments (DLE) using a bibliometric approach. The objective is to identify publication trends, major contributors, collaboration patterns, and emerging research themes supporting the development of sustainable digital education aligned with Sustainable Development Goal 4 (SDG 4).* ***Method:*** *The analysis was conducted on 2,134 documents retrieved from the Scopus database covering publications up to 2025. Data preprocessing involved duplicate removal, document filtering, and keyword harmonization. Bibliometric analysis employed performance indicators (annual publications, productive authors, sources, affiliations, and countries) and science mapping techniques (co-authorship, keyword co-occurrence, and citation analysis) using Bibliometrix and VOSviewer to visualize the intellectual structure of the field.* ***Results:*** *The findings reveal a substantial growth of research in this field, particularly following the global acceleration of digital education. China and the United States dominate research productivity, followed by emerging contributions from countries such as Indonesia. Publication sources are largely dominated by conference proceedings and journals in educational technology and computer science, highlighting the field's interdisciplinary nature.* ***Novelty:*** *This study provides a comprehensive mapping of the intellectual structure and thematic evolution of PBL research in Digital Learning Environments. It identifies research gaps, including limited international collaboration and the need for greater integration of emerging technologies such as artificial intelligence. The findings offer directions for future research to strengthen sustainable digital learning innovation and support the achievement of SDG 4.*

INTRODUCTION

Digital transformation in education is no longer merely an additional innovation but has become a fundamental necessity for ensuring the sustainability of the global education system. This transformation reflects the growing demand for educational systems to adapt dynamically to technological advancements to remain relevant to the needs of a knowledge-based society and the future workforce's competencies. In the context of Society 5.0, where digital technologies such as artificial intelligence, big data, and the Internet of Things are integrated to create human-centered solutions, education plays a crucial role in preparing learners with the digital literacy, critical thinking, creativity, and problem-solving skills required to thrive in an increasingly technology-driven world.

Various studies show that the integration of digital technology in education can increase learning flexibility, expand access to education across regions, and support the

development of 21st-century skills such as critical thinking, collaboration, communication, and digital literacy, which are key competencies in the era of digital transformation (Gao et al., 2024; Poonsawad et al., 2022; Nnamdi et al., 2025; Ríos-Muñoz et al., 2025). Advances in educational technology have led to the emergence of Digital Learning Environments (DLE) that integrate technology, pedagogy, and digital interaction into structured learning systems. Studies indicate that DLEs can enhance student engagement, interaction, and learning effectiveness (Oliver et al., 2024; Gao et al., 2024; Astuti, 2026; Handikaningtyas, 2024). Despite their widespread adoption, evidence of their effectiveness in fostering meaningful learning outcomes and higher-order thinking skills remains inconsistent across educational contexts. This issue highlights the need for further investigation to understand better the role of DLEs in improving educational quality.

In addition, the transformation of digital learning requires a shift in pedagogical approach from teacher-centered to student-centered learning. This shift is important because future learning will be oriented not only towards content mastery but also towards students' complex thinking and adaptive abilities. Various studies show that the student-centered learning approach improves deep learning, conceptual understanding, and higher-order thinking skills compared to traditional learning approaches oriented toward knowledge transfer (Gao et al., 2024; Nnamdi et al., 2025; Poonsawad et al., 2022). In this context, Problem-Based Learning (PBL) has become one of the most relevant pedagogical approaches for supporting the transformation of modern learning, as it focuses on real-world problems and encourages students' analytical and reflective abilities. PBL provides space for students to develop knowledge through investigation, discussion, and reflection on authentic problems. Empirical research shows that Problem-Based Learning can improve critical thinking, problem-solving, and analytical reasoning through contextualized problem-based learning that requires learners' active involvement in the learning process (Firmansyah, 2025; Rachman, 2025; Haikal, 2025; Nnamdi et al., 2025).

In addition to improving cognitive abilities, Problem-Based Learning also plays a role in developing independent learning skills, which are important competencies in modern education. This approach encourages students to develop self-directed learning through a structured inquiry process based on knowledge exploration. Recent research shows that implementing PBL can improve self-regulated learning, collaborative problem-solving skills, and students' ability to adapt to the complexity of real-world problems (Eminita, 2026; Haikal, 2025; Poonsawad et al., 2022; Ríos-Muñoz et al., 2025). The integration of Problem-Based Learning in Digital Learning Environments is a strategic approach to creating innovative learning relevant to the educational needs of the future. This combination enables the creation of technology-based learning that is not only interactive but also contextual and based on real experiences. Recent research shows that the integration of PBL with digital technologies such as simulation tools, collaborative digital platforms, and interactive multimedia can significantly improve learning motivation,

digital competence, collaborative engagement, and higher-order thinking skills (Astuti, 2026; Handikaningtyas, 2024; Gao et al., 2024; Nnamdi et al., 2025).

Furthermore, integrating PBL into digital learning improves the quality of education by providing a more inclusive and adaptive approach to students' needs. This shows that digital technology not only functions as a learning aid but also as an enabler of educational transformation. Several studies show that student-centered pedagogy-based digital learning, such as PBL, can improve educational inclusion, accessibility of learning, and equity in education, which are important indicators in improving global education quality (Gao et al., 2024; Yani et al., 2026; Poonsawad et al., 2022; Ríos-Muñoz et al., 2025). From a global development perspective, the integration of PBL in Digital Learning Environments is also highly relevant to achieving Sustainable Development Goal 4 (SDG 4), which emphasizes the importance of quality, inclusive, and sustainable education. Digital education based on an active approach provides opportunities to create lifelong learning that is more adaptive to global changes.

Research shows that technology-based learning innovations have a significant contribution in supporting lifelong learning opportunities, quality education, and sustainable education systems as part of the SDG 4 agenda (Gao et al., 2024; Yani et al., 2026; Poonsawad et al., 2022; Nnamdi et al., 2025). The rapid development of research on Problem-Based Learning in Digital Learning Environments also indicates that this field has become a main focus in contemporary educational research. The significant growth in publications indicates increased academic attention to the effectiveness of integrating innovative pedagogy into digital learning. Research data show an increasing global trend in publications related to PBL and digital learning, especially after the acceleration of educational digitization following the COVID-19 pandemic (Nnamdi et al., 2025; Gao et al., 2024; Yani et al., 2026; Ríos-Muñoz et al., 2025). However, this rapid growth in literature also poses challenges in comprehensively understanding the direction of research development. Without systematic scientific mapping, it is difficult to identify developments in research themes, structures of scientific collaboration, and future research directions.

Bibliometric research shows that scientific mapping analysis is crucial for understanding the intellectual structure of a research field by examining citation networks, keyword evolution, and research collaboration patterns (Donthu et al., 2021; Gao et al., 2024; Yani et al., 2026). In addition, previous research has been dominated by experimental studies examining the influence of PBL on specific learning outcomes, while studies mapping the field's overall development remain relatively limited. This condition indicates the need for research that provides a macro-level overview of the development of this research field. Bibliometric studies show that the science mapping approach can identify research gaps, emerging research themes, and future research directions more systematically than traditional literature reviews (Donthu et al., 2021; Nnamdi et al., 2025; Gao et al., 2024). The absence of comprehensive mapping of PBL research developments in Digital Learning Environments has the potential to lead to research fragmentation and suboptimal future research directions. Therefore, a study is

needed that can provide a comprehensive overview of the structure of global research developments.

Bibliometric research enables the identification of a field's intellectual structure through co-citation analysis, bibliographic coupling, and keyword co-occurrence analysis, thereby providing an in-depth understanding of research evolution (Donthu et al., 2021; Gao et al., 2024; Yani et al., 2026). Given these gaps, this research is important for providing a comprehensive mapping of the global research landscape of Problem-Based Learning in Digital Learning Environments. This study is expected to provide a scientific basis for understanding research trends and opportunities for sustainable digital learning innovation. The bibliometric approach has been recognized as an effective method for identifying global research trends, knowledge structures, and the direction of future research agendas in the field of digital education (Donthu et al., 2021; Gao et al., 2024; Nnamdi et al., 2025; Yani et al., 2026).

RESEARCH METHOD

Research design

This study uses a quantitative approach, employing bibliometric analysis to map global research developments related to Problem-Based Learning in Digital Learning Environments. This approach was chosen because bibliometric analysis can provide a systematic overview of developments in a field of study by examining scientific publications, citation patterns, research conceptual structures, and trends over a specified period. In addition, this approach also allows the identification of intellectual relationships between studies through scientific network analysis, which cannot be obtained through conventional literature reviews. Bibliometric methods have been widely used in education and learning technology research because they provide data-driven mapping of research developments and objectively identify future research directions. This analysis enables the evaluation of scientific contributions using indicators such as the number of publications, citations, author productivity, and scientific collaboration networks within a field of research (Donthu et al., 2021; Lim et al., 2022). Therefore, the use of a bibliometric approach in this study is expected to provide a comprehensive understanding of the structure of research on Problem-Based Learning in Digital Learning Environments and its contribution to sustainable digital education.

Data source and search strategy

The data for this study were obtained from the Scopus database, one of the largest scientific databases indexing reputable international journals. Scopus was chosen because it has broad multidisciplinary coverage, standardized metadata quality, and provides complete citation information, which greatly supports bibliometric analysis. In addition, this database is also compatible with various bibliometric analysis software, facilitating the scientific mapping process. Previous studies have shown that Scopus is widely used in bibliometric studies for its indexing accuracy, metadata completeness, and citation data consistency, which are important for science mapping analysis (Martín-

Martín et al., 2021; Donthu et al., 2021). The data collection process was carried out in January 2026 to ensure the consistency of the research dataset.

The search strategy was carried out using keywords relevant to the research topic, combined with Boolean operators such as AND and OR. The keywords focused on three main concepts, namely Problem-Based Learning, Digital Learning Environments, and Education. The use of a systematic search strategy is important in bibliometric research to ensure that the data obtained is relevant to the research objectives and to minimize irrelevant data (Lim et al., 2022).

Data screening procedure using PRISMA

The article selection process in this study followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) procedure to ensure transparency, systematization, and replication of the data selection process. The Prism design is seen in the following figure 1.

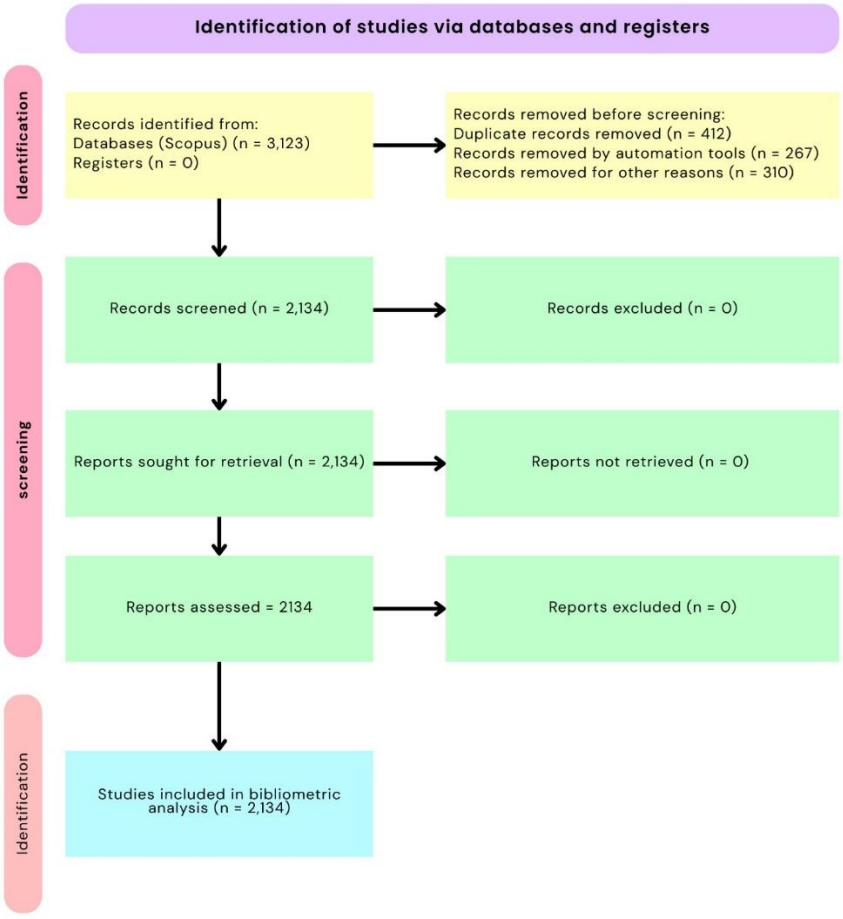

Figure 1. PRISMA flow diagram of article selection process

This procedure consisted of four main stages, namely identification, screening, eligibility, and inclusion. In the identification stage, articles were retrieved from the Scopus database using predetermined search queries. The next stage, screening, was carried out by restricting the document type to articles and reviews and the language to

English to maintain academic quality and consistency. Next, in the eligibility stage, the relevance of the title, abstract, and keywords was examined to ensure suitability with the research topic. The final stage, inclusion, produced the final dataset used in the bibliometric analysis. The use of PRISMA in bibliometric research is very important because it helps increase the transparency of the data selection process and ensures the validity of the research dataset (Page et al., 2021; Donthu et al., 2021).

Data analysis

Data analysis in this study was conducted using two main approaches, namely performance analysis and science mapping analysis. Performance analysis was used to evaluate scientific contributions using quantitative indicators such as annual publication counts, the most productive authors, the most influential journals, and the countries with the largest research contributions. This analysis provides an overview of the development of scientific productivity in the field under study. Meanwhile, science mapping is used to map the intellectual structure of research by analyzing relationships among scientific publications. This approach includes keyword co-occurrence analysis, co-citation analysis, and collaboration networks to identify research clusters and developments in research themes. Science mapping enables visualization of conceptual relationships among studies, thereby providing a deeper understanding of developments in a scientific field (Donthu et al., 2021; Aria & Cuccurullo, 2021).

Bibliometric indicators

This study uses several bibliometric indicators to measure the impact of scientific publications. One of the indicators used is the h-index, which measures the productivity and citation impact of a publication or author. The h-index is defined as the number of articles (h) that have at least the same number of citations as the h value. Mathematically, the h-index can be formulated with equation (1).

$$h = \max\,(i: c_i \geq i) \tag{1}$$

Where h is the h-index, c_i is the number of citations of article i, and i is the ranking of articles based on the number of citations. In addition, this study also uses citation impact, which is calculated by comparing the total citations with the total publications to measure the average impact of publications in the research dataset. This indicator is commonly used in bibliometric studies to measure the scientific influence of a field of research (Donthu et al., 2021).

Network analysis

Network analysis in this study is used to identify relationships between research elements such as authors, countries, and keywords. Network analysis is performed using co-occurrence networks to measure the strength of relationships among research items. Mathematically, the strength of network relationships can be calculated using equation (2).

$$L_{ij} = \sum_{k=1}^{n} w_{ik}\, w_{jk} \quad (2)$$

Where Lij indicates the strength of the relationship between nodes i and j, while w indicates the weight of the relationship between research items. This network analysis enables the identification of research clusters and conceptual relationships among research topics. This approach is widely used in bibliometric studies because it can visually and systematically describe the structure of knowledge in a field of research (Van Eck & Waltman, 2021; Donthu et al., 2021).

Thematic map analysis

This study employs thematic map analysis to identify the development of research themes based on centrality and density, which represent a theme's importance and maturity within the research network. Based on these dimensions, themes are classified into motor, basic, emerging, and niche themes, enabling the identification of research trends and future directions (Aria & Cuccurullo, 2021; Donthu et al., 2021). Furthermore, the research framework consists of three stages: data collection from the Scopus database, bibliometric processing through data cleaning and analysis, and knowledge mapping to visualize research trends and identify research gaps and future research opportunities.

Bibliometric tools

This study uses two main software programs, namely VOSviewer and Bibliometrix. VOSviewer is used to produce scientific network visualizations, such as keyword co-occurrence, citation, and collaboration networks. This software was chosen because it has strong visualization capabilities and is widely used in bibliometric research. Bibliometrix is used to perform bibliometric statistical analyses such as trend analysis, thematic evolution, and conceptual structure analysis. Using these two software programs together enables a more comprehensive analysis of the research dataset. Previous studies have shown that using VOSviewer and Bibliometrix together can improve the quality of bibliometric analysis, as the two tools complement each other in data analysis (Donthu et al., 2021; Aria & Cuccurullo, 2021).

RESULTS AND DISCUSSION

Results

Annual scientific production is used to analyze the temporal development of publication numbers and identify the dynamics of research growth in the field of Problem-Based Learning in Digital Learning Environments. This analysis is important for understanding the early stages of research development and longitudinal growth trends in the field of study. Based on the data analysis, the first publication related to this research topic was identified in 1982, with a total of 1 publication. Subsequently, no publications were found from 1983 to 1988, indicating that research in this field was still very limited in its early stages. Publications reappeared in 1989 with one article, while from 1990 to 1991, no publications were found in Figure 2.

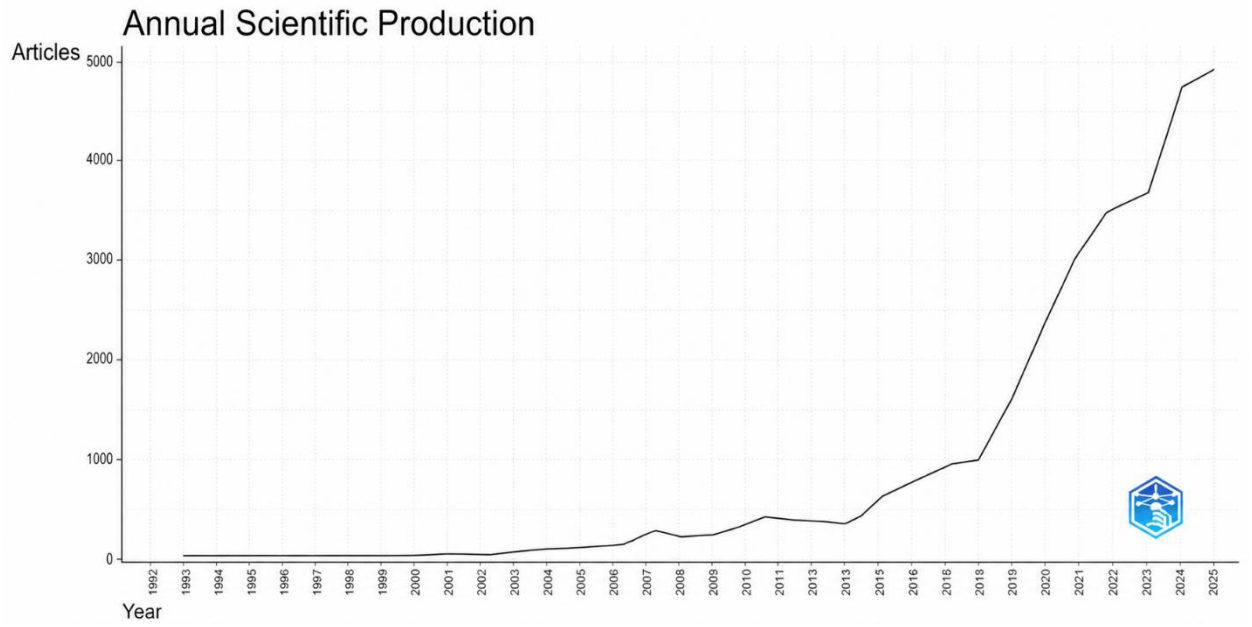

Figure 2. Shows the annual scientific production trend based on the number of publications per year.

Overall, the number of publications in this early period remained very limited, with only two articles. This condition indicates that research on Problem-Based Learning in the context of digital learning was still in its embryonic stage during that period, likely due to the limitations of digital technology at the time and the lack of widespread development of digital learning environments. These findings also indicate that research development in this field likely experienced significant growth after the development of internet technology and e-learning in the following decade. Therefore, this early period can be categorized as a phase of foundational research that laid the groundwork for further research development.

Average citations per year are used to assess the scientific impact of research in the field of Problem-Based Learning in Digital Learning Environments. This indicator is important in bibliometric analysis because it not only shows research productivity but also the scientific quality and influence of the publications produced. Based on the analysis results, the average citations per year exhibit fluctuations throughout the research period. In the early phase of research development (1982–1995), average citations remained very low, often close to zero. This indicates that research during that period was still very limited and had not yet become a major concern in the academic community, likely because digital learning environments were not yet widely developed.

In the late 1990s to early 2000s, the average citation began to increase, although it remained relatively low. This increase indicates growing academic attention to integrating technology into problem-based learning, alongside the development of the internet and e-learning. The peak in average citations occurred around 2003, with the highest value on the graph, indicating the presence of highly influential publications during that period. The high average citations in this year may indicate the existence of

seminal articles or highly cited papers that have made an important contribution to the development of research in this field.

After this period, the citation trend shows a fluctuating pattern with several significant increases, particularly around 2009 and the 2016–2022 period. The increase in this period is likely related to the growing attention to digital education, blended learning, and technology-enhanced learning, which are major topics in modern educational research. From 2016 to 2023, citation trends were relatively stable, with an upward trend, indicating that research in Problem-Based Learning in Digital Learning Environments is gaining widespread academic attention. This also shows that this field of research has entered a growth phase in the cycle of scientific development. The decline in average citations in recent years, such as 2024–2025, is a common phenomenon in bibliometric analysis because recent publications have not had enough time to obtain citations. Therefore, the low citation value in recent years does not reflect the low quality of research but is more due to the citation time-lag effect; this can be seen in Figure 3.

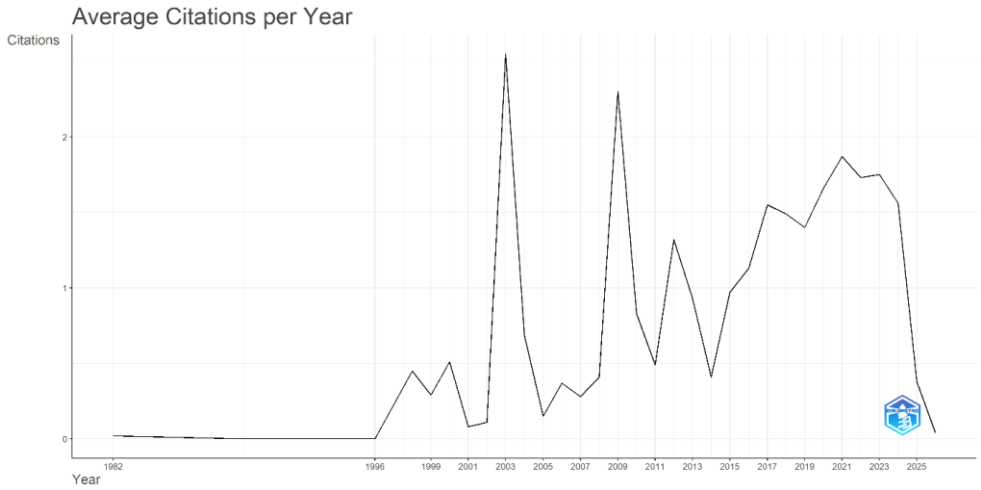

Figure 3. Average citations per year

Overall, the trend in average citations per year shows that research on Problem-Based Learning in Digital Learning Environments has increased in scientific impact, especially over the last two decades, indicating the growing relevance of this field in the context of global digital education transformation. An analysis of the most relevant sources was conducted to identify the most productive publication outlets in research on Problem-Based Learning in Digital Learning Environments. This analysis is important for understanding the contributions of journals and conference proceedings to the development of the research field and for identifying the main publication outlets central to research dissemination.

Based on the results of the bibliometric analysis, Lecture Notes in Networks and Systems was recorded as the most productive publication source with a total of 95 documents. This finding shows that this publication series has made a significant contribution to the dissemination of research on educational technology and digitally based learning, particularly in the context of intelligent systems and technology-based

learning innovations. The second most relevant publication source is the ACM International Conference Proceedings Series with 81 documents, followed by Lecture Notes in Computer Science (including the subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) with 79 documents.

The dominance of these conference proceedings indicates that research on Problem-Based Learning in Digital Learning Environments is widely published in international conferences focused on computer science, educational technology, and digital innovation. Furthermore, the ASEE Annual Conference and Exposition Conference Proceedings also made a significant contribution with 73 documents, followed by Communications in Computer and Information Science with 64 documents. This shows that the integration of education and information technology is a major focus of research and development in this field.

Several other sources that also made important contributions include CEUR Workshop Proceedings and Proceedings of the European Conference on Games-Based Learning, each with 40 publications. The presence of game-based learning conference proceedings shows that innovative approaches such as gamification and immersive learning are also closely related to the application of Problem-Based Learning in digital environments. The most relevant sources, based on publication count, are shown in Figure 4 below.

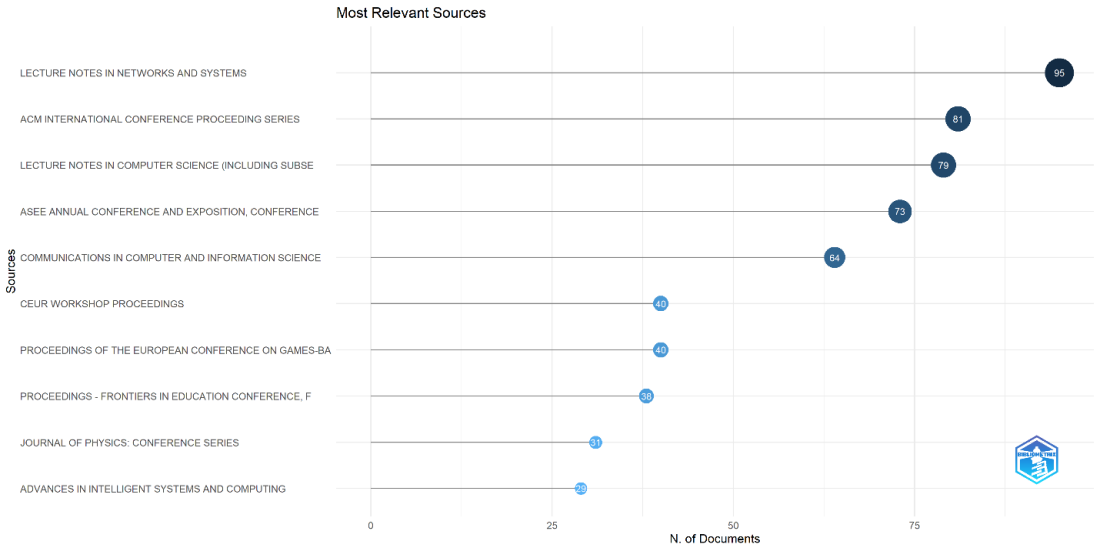

Figure 4. Most relevant sources based on number of publications

In addition, Frontiers in Education Conference Proceedings recorded 38 publications, followed by the Journal of Physics: Conference Series with 31 publications, and Advances in Intelligent Systems and Computing with 29 publications. The distribution of these publication sources shows that research in this field is multidisciplinary, covering education, information technology, artificial intelligence, and computational learning systems. An analysis of the most relevant authors was conducted to identify those who have made the greatest contributions to research on Problem-Based Learning in Digital Learning Environments. This analysis is important for understanding the main actors in

the development of this field of research and identifying researchers who are highly productive in this topic.

Based on the results of the bibliometric analysis, Wang Y is recorded as the most productive author with a total of 22 publications. This high number of publications indicates that Wang Y has made a significant contribution to research on technology-based learning and innovation in digital education. This position also shows the consistency of research in the field of digital learning and educational technology. The second position is occupied by Wang X and Zhang Y, who each have 17 publications. This shows that these two authors also play an important role in the development of research in this field, particularly in the integration of technology into education and innovative, digitally based learning approaches.

Next, Liu Y is in second place with 15 publications, followed by Li J with 13 publications. The contributions of these authors indicate the existence of a productive group of researchers who consistently advance research on Problem-Based Learning in Digital Learning Environments. Several other authors, such as Chen Y, Li X, Li Y, and Wang J, each have 11 publications, while Liu J has 10 publications. This distribution of productivity shows that a single author does not dominate research in this field but develops through the collective contributions of various researchers. In general, these results show that author productivity in this field tends to be concentrated among a small number of researchers with relatively high publication output. This pattern aligns with Lotka's law in bibliometrics, which states that a small number of authors typically produce most publications in a field of research. The most relevant authors, based on publication counts, are shown in Figure 5 below.

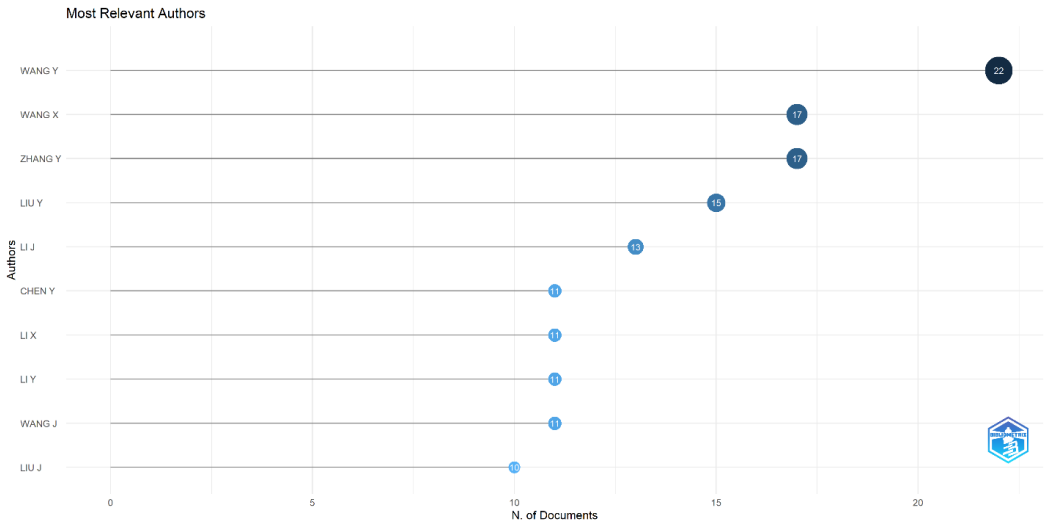

Figure 5. Most relevant authors based on number of publications

In addition, the dominance of authors from Asian backgrounds, particularly China, indicates that the region makes a strong contribution to research on digital education and technology-enhanced learning. This is in line with the region's increasing research investment in artificial intelligence, smart learning environments, and educational

technology. An analysis of the most relevant affiliations was conducted to identify the institutions that contributed most to research publications related to Problem-Based Learning in Digital Learning Environments. This analysis is important for understanding the institutional distribution of research and identifying research centers that play a role in the development of this field. Based on the analysis, the Not Reported category ranked highest, with 43 publications. This indicates that some publications in the dataset did not include complete institutional affiliations or that the affiliation metadata was unavailable in the database. This phenomenon is quite common in bibliometric analysis, especially in conference proceedings data.

Among the identified institutions, Central China Normal University and Nanyang Technological University ranked highest with 39 publications each. This finding shows that both universities have made significant contributions to research on digital learning and technology-enhanced education. The dominance of Asian institutions in these results also shows the increasing role of the Asian region in global digital education research. Furthermore, Beijing Normal University recorded 23 publications, followed by Aalborg University and Universitas Pendidikan Indonesia, which each had 22 publications. The presence of Universitas Pendidikan Indonesia on this list shows that Indonesian institutions also make significant contributions to research on Problem-Based Learning in Digital Learning Environments, particularly in the context of pedagogical innovation and educational technology. Relevant affiliations are shown in Figure 6 below.

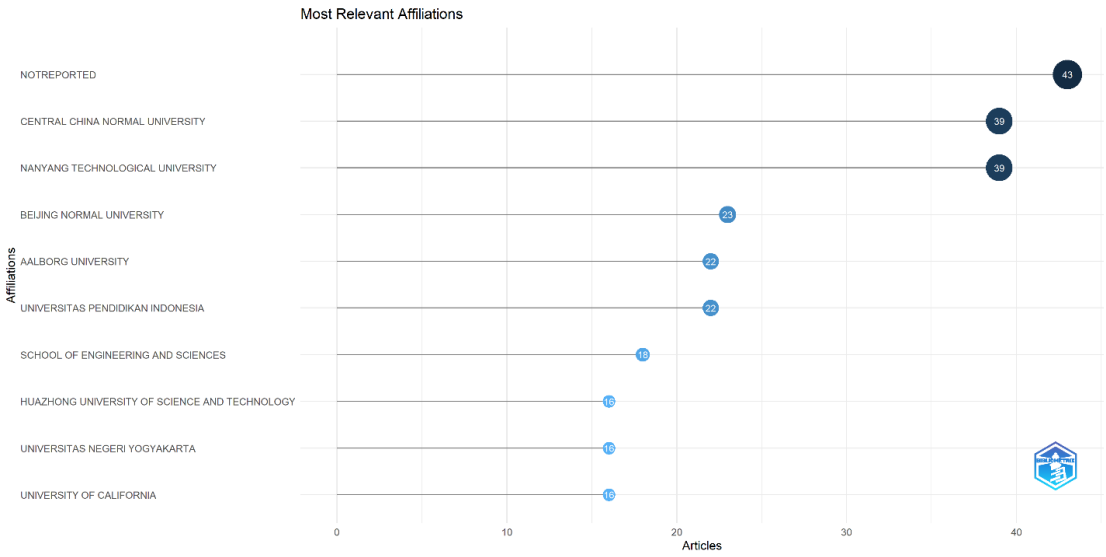

Figure 6. Most relevant affiliations based on number of publications

Several other institutions that also made important contributions include the School of Engineering and Sciences with 18 publications, as well as Huazhong University of Science and Technology, Yogyakarta State University, and the University of California, each with 16 publications. This distribution shows that research in this field is multidisciplinary, with contributions from institutions that have strengths in education, technology, and engineering. An analysis of the corresponding authors' countries was conducted to identify the geographical distribution of research contributions by country

of origin. This analysis is important for understanding global contribution patterns and the level of international collaboration in research on Problem-Based Learning in Digital Learning Environments.

Based on the analysis results, China ranks first in the number of corresponding authors, with a far higher number of publications than other countries. China's dominance in these results demonstrates the country's strong role in the development of digital education and technology-enhanced learning research. This also reflects China's increased investment in artificial intelligence, smart education, and research on digital learning systems in recent years. The United States ranks second, also showing a significant contribution to the development of research in this field. As a global research center, the United States has a strong research ecosystem in educational technology, STEM education, and digital pedagogy, which drives high scientific productivity.

Furthermore, Germany, Indonesia, and India also show significant contributions. Indonesia's presence in the top five shows that research related to Problem-Based Learning in Digital Learning Environments is also growing rapidly in developing countries, especially in the context of technology-based learning innovation and digital education transformation. Other countries such as Spain, the United Kingdom, Australia, and Malaysia also show stable contributions, indicating that research in this field is developing globally rather than concentrated in a single geographic area. In addition, the analysis also shows a difference between Single Country Publications (SCP) and Multiple Country Publications (MCP). This pattern shows that although research on Problem-Based Learning in Digital Learning Environments has developed globally, opportunities to increase international collaboration are still wide open. Cross-country collaboration is essential to accelerating digital education innovation because it enables the exchange of knowledge, technology, and best practices in the development of technology-based learning. The corresponding author's countries and international collaborations are shown in Figure 7.

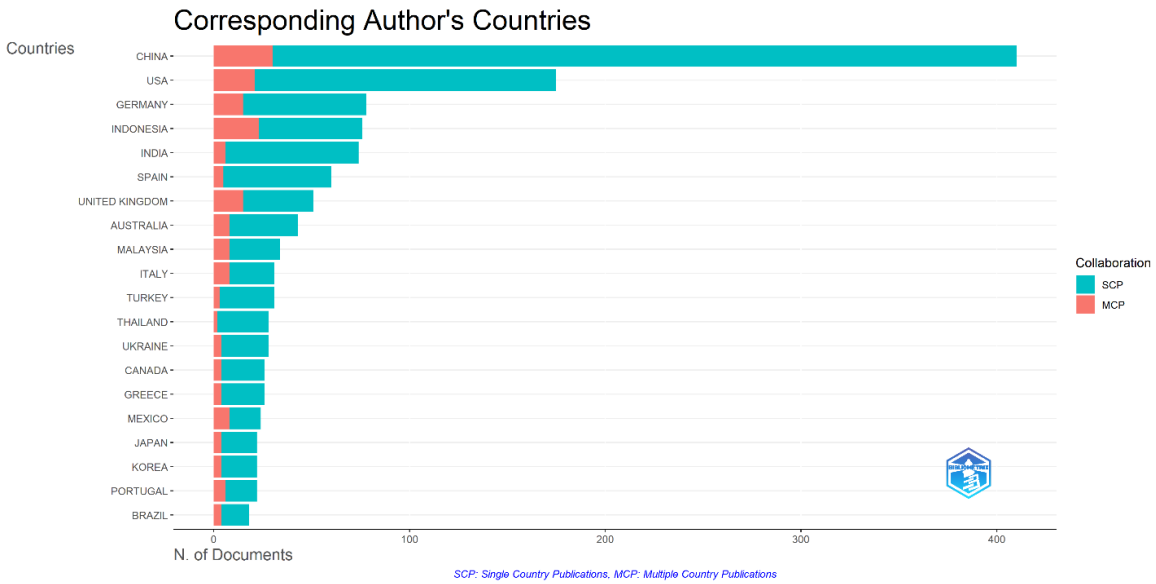

Figure 7. Corresponding author's countries and international collaboration

Overall, these results show that research in the field of Problem-Based Learning in Digital Learning Environments is globally distributed, with dominant contributions from countries with strong educational technology research capacity. These findings also highlight the importance of strengthening international collaboration to accelerate the development of digital education research. An analysis of the most-cited documents was conducted to identify publications with the greatest scientific influence in the field of Problem-Based Learning in Digital Learning Environments, based on global citation counts. This analysis is important because the number of citations reflects a publication's influence on research development in a particular field.

Based on the analysis, the publication by Dede (2009) in the journal Science ranked first with the highest number of citations, namely 1,258. This high number of citations indicates that this research is one of the foundational studies that has had a major influence on the development of research on technology-based learning and digital learning environments. Second place is occupied by Lesh (2003) with a publication titled *Beyond Constructivism: Models and Modeling Perspectives*, which received 497 citations. This publication makes an important contribution to the development of a conceptual framework for constructivist learning, the theoretical basis for the Problem-Based Learning approach.

Furthermore, Rana (2022), published in IEEE Access, received 388 citations, indicating that recent research also has a significant impact on the development of digital learning research. This shows that this field of research is still growing and has produced influential publications in recent years. Several other publications with high citation counts include Xia (2021) with 303 citations, Zydney (2016) with 299 citations, and Li (2013) with 296 citations. The high number of citations in these publications shows that research on technology-based learning, collaborative learning, and digital learning environments is highly relevant to the development of modern educational research. The following Figure 8 is the Most globally cited documents.

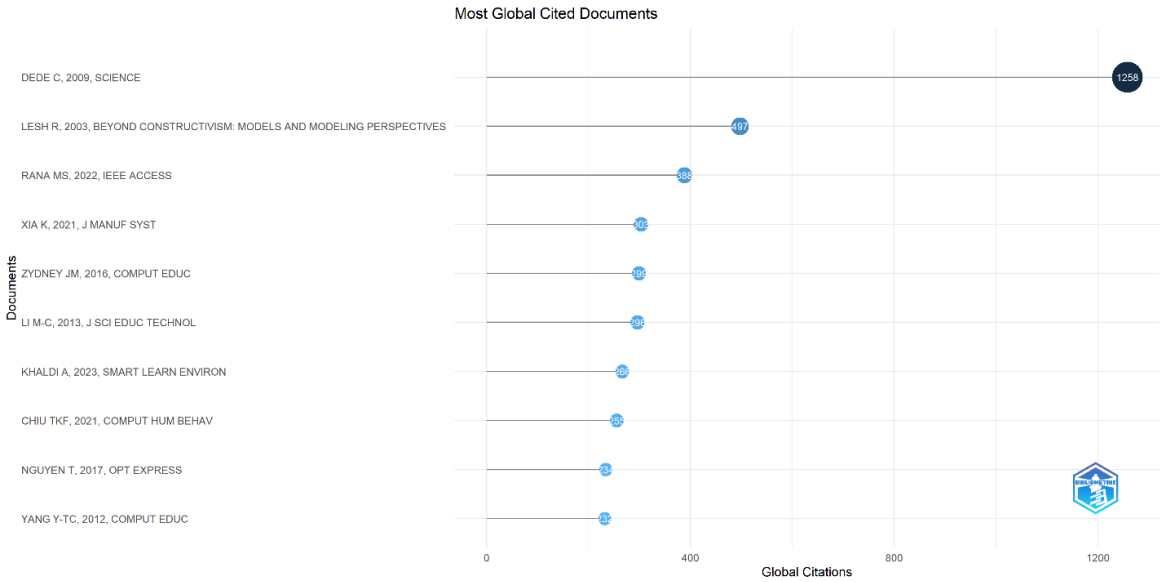

Figure 8. Most globally cited documents

In addition, more recent publications, such as Khaldi (2023) with 266 citations and Chiu (2021) with 255 citations, show that research in smart learning environments and human–computer interaction continues to have a significant impact on the development of these fields. Other publications, such as Nguyen (2017) and Yang (2012), have 234 and 232 citations, respectively, indicating that research in this field has made a continuous contribution over time. An analysis of the most frequently cited references was conducted to identify the most frequently cited references in the analyzed collection of documents. Unlike global citations, local citations indicate a reference's influence within the same field of research, thereby illustrating the intellectual foundation of research on Problem-Based Learning in Digital Learning Environments.

Based on the analysis results, Wenger (1991) was the most-cited reference locally, with 44 citations. The high number of citations indicates that Wenger's concept of communities of practice has an important influence on collaborative and social learning research and serves as a basis for the development of problem-based learning in digital environments. The second position is occupied by Vygotsky (1978) with 37 local citations. Vygotsky's theory of social constructivism and the concept of the zone of proximal development (ZPD) are important theoretical foundations in the development of student-centered learning approaches such as Problem-Based Learning.

Next, Kolb (1984) and Prensky (2001) each received 24 citations. Kolb's theory of experiential learning provides an important basis for experience-based learning that is relevant to Problem-Based Learning. At the same time, Prensky is known for his concept of digital natives, which describes the characteristics of learners in the digital age. Several other references that also have an important influence include Clarke (2006), with 21 citations, and Gee (2003), with 20 citations. These references contribute to the development of technology-based learning theory and game-based learning, which are related to modern digital learning. The following Figure 9 explains the most locally cited references.

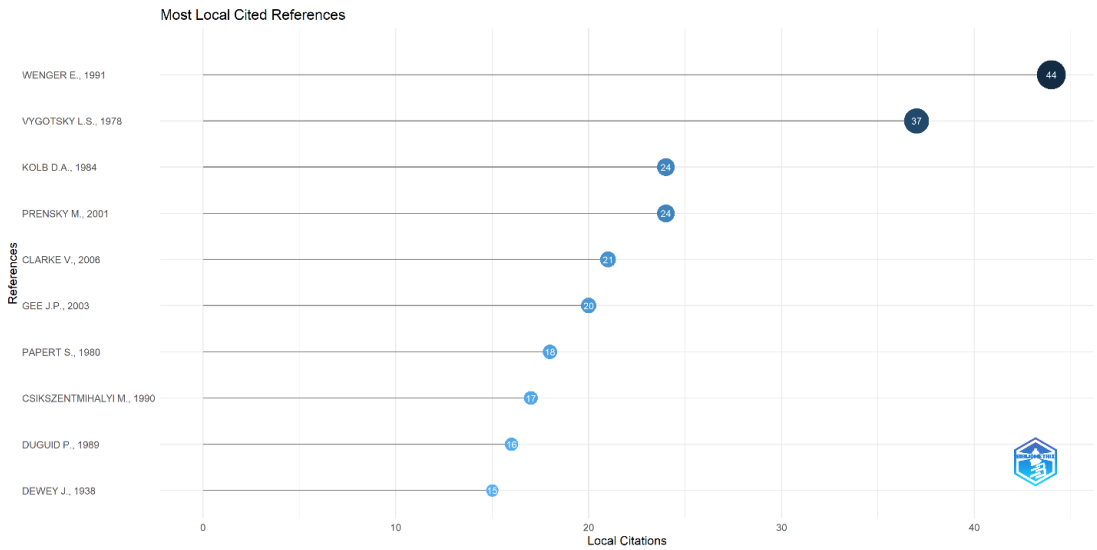

Figure 9. Most locally cited references

In addition, Papert (1980), with 18 citations, and Csikszentmihalyi (1990), with 17 citations, also show significant influence in this field. Papert's theory of constructionism and Csikszentmihalyi's flow theory contribute to the development of active and immersive learning in digital environments. Other references, such as Duguet (1989), with 16 citations, and Dewey (1938), with 15 citations, show that research in this field also has strong theoretical roots in progressive education philosophy and experiential education. An analysis of the most frequent words was conducted to identify the keywords that appeared most frequently in publications on Problem-Based Learning in Digital Learning Environments. This analysis aimed to understand the research's main focus and identify the dominant themes emerging in this field.

Based on the analysis, the keyword e-learning emerged as the most frequent, with 1,403 occurrences. The high frequency of this keyword indicates that digital-based learning is the main focus of research on Problem-Based Learning, especially in the context of technology-based education transformation. The second most frequent keyword is "students," with 1,010 occurrences. This shows that most research in this field is oriented towards student-centered learning, which is a key characteristic of the Problem-Based Learning approach. Furthermore, engineering education (752 occurrences) and teaching (726 occurrences) are also dominant themes. The dominance of these keywords indicates that Problem-Based Learning in Digital Learning Environments is widely applied in engineering education and in the context of innovation in technology-based teaching strategies. Several other keywords, such as education computing (500 occurrences), learning systems (488 occurrences), and education (487 occurrences), indicate that research in this field is closely related to the development of digital learning systems and educational technology. The following are the results of the relevant keywords in Figure 10.

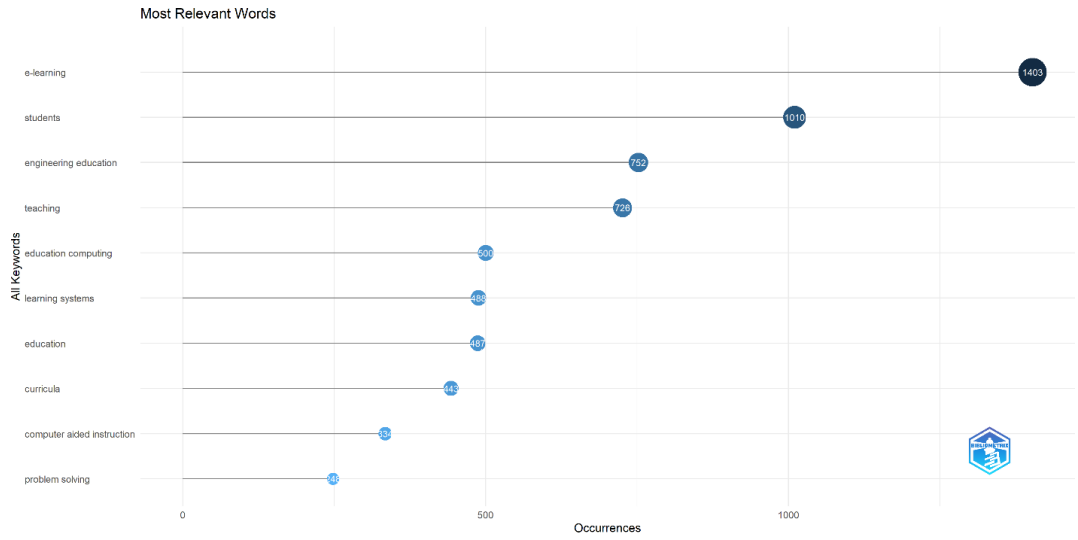

Figure 10. Most relevant words based on keyword occurrences

In addition, keywords such as curricula (443 occurrences) indicate a focus on developing technology-based curricula. In comparison, computer-aided instruction (334

occurrences) underscores the importance of integrating computer technology into the learning process. The keyword "problem solving," which appeared 248 times, shows a strong relevance between Problem-Based Learning and the development of critical thinking and problem-solving skills, which are key competencies in 21st-century education. An author collaboration network analysis was conducted to identify patterns of collaboration among researchers in the field of Problem-Based Learning in Digital Learning Environments. This network analysis is important for understanding the structure of scientific collaboration, major research clusters, and the role of key authors in building knowledge networks.

Based on the visualization of the collaboration network, the author's collaboration structure is divided into several research clusters, each indicated by a different color. Each cluster represents a group of researchers with strong collaborative relationships, evidenced by joint publications. Wang Y dominates the largest cluster (red) as the author with the highest connectivity. Larger node sizes indicate higher productivity and collaboration than those of other authors. Wang Y's position as a central node indicates his role as a research hub connecting various authors in this collaboration network. In addition, other clusters, such as Zhang Y (green cluster), also show a fairly strong collaboration network with several authors, such as Liu Z, Yang H, and Sun Y. This cluster indicates the existence of a research group that is active in developing the topics of digital learning and technology-enhanced education through intensive collaboration. The Wang X cluster (orange) also exhibits a fairly focused collaboration pattern with several researchers, including Wang S and Chen I. This indicates that research groups working more specifically on certain sub-themes in this field can be seen in Figure 11 below.

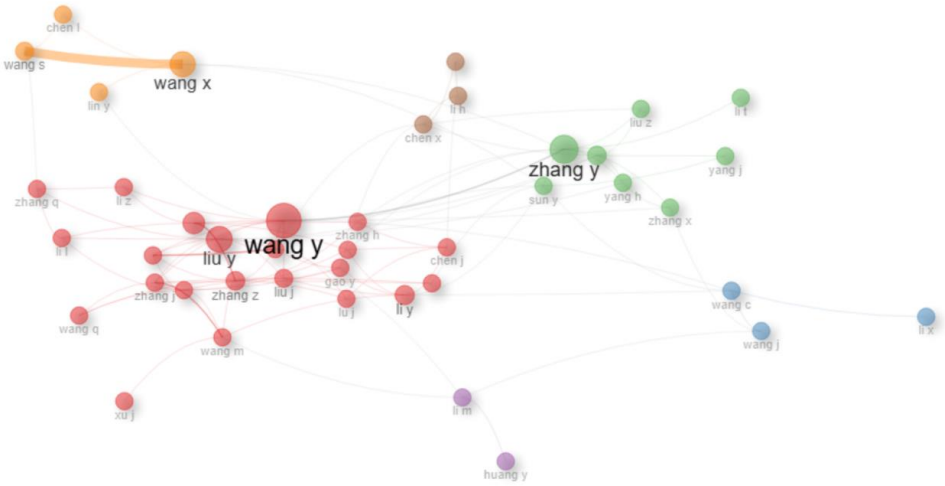

Figure 11. Author collaboration network

Several smaller clusters, such as the blue and purple clusters, show more limited collaboration groups with fewer connections. These clusters likely represent more

specific research groups or emerging research groups that are still developing. In addition, the connections between clusters indicate that collaboration between research groups also occurs, although not as intensively as collaboration within the same cluster. This indicates that knowledge exchange among research groups contributes to the development of the field as a whole.

Discussion

Growth dynamics of research on problem-based learning in digital learning environments

The results of the annual scientific production analysis show that research on Problem-Based Learning (PBL) in Digital Learning Environments (DLE) has experienced consistent growth, reflecting the global transformation of education towards a technology-based learning ecosystem. This growth not only reflects an increase in the number of publications but also indicates a shift in the focus of educational research towards integrating active pedagogy with digital technology, aiming to improve the quality of learning and the relevance of education to future needs. This transformation shows that modern education no longer focuses solely on knowledge transfer but also on the development of critical thinking, complex problem-solving, digital literacy, and collaboration, which are key requirements in 21st-century education. These findings are in line with recent studies showing that digital transformation in education has driven an increase in research on innovative learning pedagogies such as Problem -Based Learning, inquiry-based learning, and technology-enhanced learning environments as key approaches to improving the quality of modern learning (Bond et al., 2021; Crompton & Burke, 2023; Tlili et al., 2022; Zawacki-Richter et al., 2023). In addition, this increase in research has also been influenced by a shift in the educational paradigm from teacher-centered learning to student-centered learning, which emphasizes the active involvement of students in the process of knowledge construction through the use of adaptive and interactive digital technologies (García-Peñalvo, 2021; Lim et al., 2022; Selwyn, 2022).

Furthermore, the growth of this research is also closely related to the global agenda of Sustainable Development Goal 4 (SDG 4), which emphasizes the importance of inclusive, quality, and sustainable education. Digital learning environments enable greater access to education through greater flexibility, reduced educational gaps, and improved quality of learning experiences by leveraging digital technology that can reach a wider range of student groups (UNESCO, 2021; Boeren, 2022; OECD, 2023). In this context, integrating Problem-Based Learning with digital learning environments can be seen as a pedagogical strategy that supports the achievement of sustainable education goals by developing learning that is more relevant to the needs of the world of work and global society. Furthermore, from a bibliometric perspective, this increase in the number of publications indicates that the field of research on Problem-Based Learning in Digital Learning Environments has entered a growth phase in the cycle of scientific development, characterized by an increasing number of researchers, more diverse research themes, and increased scientific collaboration between institutions and countries. This phenomenon is in line with the theory of scientific development, which states that research fields

influenced by technological disruption usually experience an acceleration in scientific production due to the increasing need for pedagogical innovation that can adapt to technological developments (Donthu et al., 2021; Aria & Cuccurullo, 2021; Mishra et al., 2023).

Scientific impact and knowledge influence based on citation trends

Analysis of citation trends shows that the scientific impact of research on Problem-Based Learning in Digital Learning Environments has increased significantly, especially following the accelerated educational digitization driven by the global pandemic. This increase in citations not only reflects a rise in the number of studies but also underscores the growing relevance of this field in global academic discourse. The high number of citations in this research indicates that integrating innovative pedagogy with digital technology is a key focus in the development of future education. This phenomenon can also be explained through the perspective of knowledge diffusion theory, which states that research fields with high practical relevance to global challenges tend to have higher citation rates because they are widely used as references in further research (Wagner et al., 2021; Aksnes et al., 2023; Zhang et al., 2022). In addition, research that combines multidisciplinary approaches across education, information technology, and cognitive science tends to have greater scientific impact because it can reach a wider academic community (Lim et al., 2022; Mishra et al., 2023). Furthermore, the increase in citation impact in this field also indicates a shift in the focus of global education research towards digital resilience, namely the ability of education systems to adapt to change through the use of digital technology. Recent research shows that the COVID-19 pandemic has accelerated digital transformation in education, thereby driving an increase in research on digital learning, blended learning, and online collaborative learning (Bozkurt et al., 2022; Crawford et al., 2022; Bond, 2023). This shows that research on Problem-Based Learning in Digital Learning Environments has a strategic position in supporting the resilience of global education systems against disruption.

Knowledge dissemination and interdisciplinary research development

The dominance of conference proceedings among publication sources suggests that research on Problem-Based Learning in Digital Learning Environments is becoming an interdisciplinary field strongly influenced by technological developments. This shows that innovations in digital education often arise from integrating educational research and computer science, particularly in developing technology-based learning systems. Recent research shows that the field of educational technology is evolving through a process of interdisciplinary convergence, namely the integration of pedagogy, artificial intelligence, cognitive science, learning analytics, and human-computer interaction, which together form the modern digital education research ecosystem (Holmes et al., 2021; Viberg et al., 2023; Tlili et al., 2022; Zawacki-Richter et al., 2023). This shows that the development of Problem-Based Learning in Digital Learning Environments cannot be understood solely from an educational perspective but must also be viewed in the context

of broader developments in digital technology. Furthermore, this phenomenon reflects knowledge convergence, in which the boundaries between disciplines are blurring, giving rise to new fields of research such as smart learning environments, adaptive learning systems, and AI-supported education. These developments indicate that the future of education will be greatly influenced by the integration of smart technologies that can support personalized and adaptive learning (Crompton & Burke, 2023; Holmes et al., 2021; Lim et al., 2022).

Author collaboration and knowledge network structure

The results of the author collaboration network analysis show that research development in this field is strongly influenced by the scientific collaboration structure organized into research clusters. This structure shows that digital education innovation does not develop individually but through interconnected research communities. Recent research shows that scientific collaboration is positively associated with research productivity, innovation quality, and citation impact because it facilitates knowledge exchange and the development of multidisciplinary research (Wagner et al., 2021; Lee & Bozeman, 2023; Aksnes et al., 2023). In addition, the presence of authors who serve as central nodes in the network indicates the existence of knowledge leaders who connect research groups and accelerate the diffusion of innovation in the field of digital education (Zhang et al., 2022; Mishra et al., 2023). The network structure that has formed also shows a clustered collaboration structure pattern, indicating that research develops through several research groups with specific thematic focuses. This pattern usually appears in rapidly developing research fields due to the emergence of various new research sub-themes (Donthu et al., 2021).

Institutional and global research contributions

The distribution of institutions and countries shows that countries with high investment in educational technology dominate research in this field. China's dominance in research output indicates a shift in global research power towards countries that are actively developing digital education and artificial intelligence policies. Recent research shows that the growth of educational technology research in China is driven by national digital education policies, increased research funding, and massive university digital transformation (Chen et al., 2022; Huang et al., 2023; Zawacki-Richter et al., 2023). In addition, the contributions of developing countries such as Indonesia show that digital education transformation is also underway in countries that are beginning to adopt educational technology to improve the quality of learning (UNESCO, 2021; OECD, 2023; Boeren, 2022).

Intellectual structure and knowledge evolution

An analysis of the most cited references locally shows that this field of research has a strong theoretical foundation in constructivism, experiential learning, and social learning theories. This indicates that, despite rapid technological developments, digital learning remains rooted in classical learning theories that emphasize active learning and

knowledge construction. Recent research shows that digital pedagogy is an evolution of constructivist theory, emphasizing experience-based and collaborative learning through digital technology (Holmes et al., 2021; Viberg et al., 2023; Schindler et al., 2021). This shows that the development of Problem-Based Learning in Digital Learning Environments is an adaptation of classical learning theory to the context of modern technology.

Research themes and emerging research frontiers

Keyword analysis shows that research in this field focuses on integrating e-learning, student-centered learning, teaching innovation, and problem-solving. This indicates that research focuses not only on technology but also on how technology can be used to improve the quality of learning and student competence. Recent research shows that future research in the field of digital learning will increasingly focus on the integration of artificial intelligence, adaptive learning, immersive learning environments, and data-driven education, which will enable learning to become more personalized and effective (Holmes et al., 2021; Viberg et al., 2023; Tlili et al., 2022; Zawacki-Richter et al., 2023). The integration of Problem-Based Learning with this technology is expected to become one of the main approaches in supporting sustainable education and the development of 21st-century skills.

CONCLUSION

Fundamental Finding: The results of bibliometric analysis show that research on Problem-Based Learning in Digital Learning Environments has experienced significant growth, especially in the last two decades, in line with the acceleration of digital education transformation. This development shows that integrating problem-based pedagogy with digital technology has become a key approach in 21st-century learning innovation, particularly in supporting the development of critical thinking, problem-solving, and collaborative learning skills. **Implication:** The results also show the dominance of China and the United States in publication productivity, with increasing contributions from developing countries such as Indonesia. This indicates that this field occupies a strategic position as an interdisciplinary area of research integrating education, technology, and sustainable learning innovation relevant to achieving SDG 4. **Limitation:** This study is limited to the use of the Scopus database and focuses on bibliometric analysis without evaluating the quality of the methodology or the effectiveness of the implementation of Problem-Based Learning in digital learning practices. In addition, this study has not analyzed in depth the pedagogical impact of each study analyzed. **Future Research:** Future research is recommended to explore integrating Problem-Based Learning with technologies such as artificial intelligence, adaptive learning, and immersive learning environments, and to strengthen international collaboration to support sustainable digital education innovation.

AUTHOR CONTRIBUTIONS

Hanan Zaki Alhusni led the research design, data interpretation, and manuscript preparation. **Binar Kurnia Prahani** developed the research conceptual framework and strengthened the theoretical discussion. **Budi Jatmiko** contributed to the research supervision and validation of the scientific content. **Riski Ramadani** processed the

bibliometric dataset and conducted the data analysis and visualization. **Noer Risky Ramadhani** supported data verification, reference management, and manuscript editing. **Lindsay Natalia Bergsma** was theoretical discussion and supported data verification. **Abd. Hadi Bunyamin** was strengthened the theoretical discussion. All authors reviewed and approved the final version of the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest, either financial or personal, that could influence the content or results of this study.

ETHICAL COMPLIANCE STATEMENT

This article has met the standards of research and publication ethics. The author affirms that this research is original, conducted with academic integrity, and free from unethical practices, including plagiarism.

STATEMENT ON THE USE OF AI OR DIGITAL TOOLS IN WRITING

The final responsibility for the content of the manuscript rests entirely with the authors. The author declares that this manuscript was prepared entirely without the assistance of artificial intelligence (AI) or other digital tools. The entire process, from planning, data processing, analysis, to writing and editing the manuscript, was carried out manually by the author. Thus, full responsibility for the content and authenticity of this article rests solely with the author.

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