# Authentic Assessment Research Trends in Biology Learning: A Bibliometric Analysis

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| Article Information | ABSTRACT |
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| | Authentic assessment plays a critical role in biology education today as it addresses the growing need for competency-based evaluation methods that prepare students to apply scientific knowledge in real-world contexts. This study conducted a bibliometric analysis to map the research trends of authentic assessment in biology learning using the Scopus database. Through a quantitative approach, this study examined the temporal distribution, international collaboration, dominant keywords, and thematic evolution of 39 selected articles using bibliometric tools such as co-authorship network analysis, keyword co-occurrence mapping, and thematic evolution analysis. The results showed a significant increase in publications since 2018 with a peak during the COVID-19 pandemic, driven by the need to transform the assessment system during online learning. The analysis of scientific fields revealed the dominance of social sciences (26.1%) which overlapped with pure sciences such as biology and environmental science, while the United States and the UK were the main contributors with support from the National Science Foundation. Keyword mapping identified major theme clusters: animal-based assessment (motor theme) and potential development in molecular biology (emerging theme). This study also revealed limitations in the representation of developing countries and the lack of exploration of advanced technologies in the literature. This study contributes in three main aspects: (1) mapping scientific developments in authentic assessment research, (2) providing a bibliometric analysis protocol for similar fields, and (3) recommending future research on global collaboration, validating long-term instruments, and exploring niche themes such as biodiversity-based assessments. Furthermore, the findings have practical implications for developing context-responsive guidelines. However, the study is limited to Scopus and English-language articles, which may exclude other relevant research. |

## INTRODUCTION

Authentic assessment has become an important approach in science education, particularly in biology learning (Bedduside et al., 2021, 2021; Ristanto & Djamahar, 2020; Sutadji et al., 2021; Vlachopoulos & Makri, 2024). Authentic assessment addresses these demands by focusing on performance-based tasks that reflect actual scientific practices, thereby fostering both conceptual understanding and practical scientific skills (Guerrero & Sjöström, 2024; Southworth et al., 2023). Authentic assessment addresses these demands by focusing on performance-based tasks that reflect actual scientific practices, thereby fostering both conceptual understanding and practical scientific skills (Ernst et al., 2016; Rutherford et al., 2025; Salinas-Navarro et al., 2024). Moreover, biology as a discipline often involves abstract concepts and complex phenomena, which can be difficult to assess through traditional testing methods. Authentic assessment provides opportunities for students to demonstrate deeper learning through contextual and meaningful tasks, enhancing their scientific literacy in line with 21st-century education goals (González-Pérez & Ramírez-Montoya, 2022; Guerrero & and Sjöström, 2025; Southworth et al., 2023; Sutadji et al., 2021; Vlachopoulos & Makri, 2024; Vo & Simmie, 2025). However, research developments in this field have not been systematically mapped using a bibliometric approach.

Previous studies on authentic assessment in biology have generally focused on the development of assessment instruments such as project rubrics or portfolios on various materials or topics (Budi et al., 2023; Fuadiyah et al., 2022; Hindrasti et al., 2020; Hulinggi & Samaela, 2023; Patongai et al., 2021; Ramadhina & Subkhi, 2022; Yudiandani & Asri, 2021). However, despite these developments, there remains a significant gap in systematically understanding how these instruments have evolved over time, their applicability across diverse cultural and educational contexts, and how emerging technologies and interdisciplinary approaches are integrated into authentic assessment in biology. This lack of comprehensive synthesis limits the ability to guide future research and practice effectively. Several studies have also explored its impact on student learning outcomes and the integration of technology in assessment (Arjaya, 2019, 2019; Baines et al., 2025; Dean et al., 2025; Emery, 2001; Wakefield, Murray, et al., 2024; Wakefield, R. R., et al., 2024). However, these studies are still partial and do not provide a comprehensive picture of the development of this science on a macro scale. Bibliometric analysis can fill this gap by revealing publication growth patterns, researcher collaboration networks, and the dynamics of research themes over time.

Based on the literature review, there are several research gaps that need to be addressed. First, there has been no in-depth analysis of the temporal trends that link the development of authentic assessment research with changes in the paradigm of biology education, which is important because understanding these trends can reveal how shifts in educational goals and methods influence assessment practices over time. Without this analysis, it is difficult to identify emerging priorities or anticipate future directions in the field. Second, the majority of publications are dominated by Western countries, while the contribution of researchers from developing countries is still poorly mapped; this imbalance matters because contextual factors such as cultural, economic, and educational differences can affect how authentic assessment is designed and implemented. Ignoring the perspectives from developing countries risks limiting the global relevance and applicability of research findings. Third, the evolution of research themes from the development of basic instruments to complex issues such as artificial intelligence-based assessment has not been widely explored. Addressing this gap is crucial to keep pace with technological advances and to ensure that assessment methods evolve to effectively measure student competencies in increasingly digital learning environments.

This study aims to map the trend of authentic assessment research in biology learning through bibliometric analysis. Specifically, this study will examine the temporal distribution of publications, dominant scientific fields, most influential documents, international collaboration patterns, keyword trends, and thematic evolution. The results of this study are expected to provide theoretical contributions in the form of scientific development maps, methodological contributions in the form of bibliometric analysis protocols, and practical contributions in the form of identifying future research opportunities. The novelty of this research lies in its comprehensive bibliometric approach that systematically integrates temporal, thematic, and collaborative aspects to uncover global trends and gaps in authentic assessment research specifically within biology education, which has not been thoroughly explored in previous studies.

## RESEARCH METHODS

### Research Framework

This research is a bibliometric analysis. Bibliometric analysis is a type of library research used to determine publication trends that have been carried out in a particular field that is the focus of the research. Bibliometric analysis is a quantitative method for analyzing bibliographic data in journal databases (Donthu et al., 2021; Magadán-Díaz & Rivas-García, 2022; Passas, 2024), in this

case Scopus. This analysis is used to investigate references to articles cited in journals, map scientific fields of journals, and group scientific articles that are in accordance with the research field.

**Article Structure**

This article is structured with a systematic flow. After the introduction, the methodology section will explain the techniques for collecting and analyzing bibliometric data. Specifically, the bibliometric analysis includes co-citation analysis to identify influential publications and their relationships, co-authorship analysis to examine collaboration patterns among researchers and institutions, and keyword analysis to detect emerging research themes and trends. The results of the study are then presented visually through network maps and temporal graphs, followed by an in-depth discussion of the implications of the findings. The article ends with a conclusion that summarizes the main findings and suggestions for further research.

**Research Question (RQ)**

To achieve the stated goal of finding trends in authentic assessment in biology learning research, we set six research questions (RQ) as follows: RQ 1: What is the temporal distribution and growth rate of publications related to authentic assessment in biology learning? RQ 2: What fields of study are dominant as a starting point for researchers in studying the theme of authentic assessment in biology learning? RQ 3: What articles are included in the category of the most cited documents globally in the theme of authentic assessment in biology learning? RQ 4: Which countries are dominant in publications and what is the map of collaboration between countries on the theme of authentic assessment in biology learning? RQ 5: What is the trend of keywords that are dominantly used in the theme of authentic assessment in biology learning? RQ 6: What is the pattern of thematic evolution in the theme of authentic assessment in biology learning?

**Article Search and Inclusion Criteria**

The search focused on the words "authentic assessment" OR "alternative assessment" AND biology" in the search for "article title, abstract and keyword", as many as 39 articles were found. The number of articles is relatively small, because the prompt is specific. The search was conducted using an official subscription account from the University of Indonesia. Data simulation used "Analyze search results" available in the Scopus system. To enrich the data and analysis, the data

was exported to *CSV format (to visualize the data process with VOSviewer and RStudio) and *RIS (to be synchronized with Reference Manager [Mendeley]).

The search history in Scopus- because of its multidisciplinary coverage or relevance to reputable journals-is as follows: TITLE-ABS-KEY ("authentic assessment" OR "alternative assessment" AND biology) AND PUBYEAR > 2004 AND PUBYEAR < 2025 AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")) AND (LIMIT-TO (OA, "all")). The search resulted in 39 articles, so these articles needed to be filtered to focus the analysis. We used the Preferred Reporting Items for Systematic Reviews and Meta-analyses or PRISMA method. The order of inclusion and exclusion is shown in Figure 1.
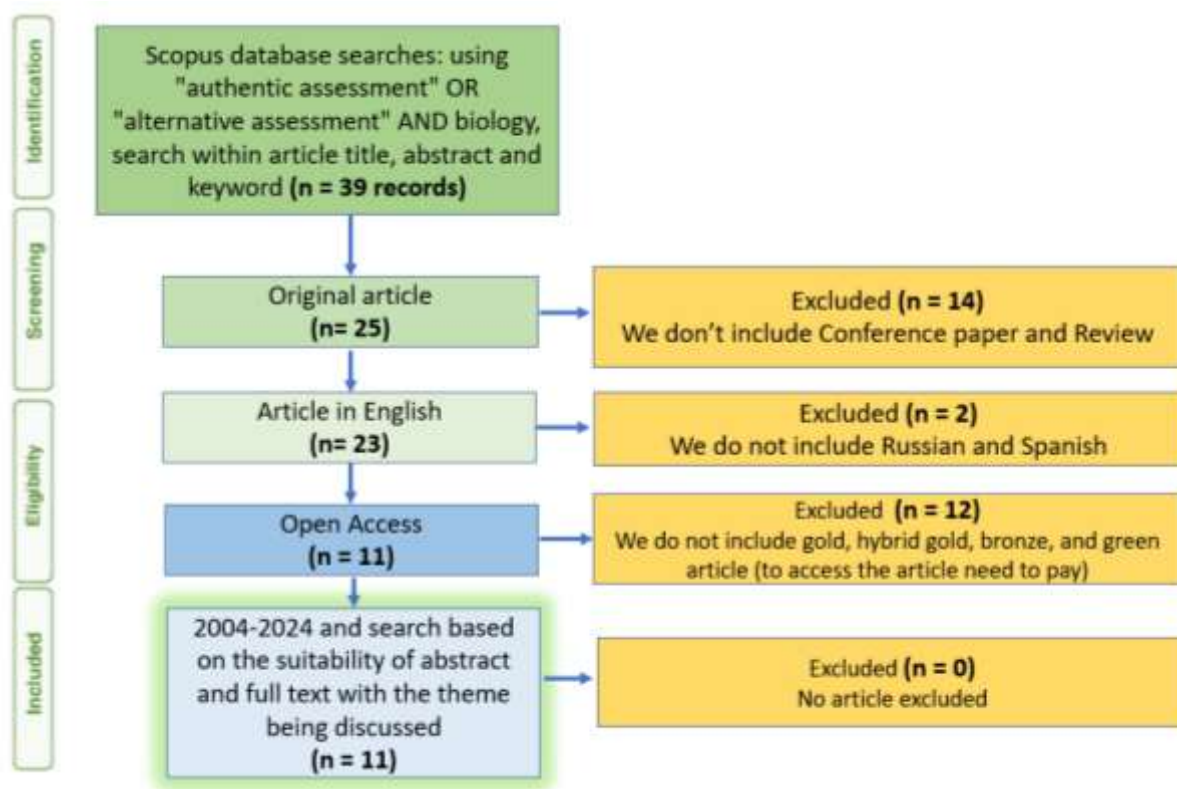


**Figure 1. Systematic review flow diagram**

The result of this process was 11 articles that met the criteria for analysis. The suitability of each article to the discussed theme was assessed independently by five researchers who reviewed the abstracts and full texts. In cases of disagreement, discussions were held to reach a consensus. The assessment was guided by specific thematic criteria focusing on the relevance of the study to authentic assessment in biology learning, ensuring that only articles directly addressing this topic were included.

## RESEARCH RESULT

### Temporal distribution (RQ 1)

Figure 2 shows the number of articles in the Scopus database per year from 2004 to 2024 ((but articles that appear or can be found only start from 2012). Based on Figure 2, the publication trend on authentic assessment in biology learning increased from 2018 and peaked in 2019 with 3 documents. After 2019, the trend tended to fluctuate during 2020–2022, corresponding to the COVID-19 pandemic period, followed by an increase again in 2023.
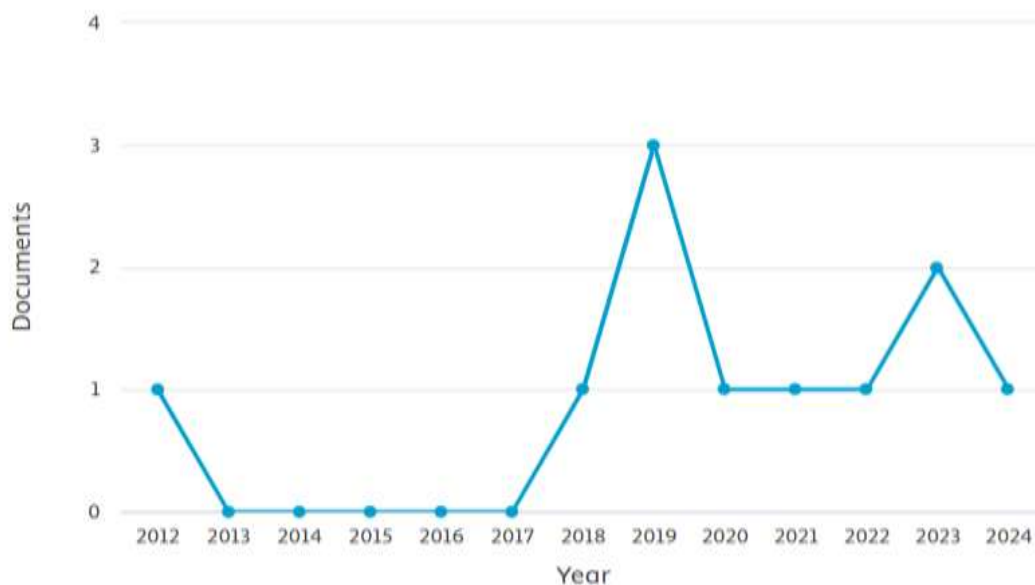


**Figure 2. Documents by year**

### Subject Area (RQ2)

Figure 3 presented shows the distribution of documents by field of study in the form of a pie chart and a numeric list. Based on the data, the field of Social Sciences has the highest percentage of 26.1% of the total documents, which shows a significant dominance in the number of publications or research related to authentic assessment in biology learning. This dominance is likely because authentic assessment emphasizes pedagogical approaches that focus on learning processes, student engagement, and skill development, areas traditionally explored within the social sciences. The integration of educational theories such as constructivism and social learning within biology education highlights the interdisciplinary nature of authentic assessment, bridging biological content with teaching methods and learner-centered evaluation. This theme can also be associated with agricultural and biological sciences, biochemistry, environmental sciences, arts and humanities, immunology, computer science, medicine, multidisciplinary, and pharmacology.
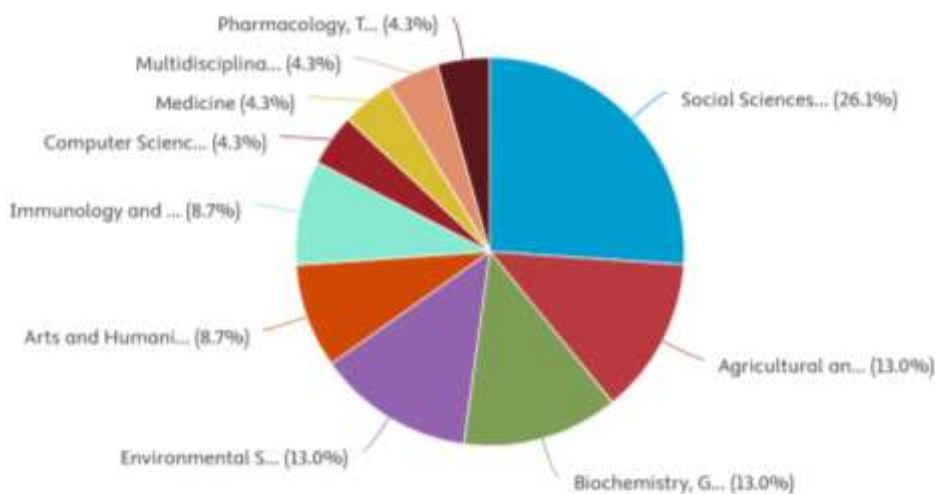
**Figure 3. Subject area**

**Most globally cited documents (RQ 3)**

Table 1 presents the data of the most cited documents globally. Based on Table 1, it can be seen that there are four main articles that are widely used as global references in the study of authentic assessment in biology learning, with the number of citations more than 20 times, namely the article entitled "Evaluating freshwater macroinvertebrates from eDNA metabarcoding: A river Nalón case study"(Fernández et al., 2018), "Assessing uncertainty in read-across: Questions to evaluate toxicity predictions based on knowledge gained from case studies (Schultz et al., 2019), "8:8 Perfluoroalkyl phosphinic acid affects neurobehavioral development, thyroid disruption, and DNA methylation in developing zebrafish (Kim et al., 2020), and "How to use Hydra as a model system to teach biology in the classroom (Bossert & Galliot, 2012). This dominance is likely because authentic assessment emphasizes pedagogical approaches that focus on learning processes, student engagement, and skill development, areas traditionally explored within the social sciences. The integration of educational theories such as constructivism and social learning within biology education highlights the interdisciplinary nature of authentic assessment, bridging biological content with teaching methods and learner-centered evaluation. Moreover, articles discussing topics like eDNA, zebrafish, or hydra models are considered relevant because they exemplify authentic, inquiry-based learning approaches in biology. These studies often involve hands-on, real-world scientific investigations that engage students in authentic practices, such as data collection, experimentation, and critical analysis, which align with the principles of authentic assessment. Therefore, despite their specialized biological focus, these articles contribute to understanding how authentic assessment can be applied effectively within biology learning contexts.

**Table 1. Most globally cited documents**

| No | Document title | Authors | Source | Year | Citations |
|---|---|---|---|---|---|
| 1 | Evaluating freshwater macroinvertebrates from eDNA metabarcoding: A river Nalón case study | (Fernández et al., 2018) | PLoS ONE, 13(8), e0201741 | 2018 | 58 |
| 2 | Assessing uncertainty in read-across: Questions to evaluate toxicity predictions based on knowledge gained from case studies | (Schultz et al., 2019) | Computational Toxicology, 9, pp. 1–11 | 2019 | 52 |
| 3 | 8:8 Perfluoroalkyl phosphinic acid affects neurobehavioral development, thyroid disruption, and DNA methylation in developing zebrafish | (Kim et al., 2020) | Science of the Total Environment, 736, 139600 | 2020 | 44 |
| 4 | How to use Hydra as a model system to teach biology in the classroom | (Bossert & Galliot, 2012) | International Journal of Developmental Biology, 56(6-8), pp. 637–652 | 2012 | 25 |
| 5 | Development of a tool to assess interrelated experimental design in introductory biology | (Killpack & Fulmer, 2019) | Journal of Microbiology and Biology Education, 19(3), 1627 | 2019 | 10 |
| 6 | Development of an evolutionary tree concept inventory | (Kummer et al., 2019) | Journal of Microbiology and Biology Education, 20(2) | 2019 | 5 |
| 7 | Phylogenetic diversity efficiently and accurately prioritizes conservation of aquatic macroinvertebrate communities | (Weglarz et al., 2021) | Ecosphere, 12(3), e03383 | 2021 | 3 |
| 8 | Alternative assessment as a means of business English skills formation in non-linguistic students | (Ponomarenko et al., 2023) | Perspektivy Nauki i Obrazovania, 62(2), pp. 293–306 | 2023 | 1 |
| 9 | Authentic research experience through mock grant application roleplay | (Tan & Lim, 2023) | Frontiers in Education, 8, 1048947 | 2023 | 1 |
| 10 | Filmmaking with biology undergraduates: combining digital technology with authentic assessment to develop students' skillset and capabilities for life after graduation | (Wakefield, Murray, et al., 2024) | Cogent Education, 11(1), 2327781 | 2024 | 0 |
| 11 | Alternative assessment as a means of foreign language communicative competence formation in natural science undergraduates | (Ponomarenko et al., 2022) | Perspektivy Nauki i Obrazovania, 57(3), pp. 324–337 | 2022 | 0 |

**Author's country and Collaboration (RQ 4)**

The country or region trends of the author's research related to authentic assessment in biology learning are presented in Figure 4. Meanwhile, collaborative research focused on this theme is presented in Figure 5.
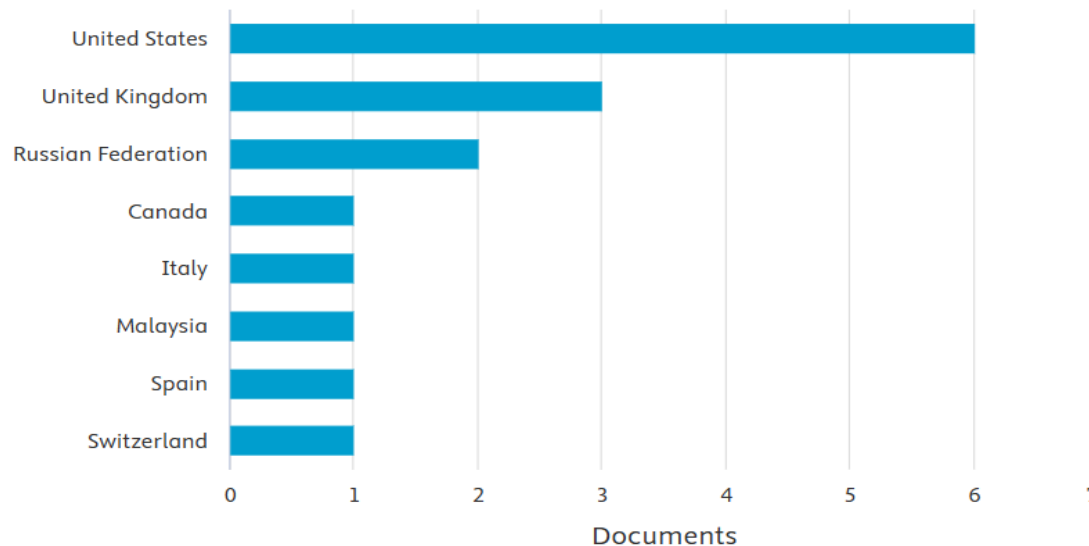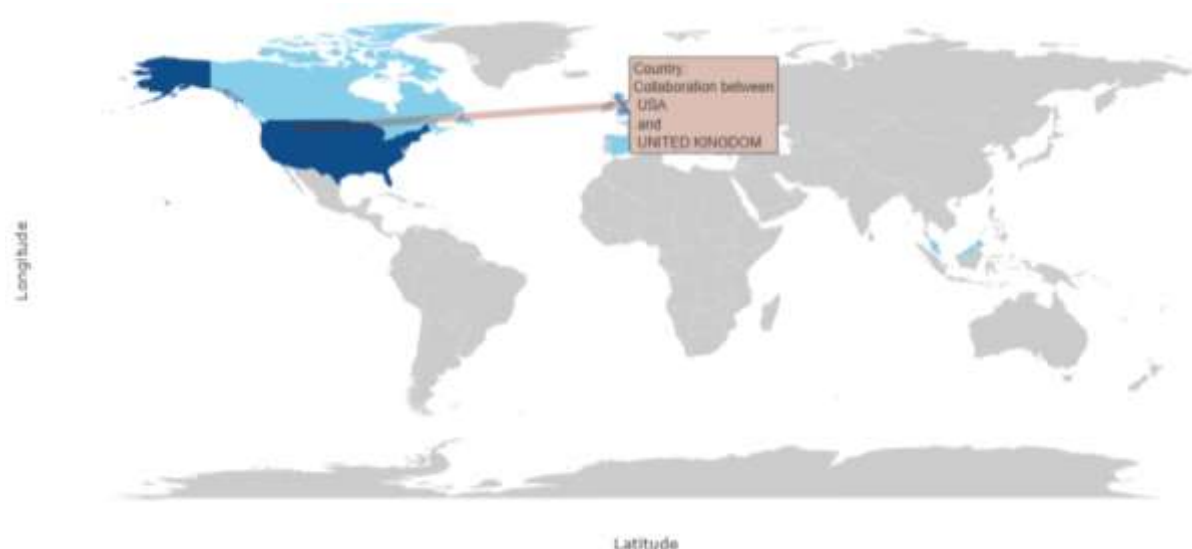


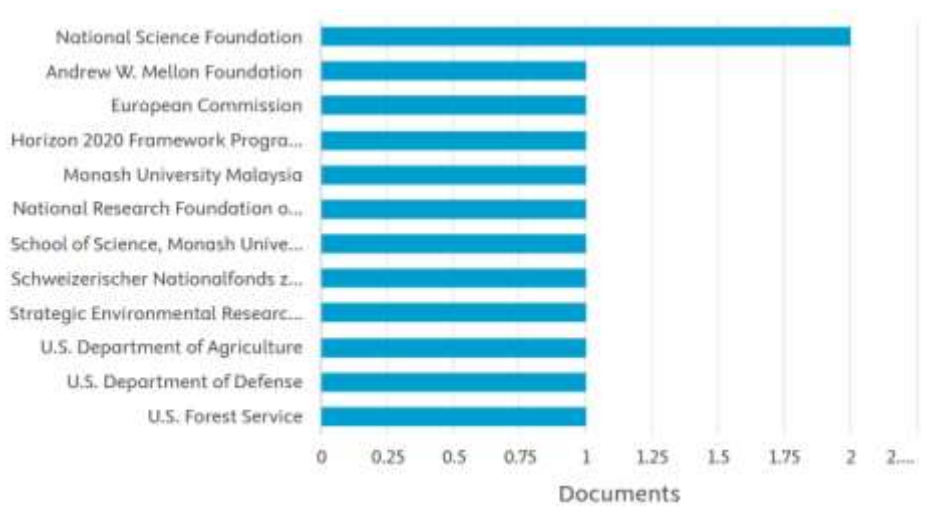**Figure 4. Author's country**



**Figure 5. Country collaboration map**

**Funding Sponsor (RQ 5)**

Figure 6 shows that all articles mention funding sponsors in their research and publications. The dominant funding sponsor is the National Science Foundation of the United States.

**Figure 6. Funding sponsor**

## Dominant Keywords (RQ 6)

The dominant keywords in authentic assessment in biology learning in the Scopus database are presented in the form of co-occurrence keyword simulation results from VOSviewer (Figure 7). Some dominant words related to "authentic assessment in biology learning" are authentic assessment, biology, animals, alternative assessment, collaboration, controlled study, and case study. These keywords can be grouped into thematic directions that indicate research development. For example, the cluster including collaboration and case study suggests a growing emphasis on context-based approaches, where authentic assessment is applied in real-world or classroom-specific settings to enhance learning relevance. Another group, featuring keywords like animals and controlled study, points to experimental or inquiry-based assessments focusing on biological subjects. This thematic grouping highlights how authentic assessment research is diversifying into both pedagogical strategies and content-specific applications.
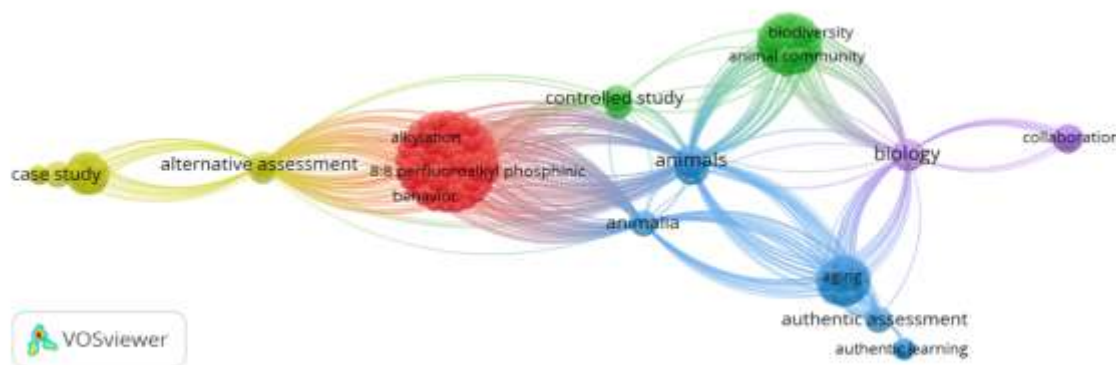


**Figure 7. Co-occurrence/keyword mapping**

**Thematic evolution (RQ 7)**

The thematic evolution (Figure 8) illustrates the development of research themes in a field of science based on bibliometric analysis. In bibliometric terms, Motor Themes represent well-developed and important topics that are central to the research field; Emerging or Declining Themes are those gaining interest or losing relevance over time; Basic Themes are foundational but less developed topics; and Niche Themes are highly specialized but peripheral. Based on Figure 8, Motor Themes include keywords like "animals" and "nonhuman," indicating strong ongoing research focus on organism-based assessments in biology learning. Emerging or Declining Themes include "alternative assessment" and "molecular biology." The categorization of "molecular biology" as a declining theme may reflect that its approaches are perceived as less contextual or authentic in assessment practices compared to more hands-on, organism-focused studies, thus attracting less research attention in the authentic assessment context. There are no keywords in Basic Themes and Niche Themes.
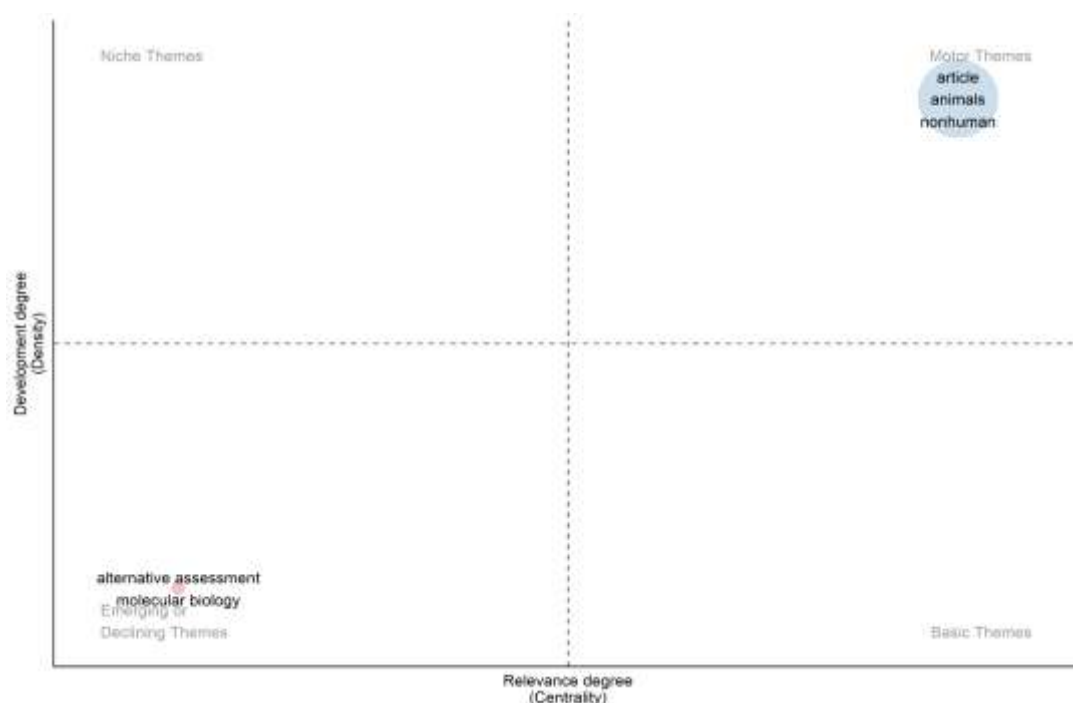


**Figure 11. Thematic evolution**

## DISCUSSION

Figure 2 shows the dynamics of the number of publications on authentic assessment in biology learning in the Scopus database over the past two decades (2004–2024). There is an interesting growth pattern: before 2018, the number of articles tended to stagnate with an average

of less than 10 publications per year. However, this trend changed significantly since 2018–2019, where there was a surge in articles (from 0 articles in 2017 to three articles in 2019). The peak of productivity occurred in 2019, with the highest number of articles published that year. During the period 2020–2022, the publication trend stabilized and fluctuated, coinciding with the COVID-19 pandemic.. This phenomenon may have been triggered by the urgency of transforming the conventional assessment system to an authentic approach during online learning, as well as the need for adaptive evaluation tools to the limitations of laboratory practicums. After 2022, the number of publications decreased in early 2023 (to one article), but showed an upward trend again at the end of 2023 (two articles). Data from 2024 (through December) recorded one article, indicating that interest in this research is still strong post-pandemic. The spike after 2018 can also be attributed to three factors: (1) the adoption of competency-based curricula in many countries, (2) the development of digital assessment technologies (e-rubrics, AI-based assessments), and (3) increasing awareness of the importance of science literacy through contextual tasks. These findings strengthen the position of authentic assessment as a relevant and growing research area in biology education.

Figure 3 shows the distribution of research documents related to authentic assessment in biology learning based on the field of science. This dominance of Social Sciences (26.1%) aligns with theoretical perspectives that position authentic assessment as a learner-centered approach emphasizing not only cognitive outcomes but also social interaction, motivation, and real-world performance (e.g.,Adamson & Darling-Hammond, 2015). The prominence of pedagogy, educational psychology, and learning policy in these studies supports the view that authentic assessment is deeply embedded in social constructivist theories, which stress learning as a social process and assessment as an integrated part of meaningful learning experiences. This is in line with the characteristics of authentic assessment that emphasizes aspects of the learning process, social skills, and performance-based evaluation—concepts that are widely discussed in the social sciences.

Meanwhile, the fields of agriculture and biology are in second place, reflecting the direct application of authentic assessment in the context of field practicums or experimental biology research. In addition to these two main fields, this research also reaches other disciplines such as biochemistry, environmental science, and medicine, indicating the interdisciplinary nature of authentic assessment in biology. The presence of contributions from the fields of computer science

(for example in the development of e-assessment) and arts-humanities (for example the integration of creativity in biology projects) strengthens the finding that this approach is not only limited to the realm of pure science. This multidisciplinary distribution indicates that authentic assessment in biology has become a bridge connecting various fields of science, while also offering opportunities for the development of more holistic and contextual assessment models. (Review of Educational Research, 2000; Sandoval, 2004; Zeidan & Jayosi, 2014).

Table 1 identifies the four most cited articles globally in authentic assessment research for biology learning, each with a citation count exceeding 20 times. However, while these articles are highly cited, it is important to critically reflect on whether they truly focus on authentic assessment or appear due to overlapping keywords related to biological topics. Most of them lean more towards pure biological research rather than explicit studies on assessment methods. This raises a methodological consideration about the limitations of bibliometric analysis relying solely on keyword extraction, which may capture articles relevant to biology content but less directly related to authentic assessment practices. The first article, by Fernández et al. (2018), focuses on the use of eDNA metabarcoding to evaluate freshwater macroinvertebrates, demonstrating how authentic assessment techniques can be applied in stream ecology research. The second article by Schultz et al. (2019) discusses a systematic approach to assessing the uncertainty of toxicity predictions, highlighting the importance of evidence-based assessment and data analysis in the context of environmental biology. Both articles reflect the integration of modern assessment methods with practical applications in biological research.

Two other articles complement the picture with different perspectives. Kim et al. (2020) examine the effects of perfluoroalkyl compounds on the neurobehavioral development of zebrafish, illustrating the use of model organisms in laboratory-based authentic assessment. Meanwhile, Bossert and Galliot (2012) provide a practical guide to utilizing Hydra as a model for biology learning in the classroom, emphasizing a hands-on approach as a form of authentic assessment. These four articles, while diverse in topic, collectively affirm that authentic assessment in biology spans a broad spectrum—from field research, to laboratory analysis, to innovative learning strategies—all of which contribute to the development of relevant and contextual assessment instruments.

Figure 4 and Figure 5 reveal the pattern of country dominance in authentic assessment research for biology learning, with the United States (6 articles) and the United Kingdom (3

articles) as the main contributors. Collaboration between researchers from these two countries is evident, indicating a strong research network in the development of authentic assessment approaches in biology. This dominance of Western countries may reflect several factors, such as greater availability of research funding, established educational infrastructure, and a long tradition in developing innovative learning assessment methods. In addition, the presence of Malaysia as the only representative from Asia in the list of dominant countries suggests that research in this region is beginning to gain global recognition, although further strengthening is still needed.

The map of research collaborations shows that most of the dominant countries are from Europe (except the United Kingdom), followed by the United States as a representative from the American continent, and Malaysia from Asia. However, the minimal contributions from many Asian and African countries may be attributed to factors such as limited digital infrastructure, restricted access to scientific publications, and gaps in research funding. These challenges hinder the ability of researchers in these regions to participate fully in global scholarly discourse. This situation underscores the urgency of expanding international collaboration and support to ensure more equitable development and adoption of authentic assessment practices worldwide. This pattern indicates that authentic assessment research in biology is still dominated by institutions in developed countries with well-structured educational systems. However, collaboration between the United States and the United Kingdom with other countries, including Malaysia, opens up opportunities for wider exchange of knowledge and best practices. Going forward, it is important to encourage the participation of more developing countries in this kind of research to ensure that authentic assessment approaches can be effectively adapted across global educational contexts. (Ahmed et al., 2022; Du Plessis, 2021; Govender, 2024; Klenowski, 2009; Sayed & and Kanjee, 2013).

Figure 6 reveals that all articles analyzed in this study include information about funding sponsors, indicating that financial support plays a crucial role in the development of authentic assessment research for biology learning. The National Science Foundation (NSF) of the United States emerged as the most dominant funding agency, reflecting the United States' strong commitment to advancing innovation in science education, especially through authentic and competency-based assessment approaches. The dominance of the NSF also confirms the United States' position as one of the main pioneers in biology education research, with systemic support

for projects that focus not only on theoretical aspects but also on practical applications in the classroom.

In addition to the NSF, several other funding agencies also contributed, although with lower frequency. This pattern indicates that research in the field of authentic assessment in biology requires significant resources, both for instrument development, teacher training, and long-term evaluation. The fact that all articles listed funding sponsors also indicates that this topic is considered strategic and worthy of investment, both from government agencies, universities, and non-profit organizations. The existence of consistent funding support can be a motivating factor for researchers from other countries to be more actively involved, as well as opening up opportunities for wider international collaboration in the future. (AlShebli et al., 2018; Bloch & Sørensen, 2015; Laudel, 2006; Luukkonen et al., 1992).

Figure 7 generated through VOSviewer analysis reveals a number of dominant keywords that are interrelated in authentic assessment research for biology learning in the Scopus database. Keywords such as authentic assessment, biology, and "animals/animalia" form the core cluster, indicating that this assessment approach is widely applied in the context of biology learning, especially those involving the study of living organisms. The presence of alternative assessment keywords indicates that authentic assessment is often positioned as a substitute or complement to traditional assessment methods, especially in evaluating students' practical skills and conceptual understanding.

In addition, keywords such as collaboration, controlled study, and case study show the variety of methodologies used in this research. "Collaboration" emphasizes the importance of collaboration between students, teachers, or even researchers in the assessment process, while "controlled study" and "case study" reflect the empirical approach that is often used to test the effectiveness of authentic assessment instruments in specific learning settings. This combination of keywords shows that research in this field focuses not only on instrument development, but also on implementation and evaluation of its impact in various biology learning contexts. These findings are consistent with previous reviews on authentic assessment in science education, which similarly highlight a shift from merely developing assessment tools toward applying and assessing their effectiveness in real learning environments (Bedduside et al., 2021; González-Pérez & Ramírez-Montoya, 2022). This continuity underscores the growing emphasis on practical impact and contextual relevance in authentic assessment research.

Figure 8, which displays the results of the thematic evolution analysis, reveals the dynamics of the development of research themes related to authentic assessment in biology learning. In the Motor Themes quadrant (main driving theme), the keywords "animals" and "nonhuman" appear, indicating that current research is very focused on the application of authentic assessment in the context of studying living organisms, both in the laboratory and in the natural environment. The dominance of this theme reflects the importance of a hands-on approach and direct observation in evaluating students' understanding of biological concepts related to animals.

Meanwhile, in the Emerging or Declining Themes quadrant, there are the keywords "alternative assessment" and "molecular biology", which provide an overview of the new direction in this research. "Alternative assessment" indicates that authentic assessment is increasingly seen as a promising alternative approach to replace or complement traditional assessment methods. The presence of "molecular biology" as an emerging theme indicates the expansion of authentic assessment applications into this specialized field, encompassing sophisticated techniques such as DNA analysis and biochemical experiments. This trend aligns with, yet also extends, previous studies on authentic assessment in biology education, which primarily focused on more general biological concepts and traditional laboratory skills. Compared to earlier thematic maps that emphasized organismal biology and ecology, the current findings suggest a notable shift toward molecular-level competencies, reflecting evolving educational priorities and the increasing importance of hands-on skills in advanced biological research.

The implications and recommendations based on this review are as follows: (1) Emphasizing animals and non-human organisms as focal topics opens a new avenue for authentic assessment design, potentially broadening the scope beyond traditional biology education to include fields like animal behavior, ecology, and physiology. (2) The identified opportunities in molecular biology suggest the need to develop authentic assessments tailored to evaluate practical competencies in molecular biology laboratories, thereby enhancing the alignment between assessment and hands-on skills. (3) The observed lack of research on both basic and niche themes highlights gaps in current literature, indicating potential areas for future studies to expand foundational concepts and explore underrepresented topics. Collectively, these findings contribute theoretically by expanding the conceptual boundaries of authentic assessment within biology education, practically by guiding educators and curriculum developers toward diverse and meaningful assessment design, and

strategically by informing STEM education policies that support comprehensive competency evaluation across varied biological subfields.

## CONCLUSION

This bibliometric study successfully maps the research trends of authentic assessment in biology learning over the past two decades (2004-2024). In response to the five research questions posed at the beginning, the main findings are as follows: (1) Research productivity has increased significantly since 2018 with a peak during the COVID-19 pandemic period (2020-2022), answering the question about temporal trends and highlighting how global events influenced research focus on assessment transformation during online learning; (2) The dominance of the social sciences (26.1%) indicates a strong pedagogical approach in this study, although it remains connected to scientific disciplines such as biology, biochemistry, and environmental science, addressing the question on disciplinary contributions and revealing the interdisciplinary nature of authentic assessment research; (3) The United States and the United Kingdom emerged as major contributors with strong support from the National Science Foundation, which responds to the question concerning geographic distribution and research funding sources; (4) Keyword analysis and thematic evolution reveal a focus on animal-based assessment as a motor theme and molecular biology as an emerging theme, answering questions about thematic developments and research frontiers in this field; (5) Identified gaps, including the underrepresentation of developing countries and limited exploration of digital technologies, highlight opportunities for future research, which relates to the research questions about existing gaps and directions for further studies.

For the development of authentic assessment research in biology learning in the future, this study recommends expanding global collaboration networks by involving more institutions from Asia, Africa, and Latin America to enrich cultural perspectives and contextual relevance. Future research should focus on emerging fields such as molecular biology and biotechnology, including digital technologies like virtual labs and AI-based assessments. It is also necessary to expand the global collaboration network by involving more institutions from Asia, Africa, and Latin America to enrich cultural perspectives in the development of assessment instruments. Future research should focus on emerging fields such as molecular biology and biotechnology, including the use of digital technology (virtual labs, AI-based assessments) that are still minimally studied, while developing a framework that bridges the gap between the dominance of social sciences and the need for pure science applications through concrete examples of applications in various sub-

disciplines of biology. There is also a need for increased funding support in developing countries for research that adapts to local contexts and infrastructure limitations, as well as exploration of niche themes such as authentic assessments based on local biodiversity or indigenous knowledge. In addition, longitudinal studies are needed to test the effectiveness of various authentic assessment models in improving students' biological literacy and knowledge retention. These findings open up opportunities for the development of practical guidelines for biology educators in designing assessment instruments that are relevant to the development of 21st-century science while being responsive to learning needs in various geographical and cultural contexts.

## ACKNOWLEDGMENTS

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