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Transforming Mechanics Education through Innovative Digital Problem-Based Learning: A Bibliometric Analysis

[1]Safina Ridka Pratiwi, [1]*Dwikoranto, [1]Rahmatta Thoriq Lintangesukmanjaya, [2]Sukarni, [3]Indri Hapsari Khansa, [4]Lindsay Natalia Bergsma
[1]Physics Education, Universitas Negeri Surabaya, Surabaya, Indonesia
[2]Primary Education, Universitas Doktor Nugroho Magetan, Magetan, Indonesia
[3]Psychology, Universitas Negeri Surabaya, Surabaya, Indonesia
[4]TSB, Tilburg University, Tilburg, Netherlands

*Corresponding Author e-mail: dwikoranto@unesa.ac.id

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Abstract

The digital transformation in education has driven increased attention to the application of problem-based learning (PBL) in technology-based mechanics learning. However, thematic developments, knowledge structures, and research directions in this field have not been systematically mapped. This study aims to analyze publication trends, knowledge network structures, and the development of research topics related to PBL in digital mechanics learning using a bibliometric approach. The research data consists of 189 documents indexed in the Scopus database for the period 2015–2025. Analysis of publication trends, geographic distribution, and relationships between keywords was conducted using VOSviewer software. The analysis results show an increase in the number of publications over the past decade, with contributions concentrated in several countries. Keyword mapping shows the relationship between PBL and topics such as e-learning, game-based learning, and terms related to computing technology such as machine learning and deep learning. Furthermore, temporal visualizations indicate changes in the trend of term usage over time. However, these findings are descriptive and reflect patterns in the analyzed literature, and therefore do not directly indicate a causal relationship or the level of conceptual integration between PBL and digital technology. This research provides a contribution in the form of bibliometric mapping which can be the basis for further research to examine the implementation and integration of PBL in digital-based mechanics learning in more depth.

Keywords: Digital; Learning; Mechanics; Problem-based learning

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INTRODUCTION

Digitalization in education aims to improve the quality of learning through the use of technology that can deepen conceptual understanding, enrich the visualization of phenomena, and increase the effectiveness of problem-solving (OECD, 2023). In the context of physics, mechanics holds a fundamental position because it serves as the foundation for understanding the laws of motion, force, and energy, which in turn underpins the development of advanced physics topics and their applications in science and engineering (Young & Freedman, 2020). However, mechanics is also known as one of the most complex and challenging subjects, requiring the integration of conceptual understanding, mathematical skills, and the application of physics principles in real-world contexts (Docktor & Mestre, 2021). Therefore, mechanics learning needs to be designed to encourage students' active involvement in contextual problem-

solving, rather than simply focusing on mathematical procedures and formula memorization (Redish, 2020).

Problem-based learning (PBL) has been widely recognized as a pedagogical approach capable of supporting learning centered on authentic problem-solving and the development of higher-order thinking skills (Hmelo-Silver et al., 2020). Simultaneously, the development of digital technologies such as interactive simulations, computer-based visualizations, and online learning platforms provides significant opportunities to strengthen the implementation of PBL in physics learning (Luckin, 2022). Conceptually, the integration of PBL and digital technology is seen as a relevant approach to address the demands of 21st-century physics learning, particularly in improving the quality of understanding of mechanical concepts.

However, in practice, the implementation of this approach still faces various obstacles. Several studies show that physics learning, particularly in mechanics, is still dominated by conventional approaches that emphasize algorithmic problem solving and the procedural use of formulas (Docktor & Mestre, 2021). The application of PBL tends to be limited and has not been used as a primary framework for designing authentic learning experiences (Hmelo-Silver et al., 2020). Furthermore, the use of digital technology in physics learning often remains at a basic level, such as the use of separate presentation media or simulations, thus failing to support in-depth conceptual exploration or complex physics modeling (Hodges et al., 2022). This situation indicates a gap between the theoretical potential of integrating PBL and digital technology and its implementation in learning practice.

From a research perspective, this gap is also reflected in the lack of a comprehensive, data-driven mapping of the development of studies at the intersection of problem-based learning, physics learning, particularly mechanics, and digital transformation. Several previous studies have examined PBL in the context of STEM education, digital learning in physics, and the integration of technologies such as artificial intelligence in education. However, these studies were generally conducted in separate contexts and employed narrative or systematic review approaches with limited focus (Zawacki-Richter et al., 2022; Secinaro et al., 2021). As such, they have not fully explained the intellectual structure, thematic relationships, and development of research topics across these three fields quantitatively and longitudinally.

Furthermore, these limitations are increasingly important to consider because potential bias in literature mapping can arise when conceptual boundaries and research domains are not clearly defined. In this context, it is crucial to ensure that the studies conducted truly represent the educational domain, specifically PBL-based mechanics learning in digital contexts, and are not mixed with literature in computational mechanics or artificial intelligence that does not focus on pedagogical aspects. Therefore, an analytical approach is needed that is not only systematic but also able to provide clarity in accurately mapping research domains.

Based on this gap, this study uses a bibliometric analysis approach to map the research landscape related to problem-based learning in physics education, with a specific focus on mechanics learning in digital contexts. Unlike previous studies, this study explicitly focuses the analysis on the intersection of three main domains: PBL as a pedagogical approach, mechanics as the content of the physics discipline, and digital technology as a learning context. The bibliometric approach is used to identify publication trends, thematic structures, relationships between keywords, and the evolution of research topics quantitatively and data-driven (Donthu et al., 2021; Aria & Cuccurullo, 2022). Thus, this research attempts to provide a more focused and representative mapping of the intended field of study.

Specifically, the objectives of this study are: (1) to analyze publication trends related to problem-based learning in digital-based physics learning, particularly in mechanics; (2) to identify dominant themes and relationships between keywords in the literature; and (3) to map the development of research topics over time. This study does not aim to produce or recommend specific learning products, but rather to provide an evidence-based analytical basis that can be used in developing further research and designing more effective physics learning.

With this approach, it is hoped that this study can contribute to clarifying the intellectual structure of this field of study and identifying the direction of future research development more accurately and measurably.

METHOD

Research Design

This study uses a quantitative approach with bibliometric analysis to map the development of research related to problem-based learning (PBL) in physics education, with a specific focus on mechanics in the context of digital learning. The bibliometric approach was chosen because it provides a systematic, objective, and data-driven analysis of publication trends, relationships between concepts, and intellectual structures within a research field (Donthu et al., 2021; Aria & Cuccurullo, 2022). This study is descriptive-analytical in nature, aiming to identify patterns, thematic relationships, and the direction of research development quantitatively and longitudinally.

Figure 1. Bibliometric analysis workflow

The research procedure followed the bibliometric analysis stages shown in Figure 1, which encompassed six main steps: defining keywords, initial search, data collection, screening and refinement, data analysis, and interpretation of results. In the keyword definition stage, keywords were systematically determined by considering three primary research domains: pedagogical approach (problem-based learning), disciplinary content (mechanics in physics), and digital learning context. This approach aimed to ensure that the literature obtained truly represented the intersection of physics education, problem-based learning, and digital transformation.

Keyword Development and Search Strategy

In the keyword definition stage, search terms were developed by considering the conceptual scope of the study. The pedagogical domain was represented by terms related to problem-based learning, the disciplinary domain was represented by mechanics and physics mechanics, and the digital learning domain was represented by terms associated with digital and technology-enhanced learning environments. This strategy was intended to obtain literature that reflected the relationship between physics education, PBL, and digital transformation.

The initial search was conducted using the Scopus database, chosen for its broad coverage, quality of data curation, and common use in bibliometric studies in education and science. The search was conducted in the title, abstract, and keywords fields using the following search strings ("problem-based learning" OR "PBL") AND ("mechanics" OR "physics mechanics") AND ("education" OR "learning" OR "teaching") AND ("digital" OR "online learning" OR "e-learning" OR "technology-enhanced learning")

The search was conducted on January 15, 2026, with restrictions on document type (journal articles and conference proceedings), language (English), and publication period between 2015 and 2025. Furthermore, to ensure relevance to the educational domain, the search was limited to subject areas related to education and physics, such as Social Sciences and Physics and Astronomy (in the educational context).

Document Screening and Selection

The document selection process followed the stages presented in the PRISMA flowchart can be seen in Figure 2. In the identification stage, a search was conducted in the Scopus database by searching the title, abstract, and keywords columns using terms such as problem-

based learning, mechanics, learning, and digital, resulting in an initial 49,401 documents. The filtering process aimed to narrow down the keyword matches and resulted in 217 documents. Next, filtering based on publication dates between 2015 and 2025 resulted in 189 relevant documents. In the matching stage, documents were selected based on the highest number of citations, resulting in 130 documents. The inclusion stage identified the five articles with the highest number of citations, which were then further analyzed to determine key themes and significant contributions to this study (Zawacki-Richter et al., 2022).

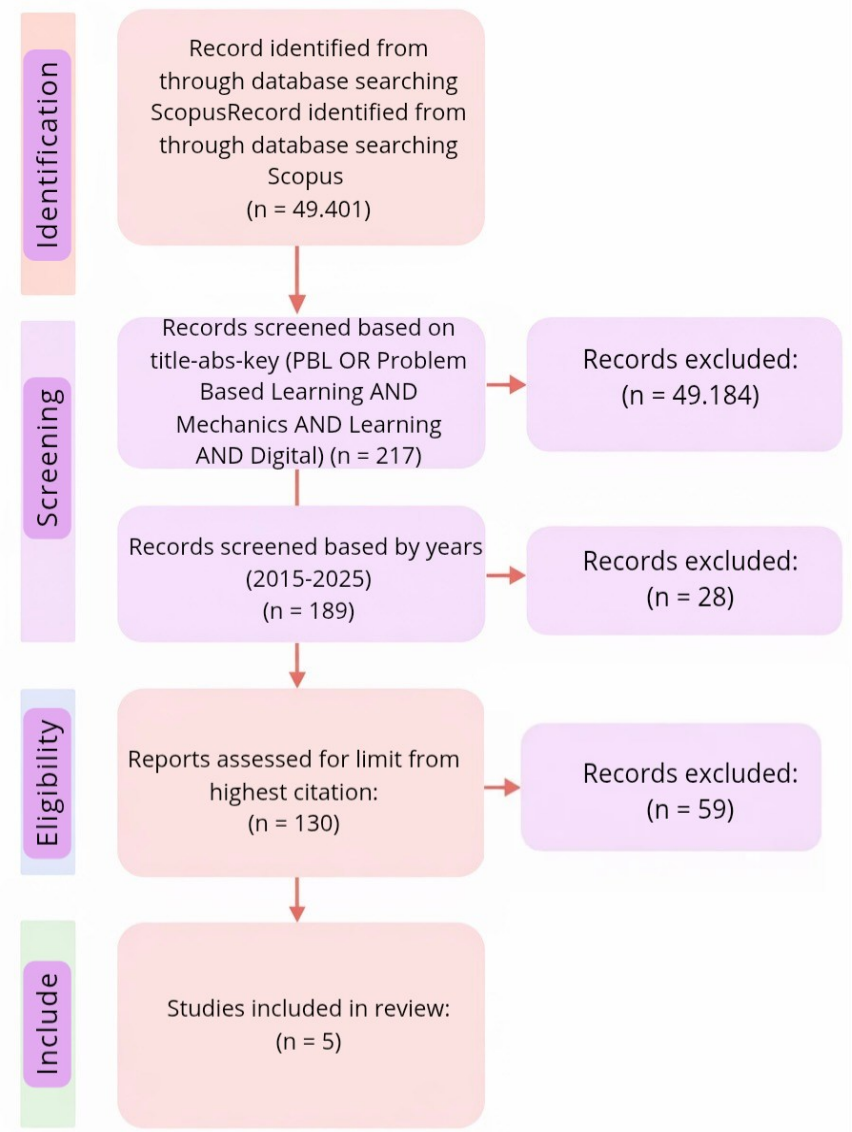

Figure 2. PRISMA flowchart of the document selection process

Data Collection and Bibliometric Analysis

The bibliographic data collected in this study included article title, publication year, author name, institutional affiliation, country, keywords, number of citations, and document type. The data was then exported in CSV (Comma-Separated Values) format to facilitate processing and analysis using bibliometric software. The analysis was conducted using VOSviewer software (van Eck & Waltman, 2020), chosen for its ability to map and visualize bibliometric networks, including keyword co-occurrence relationships, collaborations between authors, and citation patterns.

Specifically, VOSviewer was used to identify relationships between keywords, group research topics into thematic clusters, and visualize the development of research topics over time through network visualization and overlay visualization (van Eck, 2020). The analysis

included trends in the number of annual publications, keyword co-occurrence analysis, and temporal analysis to identify changes in research focus within the studied field.

Scope of Interpretation

The results of the bibliometric visualization were interpreted descriptively to illustrate patterns of research relationships, topic distribution, and temporal trends. The interpretation was conducted carefully by distinguishing between findings directly supported by bibliometric data and broader conceptual interpretations. Therefore, this study does not aim to evaluate the effectiveness of PBL implementation or to establish causal relationships between digital technology and learning outcomes. Instead, it provides an overview of research developments related to problem-based learning in digital mechanics instruction and offers an analytical basis for future studies without making conclusions beyond the available bibliometric evidence.

RESULTS AND DISCUSSION

Research Publication Trends on Problem-Based Learning in Digital Mechanics Learning

An analysis of 189 documents indexed in Scopus between 2015 and 2025 shows an increase in the number of publications related to problem-based learning (PBL) in digital mechanics instruction. Figure 3 shows a gradual increase in the number of publications, from one document in 2015 to a peak of 36 in 2023. After that, the number of publications remained relatively stable, with 34 documents in 2024 and 33 documents in 2025.

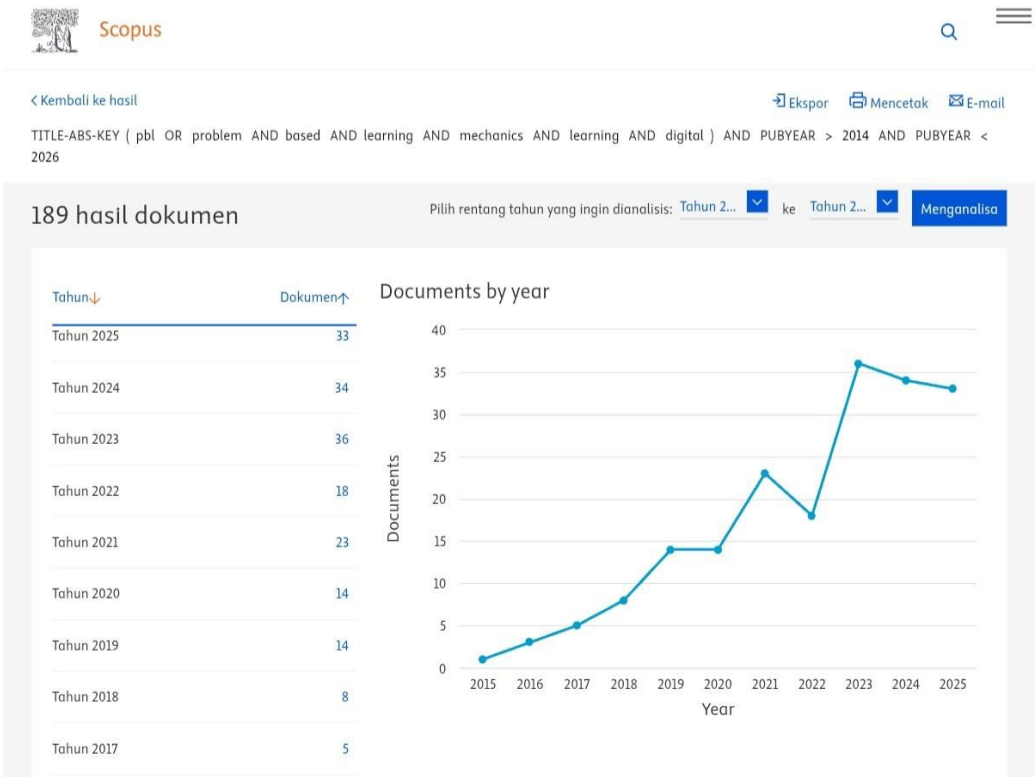

Figure 3. Publication trends from 2015 to 2025

These findings indicate that the topic of PBL in digital mechanics instruction has grown over the past decade. However, this increase in publications does not directly indicate a paradigm shift or a change in the effectiveness of the learning approach, but rather reflects increased academic attention to the integration of pedagogy and technology in physics education.

The increase in publications after 2020 can be generally attributed to the accelerated adoption of digital technology in education, including during the COVID-19 pandemic, which encouraged the use of online learning, simulations, and virtual learning environments. Furthermore, the increasing need to develop higher-order thinking and problem-solving skills

in mechanics learning has also contributed to the growing research interest in PBL approaches. However, a causal relationship between these factors and publication trends cannot be directly inferred from this bibliometric analysis and requires further investigation through other studies.

Distribution of Publication Document Types

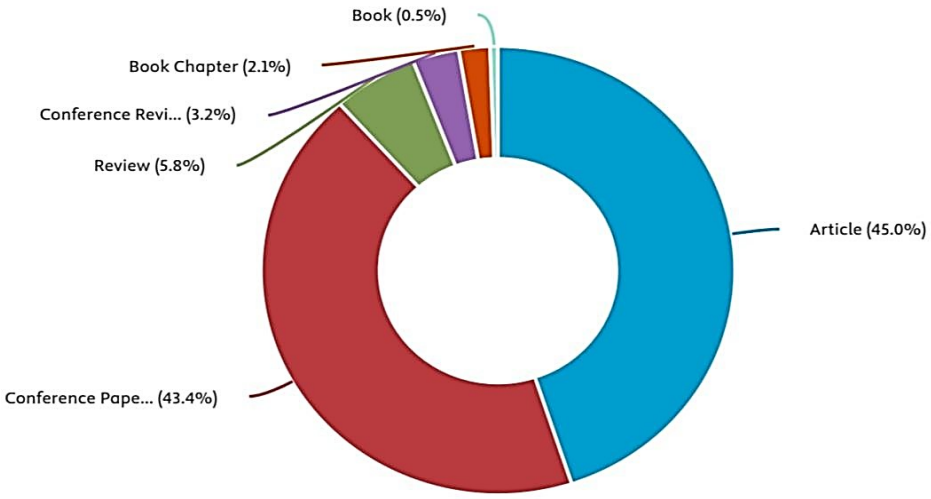

Figure 4. Documents by type

The distribution of document types in Figure 4 shows that publications are dominated by journal articles (45.0%) and conference proceedings (43.4%). This proportion indicates that this research field develops through two main channels: formal academic publication and dissemination through scientific forums.

Journal articles generally represent research that has undergone a more rigorous evaluation process, while conference proceedings often reflect initial exploration, the development of ideas, or the application of technology in learning contexts. Meanwhile, the proportion of other documents, such as reviews (5.8%), book chapters (2.1%), and books (0.5%), is relatively smaller. This may indicate that synthetic studies or the development of comprehensive conceptual frameworks are still limited. However, this interpretation requires caution, as the distribution of document types is also influenced by the characteristics of the research field and publication habits within a particular scientific community.

Country Contributions in PBL and Digital Mechanics Research

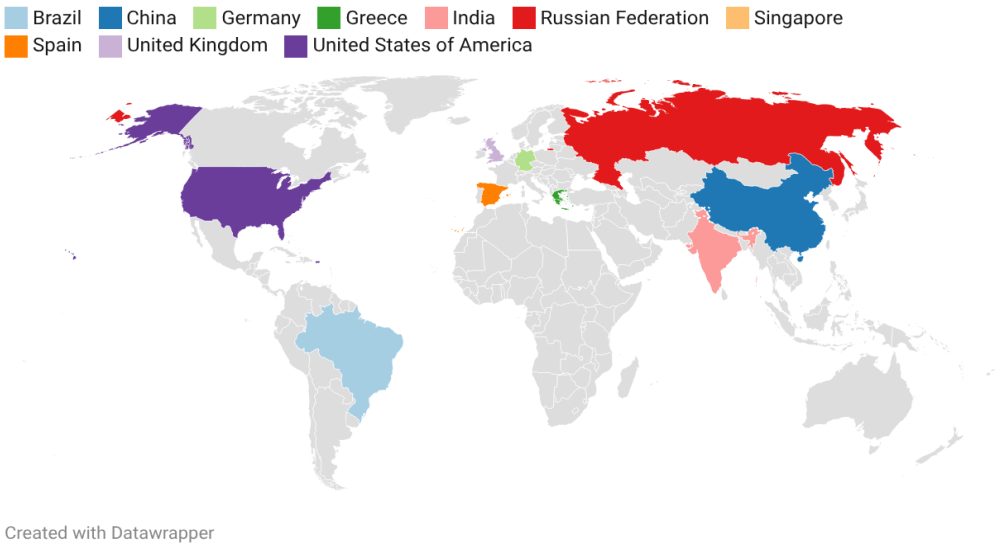

Figure 5. Top 10 countries thet contribute to PBL research in digital based mechanical learning (2015-2025)

The geographic distribution of publications shown in Figure 5 indicates that research related to problem-based learning (PBL) in digital mechanics instruction is concentrated in several countries, including the United States, China, Russia, India, Germany, the United Kingdom, Spain, Brazil, Greece, and Singapore. This pattern indicates that research contributions in this field are predominantly from countries with relatively high publication activity in education and science. However, the dominance of publications from a particular country does not directly reflect the superior quality of research or the effectiveness of its education system. Factors such as the size of the academic community, access to international publications, and publication habits can also influence this distribution. Furthermore, the relatively lower contributions from some regions, including Southeast Asia, should be interpreted with caution. This finding does not necessarily indicate a lack of research activity but may reflect limited representation in the databases used or differences in publication practices. Therefore, the results of this geographic mapping are more appropriate for identifying the distribution of contributions in the indexed literature, rather than as a basis for drawing normative conclusions regarding research gaps or development priorities.

The Relationship between Keywords and the Intellectual Structure of Research

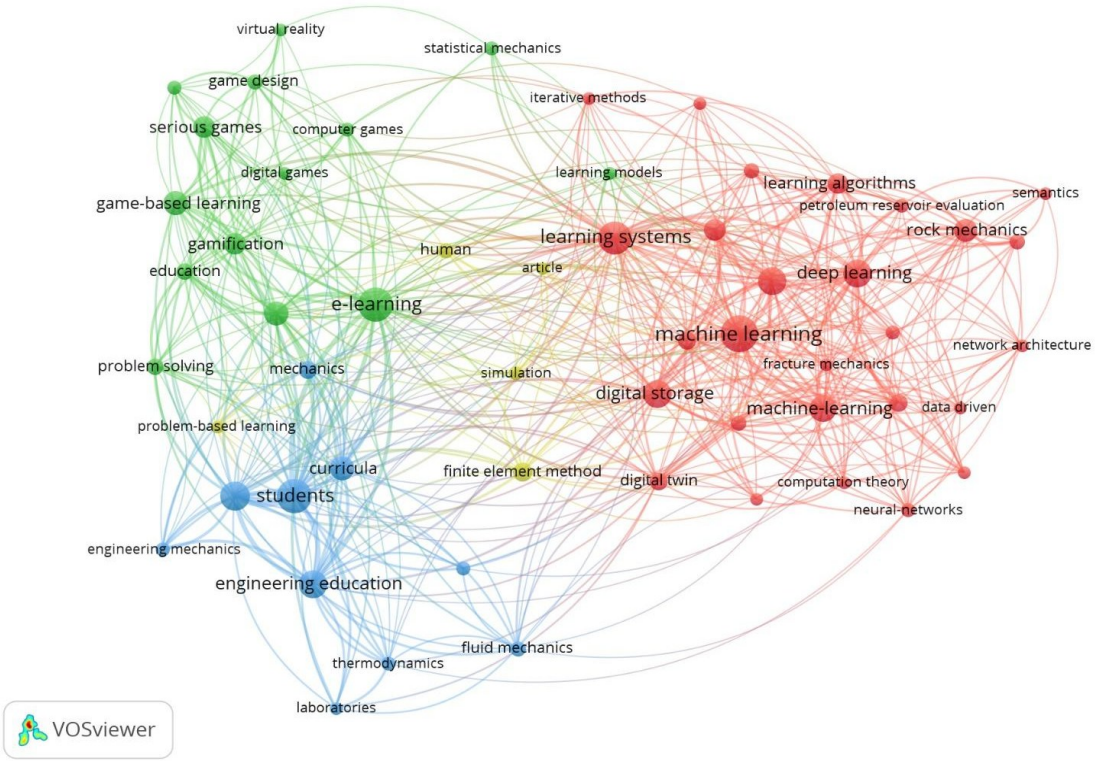

Figure 6. Shared network keywords

The relationship between keywords in research related to problem-based learning (PBL) and digital-based mechanics learning can be observed through the network visualization in Figure 6. The map shows the formation of several thematic clusters based on the co-occurrence of keywords in the analyzed literature. The first cluster includes keywords such as e-learning, game-based learning, engineering education, and students. The co-occurrence of these keywords indicates a link between pedagogical approaches and the use of digital technology in learning contexts. This cluster indicates that some research focuses on integrating PBL with various forms of digital learning environments. However, the relationships shown in this map are descriptive and do not directly indicate causal relationships or the effectiveness of specific approaches.

The second cluster includes terms such as machine learning, deep learning, educational systems, mechanics, and digital twins. The presence of this cluster indicates a link between research in mechanics and computational approaches and artificial intelligence-based

technologies. However, it should be noted that some terms in this cluster are also commonly used in the context of computational mechanics and engineering, so they do not fully represent research in the educational domain. In general, the presence of several clusters in this visualization indicates a variety of research focuses in the analyzed literature. The differences between clusters are better understood as representing a diversity of research themes and approaches, rather than as clear conceptual divisions. Therefore, interpretation of the cluster structure should be limited to the level of thematic mapping, without drawing conclusions.

Evolution of Research Topics Based on Time Dimension

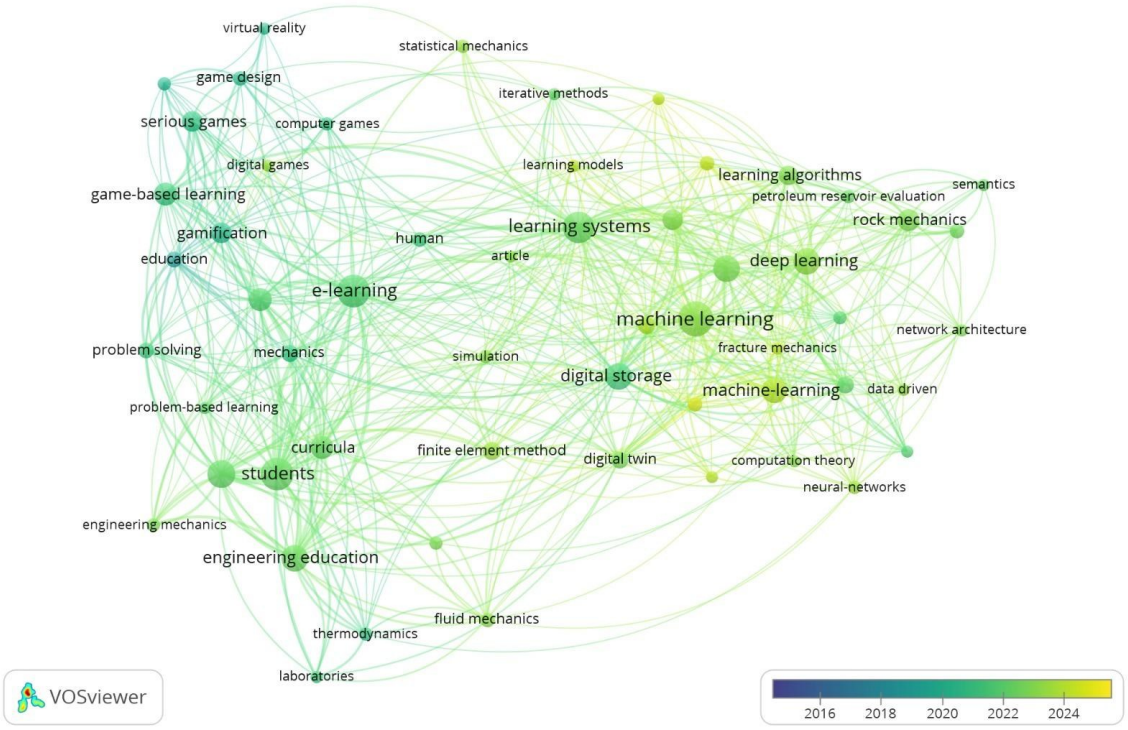

Figure 7. Overlay visualization of keyword evolution

The overlay visualization in Figure 7 shows the development of keyword occurrences in research related to problem-based learning (PBL) and digital-based mechanics learning throughout the analysis period. In the early stages, the most dominant keywords included terms such as engineering education, students, and laboratory. This indicates that most research during that period focused on practice-based learning contexts and laboratory environments.

In the more recent period, there is an increase in the occurrence of keywords such as learning systems, machine learning, and deep learning. This pattern indicates a trend toward increasing use of terms related to digital technology and computing in the analyzed literature. However, the emergence of these keywords does not directly indicate changes in pedagogical approaches or learning effectiveness but rather reflects changes in the topical focus of the publications. The color changes in the overlay visualization indicate the temporal distribution of keyword occurrences, with lighter colors representing keywords that are relatively newer in the publication period. Interpretation of this pattern should be limited to identifying temporal trends, without directly linking them to theoretical developments or transformations in learning systems.

Furthermore, the presence of terms related to artificial intelligence and computing in recent times also requires careful interpretation, as these terms do not always appear in educational contexts but can also originate from computational mechanics or engineering literature. Therefore, the results of this visualization are more appropriately understood as an indication of a shift in the focus of terms in the literature, rather than as evidence of conceptual

integration between PBL and digital technology. This research contributes by mapping the patterns of topic emergence and their bibliometric relationships. However, this analysis is not intended to evaluate the effectiveness of learning approaches or determine the direction of specific pedagogical development, but rather to provide an initial overview of the development of research themes in the field under study.

Novelty and Implications for Development

The results of the bibliometric analysis indicate that research related to problem-based learning (PBL) and the use of digital technology in mechanics learning encompasses a variety of focuses. Some studies emphasize the pedagogical aspects of PBL, while others focus more on the use of digital technology in learning and modeling contexts. This variation indicates that the existing literature has not yet fully focused on a single, integrated approach.

However, these findings should be interpreted with caution, as the bibliometric analysis used in this study only represents patterns of interconnectedness and topic trends in publications, not the level of conceptual integration or the effectiveness of implementation in learning practice. Therefore, terms such as "fragmentation" or "disintegration" cannot be definitive conclusions but rather serve as initial indications of the diversity of research directions. This research contributes by mapping bibliometrically the development of topics and the interconnections between concepts in the related literature. The results of this mapping can be used as a basis for identifying emerging research areas and those that are still limited in terms of publication representation. However, further implications regarding the development of learning approaches or pedagogical innovation require additional study using more in-depth methods, such as content analysis or empirical studies.

5 (Five) Most Cited Articles

The most cited articles were analyzed to determine the most significant intellectual contributions to this research field. Highly cited articles demonstrate significant influence on the advancement of the field and often serve as primary references for further research. To achieve this goal, Table 1 displays the five most cited articles on digital mechanics teaching and problem-based learning, along with their contributions to the advancement of this research discipline.

Table 1. Five most cited articles

No	Author	Year	Journal (Quartile)	Citation	Contribution to Research
1	Zuo et al.	2022	Light: Science and Applications (Q1)	660	Deep learning mechanics
2	Santos et al.	2020	Advances in Water Resources (Q1)	202	AI fluid mechanics
3	Vadyala et al.	2022	Results in Engineering (Q2)	183	Physics AI
4	Chen & Zhang	2021	Water (Switzerland) (Q2)	145	Flow modeling
5	Tripura & Chakraborty	2023	Computer Methods in Applied Mechanics and Engineering (Q1)	130	Numerical mechanics

Table 1 shows that the articles with the highest number of citations mostly originate from research that combines mechanics with computational approaches and artificial intelligence, such as machine learning and deep learning (Zuo et al., 2022). This indicates that the main direction of research in digital mechanics currently focuses on the use of numerical modeling, simulation, and physical data analysis to understand complex mechanical phenomena (Tripura & Chakraborty, 2023). These computational approaches are important because they improve the accuracy of modeling and help visualize mechanical concepts that are difficult to directly observe in physics (Chen & Zhang, 2021).

Despite the fact that these articles make significant contributions to the advancement of computer science and technology, most have not explicitly incorporated problem-based pedagogical concepts into the structure of well-designed digital teaching materials (Hmelo-Silver et al., 2020). This situation suggests that the use of digital technology in mechanics research tends to focus on technical aspects rather than the application of learning strategies that help students solve problems (Hodges et al., 2022). Consequently, digital mechanics instruction that combines advanced technology with a problem-based learning approach has great potential to close this research gap. This method aims to encourage knowledge acquisition and teamwork in physics education (Zawacki-Richter et al., 2022).

Research Evaluation

Based on the results of the bibliometric analysis, research related to problem-based learning (PBL) in physics education, particularly on mechanics in a digital context, shows a fairly diverse focus. Some publications emphasize the pedagogical aspects of PBL, while others focus more on the use of digital technology and computational approaches. This pattern indicates a diversity of research directions in the analyzed literature.

However, it should be emphasized that these findings are based on an analysis of keyword associations and publication trends, and therefore cannot be directly used to assess the level of integration between pedagogical approaches and technology in learning practices. Therefore, interpretation of the relationship between digital technology developments and PBL implementation requires caution.

The results of this mapping can provide an initial overview of emerging research areas and topics that are relatively underexplored in the literature. In this context, future research can be directed to more in-depth examinations of how the integration of PBL and digital technology is implemented in mechanics learning, for example through empirical studies, analysis of learning designs, or experiment-based approaches.

Furthermore, the development of PBL-based digital learning tools, such as e-LKPD in the context of mechanics, can be considered as a further research direction. However, these proposals should be positioned as potential future developments and require further validation through empirical research. Therefore, this study does not aim to recommend specific solutions, but rather to provide a mapping framework that can support the development of more focused, evidence-based follow-up studies.

CONCLUSION

Based on an analysis of 189 documents indexed in Scopus for the period 2015–2025, research related to problem-based learning (PBL) in digital-based mechanics instruction shows an increasing trend in the number of publications over the past decade. This finding reflects the growing academic attention to the integration of pedagogical approaches and digital technology in physics education. However, the increase in the number of publications does not directly indicate a change in learning paradigms or the effectiveness of a particular approach.

The results of bibliometric mapping indicate a variety of focuses in the analyzed literature. Some studies focus on pedagogical aspects and the use of digital technology in learning contexts, while others overlap with the fields of computational mechanics and modeling. Therefore, the identified thematic structure is better understood as a representation of diverse research directions, rather than a clear conceptual separation. Keyword network analysis and temporal visualization indicate changes in terminology usage trends over time, including the increasing emergence of terms related to digital technology and computing. However, these findings are limited to a descriptive level and cannot be used to directly infer conceptual integration or pedagogical developments.

The primary contribution of this research lies in providing a bibliometric mapping that illustrates the patterns of relationships, topic distribution, and trends in research development in the fields of problem-based learning and digital mechanics learning. This mapping can serve

as an initial basis for identifying emerging research areas and those that are still limited in their literature representation. However, this study has limitations, particularly related to the potential diversity of dataset coverage, which includes literature outside the strictly educational domain. Therefore, future research is recommended to employ more in-depth approaches, such as content analysis or empirical studies, to more comprehensively understand how the integration of PBL and digital technology is implemented in mechanics learning.

RECOMMENDATION

Based on the analysis, further research is recommended to further explore how the integration of problem-based learning (PBL) and digital technology is implemented in mechanics learning through more in-depth approaches, such as empirical studies, learning design analysis, and experiment-based research. These approaches are needed to complement descriptive bibliometric findings and provide a more comprehensive understanding of learning practices in the field.

Furthermore, the development of PBL-based digital learning tools, such as e-LKPD in the context of mechanics, can be considered as a further research direction. However, such development needs to be based on a clear needs analysis and validated through empirical testing before it can be widely implemented.

Further research can also expand the scope of contexts, including various educational levels and geographic regions that are still underrepresented in the literature, such as developing countries. This is crucial to obtain a more diverse picture of the implementation of digital-based PBL in mechanics learning across various educational settings. It should be emphasized that this research does not directly recommend a specific model or approach as a solution, but rather provides a baseline that can be used to support the development of more focused and evidence-based follow-up research.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Safina Ridka Pratiwi	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓	
Dwikoranto	✓	✓		✓						✓		✓		
Rahmatta Thoriq Lintangesukmanjaya		✓		✓			✓			✓		✓		
Sukarni							✓			✓		✓		
Indri Hapsari Khansa	✓									✓	✓	✓		
Lindsay Natalia Bergsma				✓						✓				

CONFLICT OF INTEREST STATEMENT
Authors state no conflict of interest.

INFORMED CONSENT
We have obtained informed consent from all individuals included in this study.

ETHICAL APPROVAL
This study did not involve human participants, animal subjects, clinical procedures, personal data collection, or direct intervention in educational settings. The research was conducted using secondary bibliographic metadata obtained from the Scopus database, including publication titles, authorship information, keywords, citation counts, publication years, and document types. Therefore, formal ethical approval was not required for this bibliometric study. All data analyzed in this research were publicly available bibliographic records and were used solely for academic mapping, trend analysis, and visualization of research developments. The study was conducted in accordance with principles of research integrity, transparency, and responsible use of scholarly metadata.

DATA AVAILABILITY
The data used in this study consist of bibliographic metadata retrieved from the Scopus database, including article titles, publication years, author information, institutional affiliations, countries, keywords, citation counts, and document types. The datasets generated and analyzed during this study are available from the corresponding author upon reasonable request. Because the data were obtained from the Scopus database, access to the original records may depend on institutional subscription or database access rights. The processed data used for bibliometric mapping and visualization can be provided for academic verification and research purposes, provided that its use complies with relevant database terms and conditions.

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