



Opportunities for integrating gamification and emerging technologies with direct observation in biology education: A bibliometric analysis

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Abstract

Digital transformation in higher education has led to the emergence of gamification, direct observation, and new technologies in biology learning, but previous studies have discussed them separately. To date, there has been no bibliometric study that systematically maps the integration of these three approaches. This study aims to analyze global research trends, thematic gaps, and potential integration across topics using a bibliometric approach. Data were retrieved from Google Scholar through the Publish or Perish application using the keywords “gamification,” “emerging technology,” and “biology,” covering publications from 2020 to 2024. A total of 207 relevant articles were analyzed and visualized using VOSviewer to map bibliometric relationships based on keyword co-occurrence, citation networks, and topic evolution. The results indicate a significant increase in publication growth over the past five years, with dominant themes such as artificial intelligence, deep learning, and virtual simulation, reflecting a shift toward emerging and adaptive learning models. Cluster mapping identified four major research groups: digital gamification, data-driven learning, virtual simulation, and implementation-based studies. These findings confirm that international research in biology education is moving toward the synergy of interactivity, analytics, and technology-based experiential learning. Nevertheless, the integration of gamification and direct observation with emerging technologies remains limited, representing a strategic opportunity for future empirical exploration. This study reinforces experiential learning and situated cognition as the basis for integrating interactive digital technology and direct observation practices. These findings also provide strategic direction for the design of adaptive, evidence-based pedagogical innovations in biology education.

Keyword: gamification; direct observation; emerging technology; biology education; bibliometrics

Abstrak. Transformasi digital dalam pendidikan tinggi mendorong munculnya gamifikasi, pengamatan langsung, dan teknologi baru dalam pembelajaran biologi, namun kajian sebelumnya masih membahasnya secara terpisah. Hingga kini, belum ada studi bibliometrik yang memetakan secara sistematis integrasi ketiga pendekatan tersebut. Penelitian ini bertujuan untuk menganalisis tren penelitian global, kesenjangan tematik, serta potensi integrasi antartopik melalui pendekatan bibliometrik. Data diperoleh dari basis Google Scholar menggunakan aplikasi Publish or Perish dengan kata kunci “gamification”, “emerging technology”, dan “biology”, mencakup publikasi tahun 2020–2024. Sebanyak 207 artikel yang relevan dianalisis dan divisualisasikan menggunakan VOSviewer untuk menggambarkan keterkaitan bibliometrik berdasarkan jejaring kata kunci, sitasi, dan evolusi tren riset. Hasil analisis menunjukkan peningkatan publikasi yang signifikan dalam lima tahun terakhir, dengan dominasi tema artificial intelligence, deep learning, dan virtual simulation yang mencerminkan pergeseran riset menuju integrasi teknologi imersif dan pembelajaran adaptif. Pemetaan klaster mengidentifikasi empat kelompok utama, yaitu gamifikasi digital, pembelajaran berbasis data, simulasi virtual, dan penelitian implementatif. Temuan ini menegaskan bahwa riset internasional dalam pembelajaran biologi bergerak ke arah sinergi antara interaktivitas, analitik, dan pengalaman belajar berbasis teknologi. Kajian ini juga mengungkap bahwa integrasi gamifikasi dan pengamatan langsung dengan teknologi baru masih terbatas, sehingga menjadi peluang strategis untuk penelitian lanjutan. Penelitian ini memperkuat dasar experiential learning dan situated cognition sebagai landasan integrasi antara digital interaktif dan praktik observasi langsung. Temuan ini juga memberikan arah strategis bagi perancangan inovasi pedagogis yang adaptif dan berbasis bukti dalam pembelajaran biologi.

INTRODUCTION

The development of digital transformation in higher education has given rise to various new approaches to improve the quality of learning (Wang & Nie, 2023; Fajeriadi & Fitriani, 2024), including through the application of gamification (Kartika et al., 2025), direct observation (Fajeriadi et al., 2025), and technology (Jainab et al., 2025) in the context of biology learning (Fahmi et al., 2021; Fajeriadi & Fitriani, 2024). Studies on technology-based learning innovations show a significant increase in recent years, particularly in terms of student engagement and the achievement of deep learning (Li & Xing, 2021; Zhao et al., 2022; Wu, 2024). The integration of these three approaches is based on the importance of experiential learning in building conceptual understanding, and situational cognition in optimizing learning through authentic contexts. Thus, gamification is considered to encourage engagement, direct observation provides meaningful experiences, and immersive technology presents contextual simulations that have the potential to support each other. Although digital innovations have been widely implemented, there has been no comprehensive study mapping the relationship between gamification-based approaches, direct observation activities, and the use of new technologies in the context of biology learning, which requires a balance between empirical experience and digital engagement.

A number of studies have proven the effectiveness of gamification in increasing motivation (Figueiredo & García-Peñalvo, 2020) and student interaction in various fields of education (Aguiar-Castillo et al., 2020; Raju et al., 2021). On the other hand, direct observation remains an important element in biology learning because it supports students' scientific thinking skills and analytical abilities (Hayati et al., 2021; Contractor et al., 2025). In addition, the emergence of emerging technologies such as augmented reality (AR), virtual reality (VR), and artificial intelligence (AI) has also enriched learning methods through visualization and interactive simulations (Gandedkar et al., 2021; Al Balushi et al., 2024). These three approaches actually operate on different dimensions of learning but complement each other. These approaches support cognitive, affective, and psychomotor aspects, which should be integrated into a modern biology pedagogical framework. These findings indicate that gamification, direct observation, and immersive technology, which were studied previously, still stand alone, even though they complement each other in improving motivation, conceptual understanding, and scientific skills. Therefore, an integrated pedagogical approach is needed in biology learning.

Biology learning strategies are expected to integrate gamification, direct observation, and emerging technology as a unified strategy to strengthen deep learning and scientific engagement. However, there has not been much research that comprehensively maps the direction of development, topic dominance, author collaboration, and publication trends in these three themes simultaneously. The main reason is that bibliometric analyses specifically examining the knowledge map and thematic relationships between gamification (Khatibi et al., 2021; Nadi-Ravandi & Batooli, 2022) and emerging technology (Chen et al., 2021; Jing et al., 2024) in the context of biology learning has not been integrated with direct observation. As a result, the potential synergy between these approaches has not been optimally utilized by researchers and education practitioners. Therefore, this study is the first systematic attempt to map the knowledge landscape related to gamification, direct observation, and emerging technology in biology learning through a bibliometric approach, in order to identify patterns of integration and opportunities for learning innovation in the digital era.

The proposed solution is to conduct a bibliometric analysis to identify trends, research maps, and research developments related to these three topics in the context of biology education. This analysis will enable the identification of the most productive research areas, emerging themes, and potential for integration between topics in the future. Thus, the focus of this research is to combine the three main fields (gamification, direct observation, and emerging technology) through a bibliometric analysis approach to map global research trends and gaps in biology learning. This research not only provides a comprehensive picture of the direction of scientific development but also serves as the basis for formulating a research agenda and developing learning innovations in the digital age. This research contributes to scientific mapping by analyzing the relationship between gamification, which is generally supported by immersive technology, and its potential integration with direct observation in biology learning. Previous research has not been examined in an integrated manner using a bibliometric approach, so it is hoped that this study will provide a new perspective on the potential integration of these three approaches.

This approach makes an important methodological contribution by connecting three previously separate fields of research through integrative bibliometric mapping. Specifically, this study aims to (1) analyze publication trends on gamification, direct observation, and new technologies in biology learning; (2) identify conceptual gaps and opportunities for integration between themes; and (3) provide recommendations for research directions and pedagogical innovation development in the era of digital transformation. In summary, this study aims to map research trends, identify gaps and potential for integration between the three approaches mentioned above, and recommend further direct research.

RESEARCH METHODS

This study uses a bibliometric approach with descriptive analysis to map publication trends, scientific collaboration, and research developments in gamification, direct observation, and emerging technology in biology education. This approach was chosen because it allows for a comprehensive analysis of the productivity patterns and scientific influence of a field based on publications and citations, while also providing a conceptual overview of the interrelationships between research topics (Donthu et al., 2021).

The data source was obtained from the Google Scholar database, which was chosen because it has a broad coverage of interdisciplinary scientific literature and is able to accommodate articles from various academic publishers. The data collection process was carried out using the Publish or Perish (PoP) application to extract publication metadata such as title, author name, year of publication, publication source, keywords, and number of citations. The search was conducted in June 2025 using a combination of keywords: “gamification,” “emerging technology,” “biology,” and “deep learning.” The search results focused on English-language scientific journal articles published between 2020 and 2024. Next, the exported data was selected to eliminate duplicates and publications that were not relevant to the context of biology learning.

The cleaned data was then processed and analyzed using VOSviewer (version 1.6.20) to visualize bibliometric relationships between elements such as co-authorship, keyword co-occurrence, citation networks, and bibliographic coupling. This application was used to generate thematic network maps and topic evolution trends that represent conceptual relationships between studies. The visualization results included network visualization and overlay visualization, which were used to interpret the dynamics of research theme changes over time. The analysis was descriptive, interpreting the patterns of interconnections between topics and the scientific contributions that emerged from the mapping results. The research stages are presented in Figure 1.

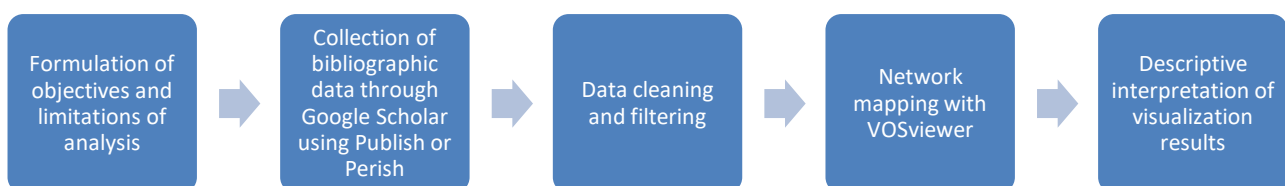


Figure 1 The implementation stage of bibliometric analysis

RESULTS AND DISCUSSION

A literature search covering publications from 2020 to 2024 shows a significant increase in studies related to gamification, direct observation, and emerging technology in biology education. Based on 207 articles analyzed, there were a total of 8547 citations, with an average of 41.29 citations per article and 1709.4 citations per year, indicating a high level of relevance and citation power in this field. The h-index value of 38 and g-index of 91 show that a number of studies have had a broad and consistent citation impact. In addition, an average of 2.73 authors per article indicates fairly intensive research collaboration among authors, although the dominance of topics is still spread across certain sub-themes. The distribution of papers with accumulated citation counts (ACC) $\geq 1, 2, 5, 10$, and 20 is 124, 102, 81, 54, and 35 articles, respectively, which describes a group of core articles with high citation influence. Overall, this trend shows that research on the integration of gamification, direct observation, and new technologies in biology education has grown rapidly

in the last five years, indicating that this topic is increasingly recognized as a strategic area in digital-based educational innovation.

The analysis of the number of publications in Figure 2 shows a consistent upward trend over the past five years. In 2020, there were 20 articles, which increased to 24 articles in 2021, remained stable at 24 in 2022, and jumped sharply to 55 articles in 2023, reaching a peak of 72 articles in 2024. When compared to the total of 207 articles identified during the 2020–2024 period, approximately 195 articles (94.2%) had a detected year of publication, while the other 12 articles (5.8%) did not have a definite year of publication due to limitations in the metadata in the bibliometric database. Nevertheless, the annual distribution still shows a clear upward trend, with the largest contribution coming from the last two years (2023–2024), which accounted for nearly 61.8% of total publications. This pattern indicates a significant acceleration in research interest related to gamification, direct observation, and emerging technology in biology education. The sharp upward linear trend in the last two years confirms that the topic of integrating digital innovation in biology education is in a phase of rapid growth and is becoming a major focus in global technology-based education research.

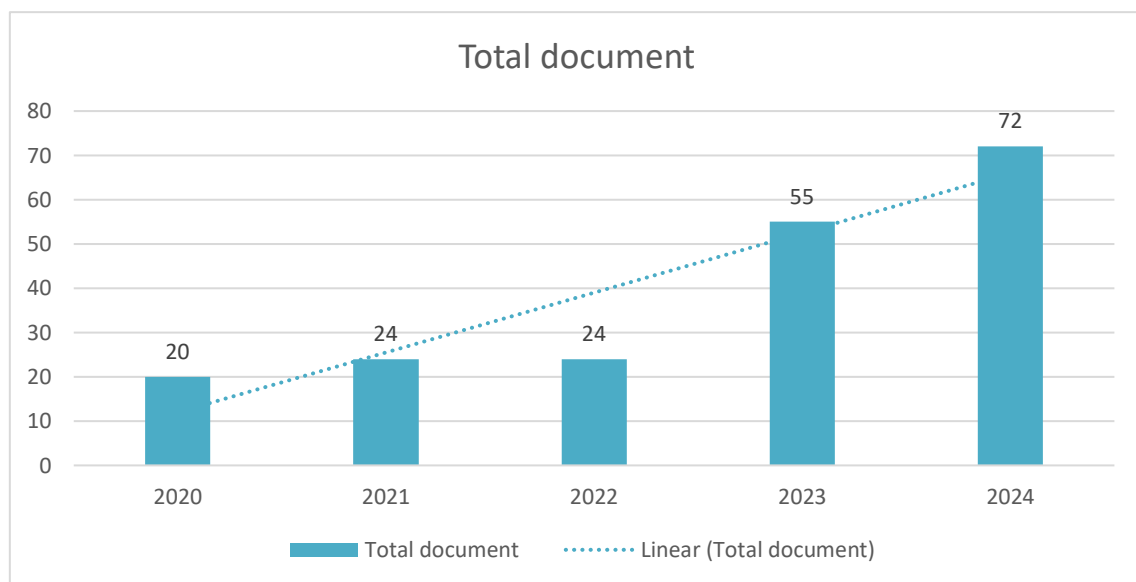


Figure 2 Trends in publications per year over the last five years

After analyzing publication trends, the next step is to examine thematic trends through keyword analysis, as shown in Figure 3. This visualization illustrates the conceptual relationships between the main topics in research on gamification, direct observation, and emerging technology in biology education. Figure 3 A shows the most frequently occurring keywords, where “technology,” “gamification,” “deep learning,” and “artificial intelligence” are the main hubs of the network, indicating that these topics have dominated scientific discourse in the last five years. The dense pattern of connections around these terms shows that recent research not only discusses the application of technology in a pedagogical context, but also begins to integrate aspects of deep learning experiences and learning automation through artificial intelligence.

Furthermore, Figure 3 B presents a network visualization that divides the research map into several color clusters. The red cluster focuses on the theme of gamification and its application in the context of digital learning, covering keywords such as engagement, motivation, and learning models. The green cluster highlights the integration of machine learning, artificial intelligence, and data-driven learning, representing the direction of research towards analytics-based adaptive learning. The blue cluster reflects topics of deep learning, metaverse, and virtual simulation, indicating the expansion of emerging technology utilization in the process of biological observation and exploration. Meanwhile, the yellow cluster shows a focus on integration, challenge, and study, signaling a shift from conceptual research to implementative and evaluative research in the field.

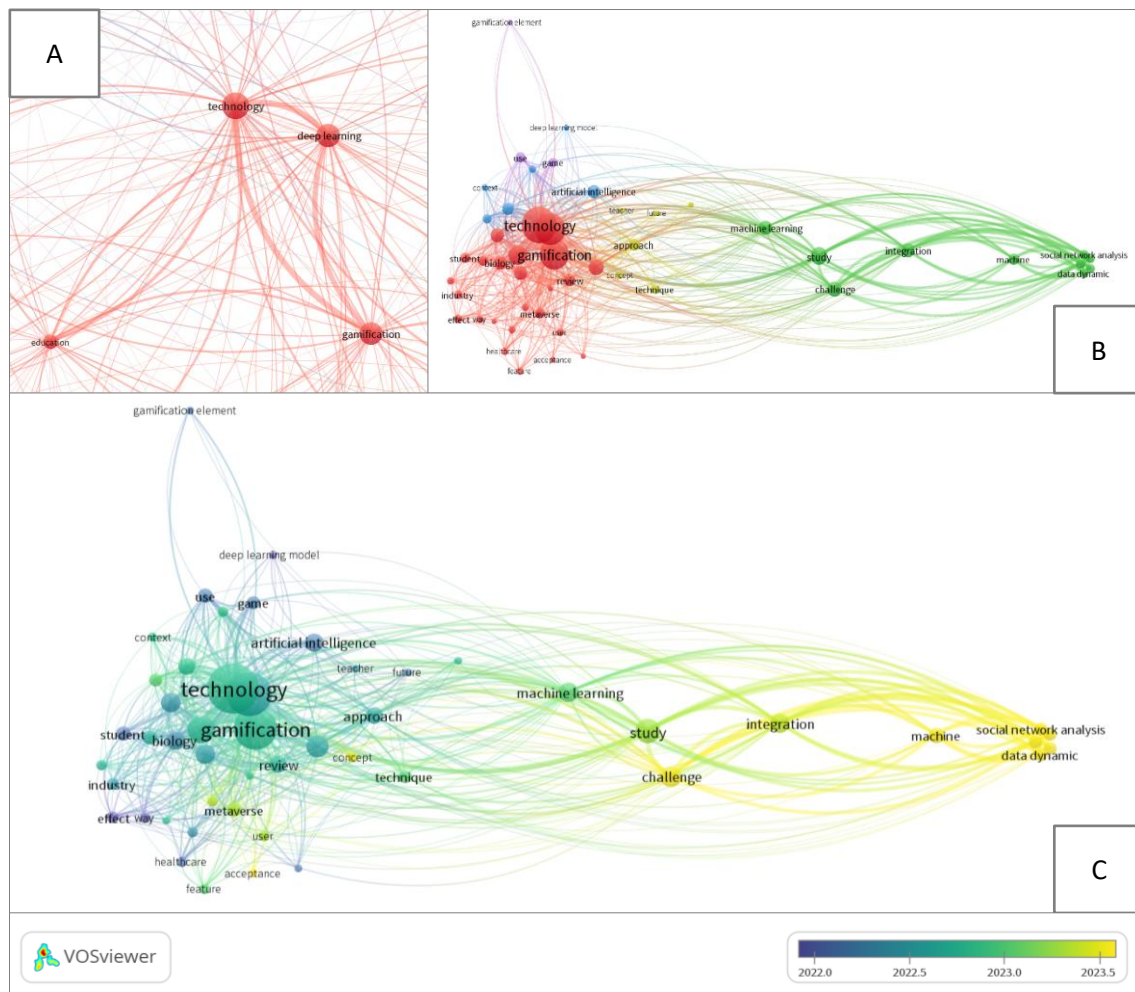


Figure 3

A is an enlargement of the most frequently occurring keywords, B is a network visualization, and C is an overlay visualization

The relationship between these clusters is consistent with learning theory and research findings, whereby gamification activities support motivation according to Self-Determination Theory (Luarn et al., 2023), virtual and immersive simulations support Situated Cognition (Wang et al., 2024; Wang et al., 2025) and Experiential Learning through authentic contexts (Huang et al., 2023), and adaptive systems based on artificial intelligence (AI) follow the principles of Learning Analytics (Ouyang et al., 2023) and personalized learning (Gupta et al., 2022). Thus, these clusters illustrate how technological and pedagogical dimensions synergize to enhance deep learning and interactive scientific exploration.

In Figure 3 C, the overlay visualization shows the dynamics of research trends over time. Dark blue represents themes that emerged earlier in the 2020-2021 period, such as gamification and technology use, while green and yellow indicate newer themes (2023-2024), such as machine learning, integration, and data dynamics. Specifically, studies published in 2020-2021 focused on the initial exploration of technology integration in biology learning, emphasizing keywords such as gamification, technology, student, and biology. In 2022, the thematic development shifted toward the adoption of artificial intelligence and data-driven approaches, indicated by the emergence of deep learning model, review, and approach. Meanwhile, 2023-2024 marked a transition into more advanced themes, including machine learning, integration, social network analysis, and data dynamic, showing a movement toward analytical and interconnected research models.

This pattern shows an evolution of topics from the stage of exploring technology application to a more complex approach, where the integration of gamification, AI, and data analytics has become the dominant direction of current research. Thus, the results of this visualization reinforce the findings of previous trends

that research in the field of technology-based biology learning is moving towards a phase of synergy between topics, combining interactive, analytical, and emerging approaches to support deep learning.

Table 1 Ten documents with the most citations

No.	Author(s) (Year)	Source/publisher	Main contribution	Σ citations
1	Raisch & Krakowski (2021)	<i>Academy of Management Review</i> (AOM)	Analyzing the paradox of automation vs. augmentation in AI-based management; defining the role of AI in decision-making and business strategy.	2165
2	Maroungkas et al. (2023)	<i>Electronics</i> (MDPI)	A study of VR-based learning theory; highlighting the gamification approach to deep learning.	636
3	Chengoden et al. (2023)	<i>IEEE Access</i>	Survey of metaverse applications in healthcare; discussing opportunities and challenges as well as the role of gamification and deep learning.	523
4	Brown et al. (2020)	<i>Educause/ LearnTechLib</i>	Presenting trends in educational technology: AI, gamification, NLP, and digital learning.	489
5	Lampropoulos et al. (2022)	<i>Applied Sciences</i> (MDPI)	Systematic review of AR and gamification in education; assessing the effectiveness of empirical applications.	455
6	Huang et al. (2023)	<i>Big Data Mining and Analytics</i> (IEEE)	Comprehensive survey of metaverse security and privacy; links to deep learning and gamification models.	309
7	Lahoz-Monfort & Magrath (2021)	<i>BioScience</i> (Oxford Univ. Press)	Reviewing conservation technologies: AR, gamification, blockchain, and deep learning in ecology.	280
8	Abbasi et al. (2021)	<i>PLOS ONE</i>	Crypto adoption models using deep learning and SEM-ANN; explaining user behavior towards disruptive technologies.	233
9	Mantello et al. (2023)	<i>AI & Society</i> (Springer)	Cross-cultural analysis of attitudes towards emotional AI; using a sociotechnological and bio-sensor approach.	193
10	Melumad & Meyer (2020)	<i>Journal of Marketing</i> (SAGE)	Experimental study on the effects of smartphones on consumer openness behavior; relevant to voice technology and AI.	165

After analyzing publication trends and thematic tendencies through the visualization in Figure 3, the most influential documents in shaping the direction of research in this field were selected based on the highest number of citations as an indicator of scientific impact and conceptual influence. Ten articles with the most citations were then selected as representative of the works that contributed most to the development of studies on gamification, artificial intelligence, and emerging learning technology, as presented in Table 1. The article with the greatest influence was written by Raisch & Krakowski (2021), which discusses the paradox between automation and augmentation in AI-based management, with a total of 2165 citations, demonstrating a strong conceptual position in the discourse of technology and artificial intelligence-based decision making. The next articles by Maroungkas et al. (2023) and Chengoden et al. (2023) focus on the application of virtual reality and the metaverse for learning and healthcare, marking the expansion of the topic of gamification into the realm of emerging technology. A similar trend is seen in Lampropoulos et al. (2022) and Brown et al. (2020), which highlight the integration of augmented reality, AI, and gamification in the context of digital education.

Meanwhile, articles by Huang et al. (2023) and Lahoz-Monfort & Magrath (2021) broaden the perspective towards data security, privacy, and ecological conservation through the application of technologies such as deep learning and blockchain, demonstrating the diversification of gamification concepts and new technologies beyond the realm of education. On the other hand, articles by Abbasi et al. (2021) and Mantello et al. (2023) reflect the development of analytical and socio-technological approaches in understanding user behavior towards disruptive technologies. Finally, the study by Melumad & Meyer (2020) concludes the list by focusing on the psychological impact of digital technology, demonstrating the cross-disciplinary relevance between marketing, consumer behavior, and AI. Overall, the contribution patterns of these ten articles indicate that the most highly cited research tends to highlight the integration of gamification, deep learning, and artificial intelligence, as well as the expansion of their application from the field of education to health, management, and conservation. This confirms that the global research focus is no longer limited to technology application but has shifted toward multidisciplinary synchronization emphasizing efficiency, interactivity, and data-driven learning experiences.

However, the topic of gamification in biology learning has not been fully integrated with the direct observation approach (Khatibi et al., 2021; Chen et al., 2021; Nadi-Ravandi & Batooli, 2022; Jing et al., 2024). Most publications still focus on the application of emerging technologies such as virtual reality, augmented reality, and artificial intelligence to enhance motivation, engagement, and simulation-based learning experiences (Gandedkar et al., 2021; Al Balushi et al., 2024). Only a few studies explicitly combine gamification elements with real observation activities in the field or laboratory. In fact, according to the perspectives of experiential learning theory (Passarelli & Kolb, 2023) and situated cognition (Bereiter, 2021; Walkerdine, 2021), biology learning becomes more meaningful when students directly experience the process of observation, data collection, and reflection on the natural phenomena observed. The integration of gamification in the context of direct observation can strengthen student engagement through interactive reward, challenge, and feedback mechanisms, while maintaining the authentic dimension of empirical learning experiences. Thus, although global trends show significant progress in the use of emerging technology, future research opportunities remain wide open for developing biology learning models that combine digital gamification with direct observation experiences as a holistic and contextual learning strategy.

The findings of this study indicate that the current research landscape still lacks integrated pedagogical models that link digital gamification with direct observation-based learning, confirming the theoretical gap identified in the introduction. Uniquely, this bibliometric analysis maps the specific position of direct observation within technology-based research clusters and reveals that this component remains under-explored in global trends, suggesting the need for integration strategies. This contribution is relevant to the future of biology education, where learning ecosystems must balance immersive digital experiences with field-based empirical investigation to prepare students for authentic scientific practice in data-driven real-world environments. Therefore, the results of this study highlight a strategic direction for developing an innovative instructional framework that combines gamification, observation, and emerging technologies as a new learning model.

CONCLUSION

This bibliometric study reveals a significant increase in research on gamification, direct observation, and emerging technology in biology education between 2020 and 2024. The growing number of publications indicates that technology-based learning has become a central focus in global biology education research. Keyword mapping highlights the dominance of topics such as artificial intelligence, deep learning, and virtual simulation, suggesting a shift toward more complex and interactive approaches that enhance deep learning experiences. The analysis also shows that while gamification and data-driven learning have gained attention, studies integrating these approaches with direct observation remain limited. Most influential works are multidisciplinary, linking education with computer science and data analytics. The thematic analysis identifies four major clusters: (1) gamification and student engagement, (2) machine learning, artificial intelligence, and data-driven learning, (3) deep learning, virtual simulation, and metaverse-based laboratories, and (4) integration and implementation challenges that indicate a shift from conceptual exploration to applied and evaluative studies. Overlay visualization also demonstrates the evolution of research from early technology adoption (2020–2021) toward integrated and adaptive approaches (2023–2024), reflecting a growing focus on synergy between interactive, analytical, and immersive learning methods. However, the use of only Google Scholar as a data source limits coverage and may exclude non-indexed literature. In addition, inconsistency in keyword labeling across publications may influence clustering accuracy and interpretation of thematic networks. Future studies should employ broader databases and combine bibliometric with content analysis to better capture conceptual depth. Further research should also explore empirical validation to develop integrated models linking gamification, emerging technologies, and direct observation, as well as comparative bibliometric studies across databases and regions to enhance reliability. Theoretically, this study reinforces the role of experiential learning and situated cognition as the foundation for integrating digital learning engagement with authentic empirical experiences. Practically, the findings contribute by providing direction for the development of innovative pedagogical frameworks that balance immersive technology with field-based observation in adaptive biology learning ecosystems.

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