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Assessment of biology learning outcomes in education: A systematic literature review

Sagita Nea Rahmi*, Megawati, Heffi Alberida, Muhyiatul Fadilah

Biology Education, Faculty of Mathematics and Natural Science, Universitas Negeri Padang, Indonesia

*Corresponding author: sagita.nea.rahmii@gmail.com

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ABSTRACT

Learning outcomes assessment is a crucial aspect in determining the effectiveness of a curriculum or teaching process. However, approaches to assessment in the education system often raise questions about the efficiency of various assessments systematically reviewed in the literature on biology learning outcomes assessment in education by analyzing 36 articles from the Scopus database between 2018 and 2023 using the PRISMA approach. The main focus of this review study was to evaluate the most effective assessment methods, as well as further identify the challenges educators face in assessment and understand the implications of changing assessment methods for biology education. Through analyzing data using VOSviewer software, this study revealed trends in the use of technology in assessment, prevalent assessment methods such as formative assessment, and key challenges such as the complexity of biological concepts and technology integration. The results showed the dominance of formative assessment and a shift towards technology in assessment, which emphasizes developing critical thinking skills, scientific reasoning, and inquiry skills. In addition, the study highlighted an increased focus on equity, diversity, and inclusion in assessment practices and the impact of the adoption of distance and online learning on assessment practices.

INTRODUCTION

In the era of globalization, the progress of scientific work is constantly growing every year, especially in biology education, which is a fundamental aspect in determining the effectiveness of curriculum and teaching (Fitria et al., 2024; Zhan & Niu, 2023). Biology studies life, environment, health, and emerging biomedical technologies (Banerjee et al., 2019; Sheikhpour et al., 2020). In terms of the complexity of the material requirements, a more theoretical understanding of practical applications is required, making the assessment process more challenging and allowing further implementation in the world of education (Marougkas et al., 2023). Accordingly, biology education plays a vital role as the central pillar in measuring biology learning outcomes using an approach that assesses in a measurable and structured manner to ensure the acquisition of a better understanding of students.

However, in implementing the assessment of biology learning outcomes, the majority still has some weaknesses that often raise questions regarding the effectiveness of various assessment strategies, especially in theoretical and practical aspects (Ifenthaler et al., 2023; Stanja et al., 2023). Conversely, integrated biology education utilizing the STEM (Science, Technology, Engineering and Math) approach is very supportive in the aspects of scientific assessment and understanding, which positively enhances students' understanding for the better in natural contexts (Agus Supriyadi et al., 2023; Ilma et al., 2023). As technology advances, new assessment methods are being introduced, including the use of digital simulation, augmented reality, and virtual reality, which are promising approaches to support the assessment process and enrich the learning experience of students to be more varied (Prasetya, Fajri, et al., 2023; Prasetya, Fortuna, et al., 2023; Samala et al., 2024; Waskito et al., 2024).

Recently, findings show a shift in assessment methods from predominantly summative to more authentic and formative, focussing on the process of learning and deep understanding rather than learning outcomes alone (Moosvi & Bates, 2023; Svensäter & Rohlin, 2023; Wakefield et al., 2023). On the one hand, the application of this innovative assessment method is still varied and needs further evaluation by examining the assessment framework more deeply based on aspects of success and failure so that it can be effectively applied in the current education system. Nevertheless, it is crucial to recognize significant challenges in adopting formative assessment methods into the existing biology learning curriculum (Cardozo et al., 2023). Factors such as resource availability, infrastructure facilities and teacher training also play a crucial role in implementing this strategy (Muthanna & Sang, 2023).

Additionally, the perceptions and expectations of stakeholders in education, such as policymakers, teachers, students and parents, influence the adoption of new assessment practices. Moreover, resistance to changing traditional assessment methods towards more dynamic approaches can be challenging, especially in institutions that are less open to changes in teaching and assessment methods (Abulibdeh et al., 2024; Alenezi et al., 2023). Nevertheless, formative assessment offers many advantages in enhancing learners' engagement and the real-life relevance of learning materials, which is assumed to be a challenge in resource-constrained environments (Alam & Mohanty, 2023; Naghdipour & Manca, 2022). Consequently, this research review is not limited to identifying and evaluating assessment methods but also considers the specific conditions under which such assessment methods can be successful.

This research aims to conduct a systematic literature review through 36 predetermined studies of empirical research results between 2018 and 2023 in experiencing biology learning outcomes at various levels of secondary education to higher education. By further reviewing the published research results, it seeks to gain an in-depth understanding to provide valuable recommendations for researchers, educators, and policymakers so that they can be adapted in the future. This review will thus delve deeper into the most effective assessment methods, challenges, opportunities, and current technological trends used in biology education that are more inclusive and contribute significantly to improving the quality of biology education at the international level. In order to achieve the objectives of this research, we formulated several research questions to answer the targeted objectives.

RQ1. How has the trend of using technology in biology learning outcomes assessment affected students' academic achievement from 2018 to 2023?

RQ2. What methods of assessing biology learning outcomes are frequently used in secondary to higher education?

RQ3. What are the primary challenges and opportunities educators face in implementing effective assessment methods for learning outcomes in biology?

RQ4. What are the implications and contributions of the changes of the last five years to future assessment methods in biology education?

METHODS

Data Collection

In collecting systematic literature review research data, the approach used in this study is the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) approach is the primary acceptable method of presenting evidence in systematic literature reviews, including the process of identification, screening, eligibility, and inclusion (Page et al., 2021). The main focus of this study was to identify and evaluate the most effective assessment methods for biology learning outcomes in education. The primary source of this research, based on the results of empirical studies determined by researchers and peers, focuses more on 36 articles out of 80 that have been assessed for eligibility, especially within the scope of the Scopus database on publications in highly reputable International Journals. In addition, the main keywords used in the Scopus database search engine were "assessment", AND "biology and learning", AND "learning and outcomes", AND "education". The following are the details of the research data retrieval presented in Table 1.

Table 1
Details of information from the systematic literature review

Primary Data Source Search	Database from Scopus
Primary keyword search	(TITLE-ABS-KEY (assessment) AND TITLE-ABS-KEY (biology AND learning) AND TITLE-ABS-KEY (learning AND outcomes) AND TITLE-ABS-KEY (education)) AND PUBYEAR > 2018 AND PUBYEAR < 2023 AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "cp")) AND (LIMIT-TO (LANGUAGE , "English"))
Duration (year)	2018 – 2023
Data retrieval date	4th April 2024

Criteria for Inclusion and Exclusion

The search process was specified using inclusionary article selection criteria (Lindner et al., 2023). Firstly, articles published in Scopus Indexed International Journals that have passed the peer-review stage to ensure the highest quality of review. In addition, aspects of research topics, the language used, and relevant research data. Finally, the results of how many publications in the last five years (2018-2023). In contrast, the determination of exclusion criteria includes results opposite to the inclusion criteria (Xie & Correia, 2024). One of them is articles that cannot be accessed by researchers, for example, in the form of reviews, editorials, or newspapers, which are not relevant to the research topic, and publication results in languages that are not understood by researchers, as well as articles that do not present data or research results that are relevant to the research objectives of this systematic literature review.

Research Design and Procedure

This study utilized a systematic literature review using the PRISMA approach to identify, evaluate and synthesize assessment methods for biology learning outcomes in relevant educational contexts from all existing assessment methods (Bahroun et al., 2023; Vázquez-Villegas et al., 2023). The first step in following this research procedure was to determine the objectives in evaluating the effectiveness of various assessment methods in measuring biology learning outcomes.

Moreover, the inclusion and exclusion criteria were determined using predetermined keywords to select relevant research literature, especially research results in the form of articles and conference proceedings. Fundamental data analysis was applied using VOSviewer software to identify research gaps in network visualization. After that, relevant articles will be filtered based on the relevance of the research topic, especially the title, abstract, and its quality in conducting the research process and research methods used. The collected data will be analyzed systematically, and the visualization of the analysis will be interpreted to evaluate the effectiveness of various assessment methods. In summary,

research conclusions will be drawn based on these findings and their implications for educational practice. The research procedure has been summarised in Figure 1.

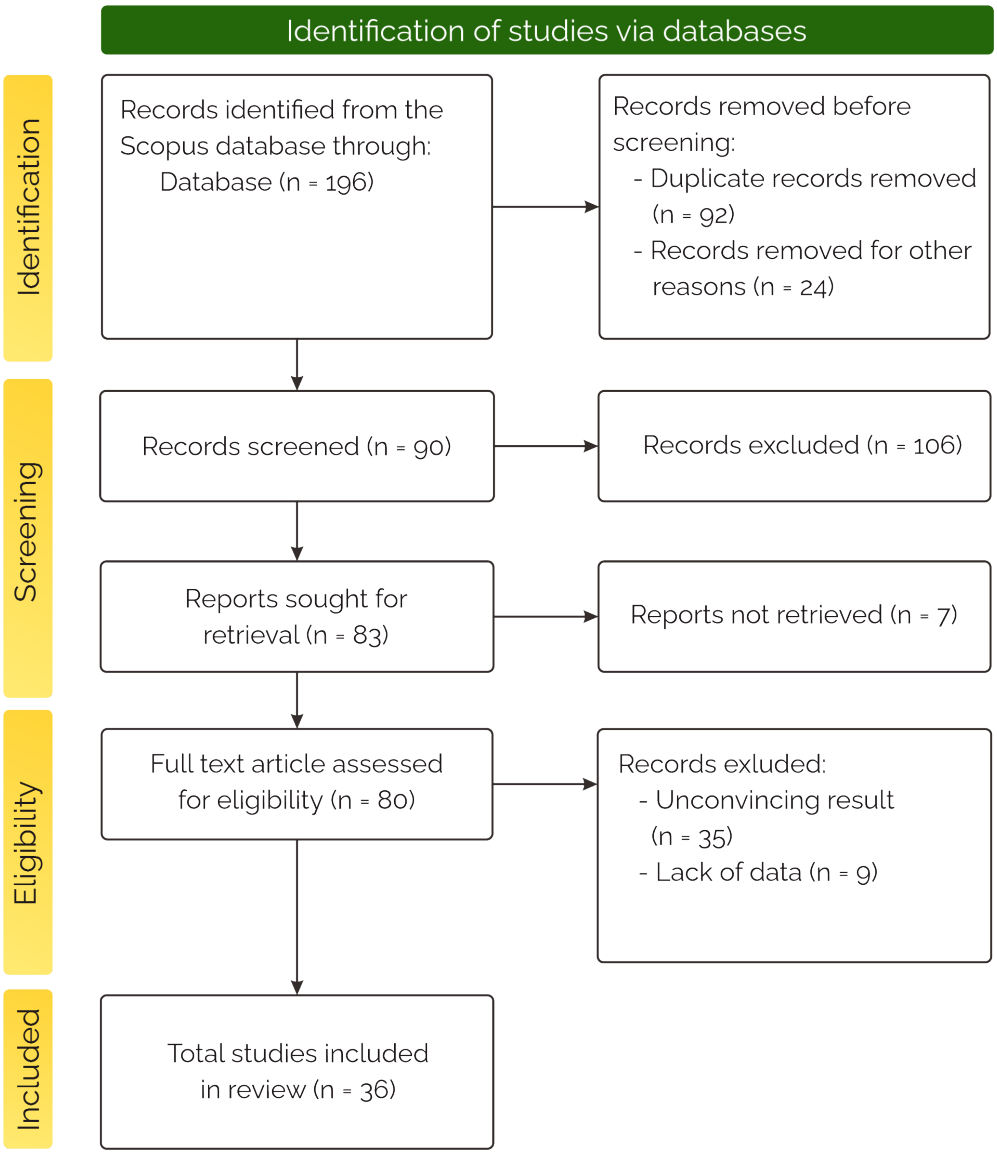

Figure 1. The PRISMA flowchart on Biology Learning Outcomes Assessment

RESULTS AND DISCUSSION

Assessment Research Trends and Keyword Analysis

RQ1. *How has the trend of using technology in biology learning outcomes assessment affected students' academic achievement from 2018 to 2023?*

Figure 2 provides a visualization of the network of connections between various concepts related to education, biology, and human studies. The network has several colours in the form of nodes and lines that show how these topics relate. Firstly, the green cluster focuses on education, with terms such as "technical education", "computing", "students", and "teaching". Secondly, the red cluster seems to be about "human studies", including "human," "procedures," "educational measurement," and "medical education". Finally, the blue cluster is related to "biology," featuring terms such as "biology," "molecular biology," "genetics," and "laboratory." Meanwhile, the term "education" sits in the centre, connecting all the clusters, indicating that it is a crucial concept across all these fields. The figure also includes terms such as "learning outcomes," "assessment," and "problem-based learning," indicating a focus on educational methods and outcomes.

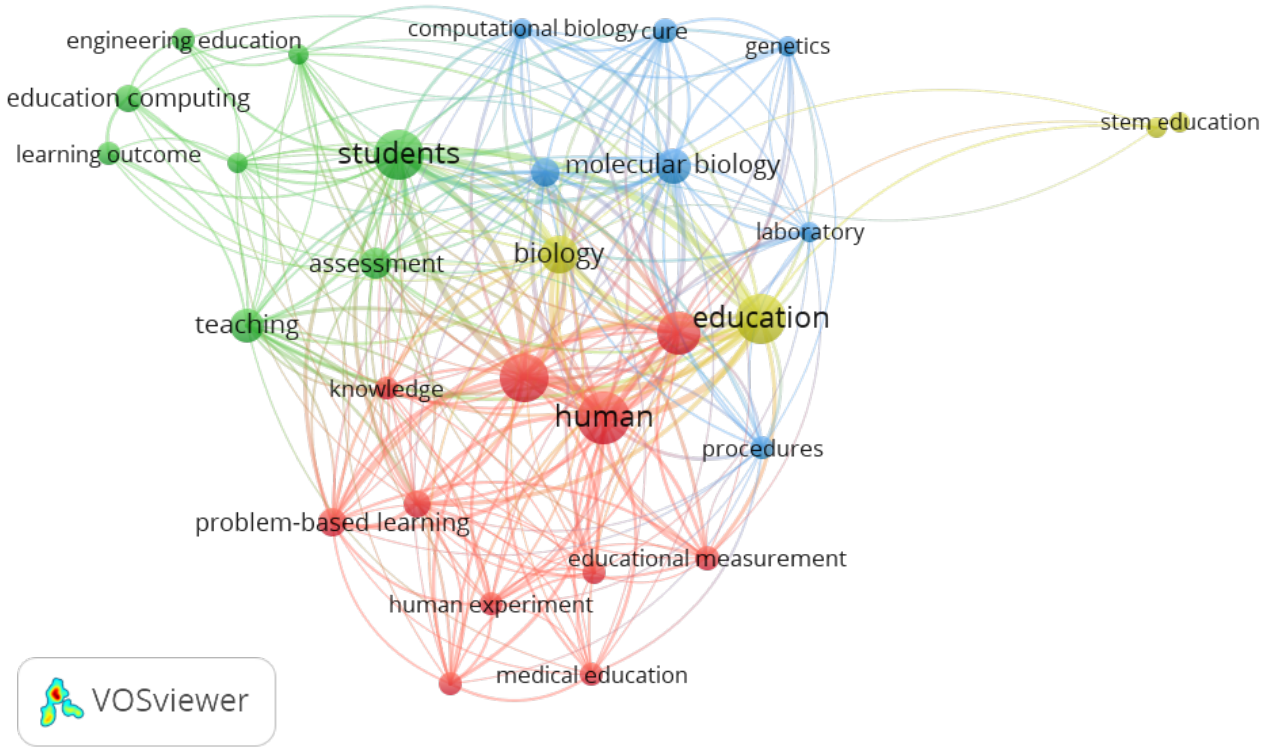

Figure 2. Network visualization for terms and keywords in Assessment of Biology Learning Outcomes

This was done to identify and interpret the research gaps based on the visualization of Figure 2, which considered the connections and clusters identified in the network graph. Initially, the identification was based on interdisciplinary opportunities that show the connections of each cluster, particularly education, human studies, and biology, which are assumed to have gaps between research in these areas for specific educational strategies that can be optimized to teach complex biology or human studies concepts. Whereas, in the context of educational methods, emerging terms such as "problem-based learning", "assessment", and "learning outcomes" indicate a focus on educational outcomes, which may exist in the effectiveness of different teaching methodologies in various disciplines, especially in emerging technological fields, e.g., computational biology.

Furthermore, terms such as "engineering education" and "computing" may have gaps in previous research on integrating new technologies into educational curricula, thus impacting learning outcomes in STEM fields. In addition, biology education being clustered between biology," "molecular biology," and "genetics" implies potential gaps in how these subjects are taught and understood by learners, especially the rapid advances in recent fields. On the one hand, assessment techniques based on the keyword "educational measurement" implies a research gap in developing and validating new assessment techniques that accurately measure student understanding in more complex biology subjects. On the other hand, the most dominating role of education in linking different disciplines may be interdisciplinary knowledge transfer methods of communication.

The diagram in Figure 3 illustrates the outcomes of the keyword network visualization, which likely portrays the interconnections among different academic terms and concepts about the assessment methods of biology learning outcomes from 2018 to 2023. Moreover, this visualization was created by utilizing VOSviewer software, which is famous for its bibliometric analysis in identifying trends, popular topics, and potential gaps in this research. A visual representation of the bibliometric network analysis is shown based on The colour gradient from dark blue to yellow, which represents the timeline from 2018 to 2023, indicating the evolution or trends in the focus areas in education and biology research during this period (McAllister et al., 2022). Darker colours, such as dark blue, represent earlier years around 2018, while lighter colours, such as green and yellow, indicate more recent years, up to 2023.

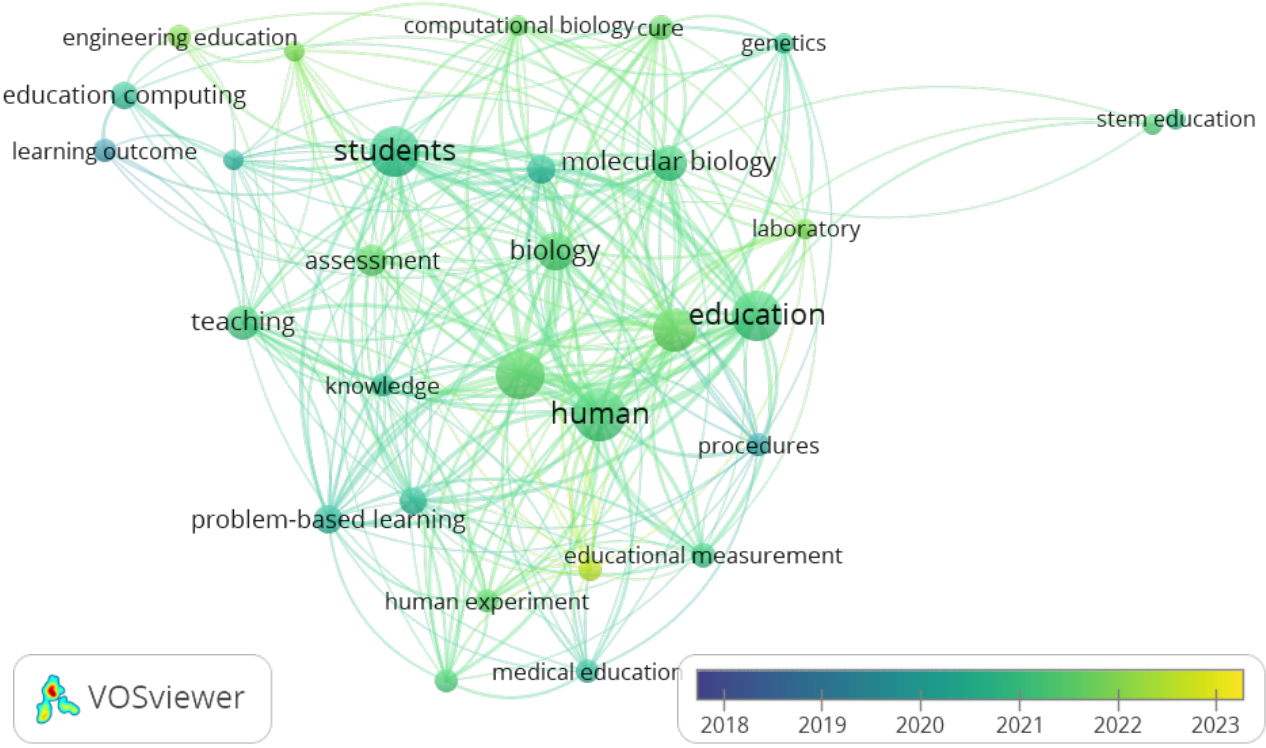

Figure 3. Network visualization of 2018-2023

Literature Review Findings

RQ2. *What methods of assessing biology learning outcomes are frequently used in secondary to higher education?*

The literature review systematically engaged 36 relevant studies to assess the assessment methods used for biology learning outcomes ranging from secondary to higher education. Table 2 depicts a series of publications that have undergone a rigorous peer review process, specifically in education and biology, detailing the author, region, number of citations, and journal in which each work was published. These publications were extracted from the Scopus database and sorted by the number of citations received, which is vital in recognizing articles as a critical indicator of their impact on future research developments.

Table 2
Recapitulation of all systematic literature review articles

No	Author	Education Level	Region	Cites	Assessment Types	Journal
1	(Arneson & Offerdahl, 2018)	Washington State University	United States	126	Summative Assessments	CBE: Life Sciences Education
2	(Rodríguez et al., 2019)	Pompeu Fabra University	Spain	109	Formative Assessments	BMC Medical Education (Springer Nature)
3	(Wilton et al., 2019)	University of California, Santa Barbar	United States	73	Formative Assessments	CBE: Life Sciences Education
4	(Clemmons et al., 2020)	University of Washington	United States	67	Rubrics and Checklists	CBE: Life Sciences Education
5	(Hancock et al., 2018)	University of Sydney	Australia	31	Self and Peer Assessments	Biochemistry and Molecular Biology Education
6	(Bassett et al.,	Missouri University of	United	27	Formative	CBE: Life Sciences

No	Author	Education Level	Region	Cites	Assessment Types	Journal
	2020)	Science and Technology	States		Assessments	Education
7	(Irby et al., 2018)	Purdue University	United States	26	Performance Assessments	Biochemistry and Molecular Biology Education
8	(Bertolini et al., 2021)	The University Corpus	United States	26	Novel Assessments	Journal of Science Education and Technology
9	(Tomažič et al., 2020)	Lower Secondary School Students	Germany	23	Observational Assessment	Journal of Biological Education (Taylor & Francis)
10	(O'Connell et al., 2021)	Universities across the United States	United States	21	Summative Assessments	Journal of Geoscience Education (Taylor & Francis)
11	(Katzman et al., 2021)	Undergraduate Cell Biology	United States	19	Formative Assessments	Journal of Microbiology & Biology Education
12	(Tahir et al., 2022)	McMaster University	Canada	19	Performance Assessments	FEBS Openbio (Wiley Online Library)
13	(Hodges et al., 2021)	Secondary School of Biology Classroom	United States	16	Formative Assessments	Journal of Science Education and Technology
14	(Hills et al., 2020)	MacEwan University	Canada	14	Formative and Summative Assessments	Biochemistry and Molecular Biology Education
15	(Fried et al., 2020)	University of Colorado	United States	13	Summative Assessments	Evolution: Education and Outreach
16	(Guarracino, 2020)	College of New Jersey	United States	13	Self and Peer Assessment	Journal of Chemical Education
17	(Kulkarni & Vartak, 2019)	Higher Education	India	12	Self and Peer Assessments	Biochemistry and Molecular Biology Education
18	(Reen et al., 2021)	University College Cork	Ireland	12	Self and Peer Assessments	Frontiers in Virtual Reality
19	(Knutstad et al., 2021)	Oslo Metropolitan University	Norway	10	Performance Assessments	Nursing Open Wiley Online Library)
20	(Kumar et al., 2023)	Medical Higher Education	India	9	Technology-Enhanced	Electronics (Switzerland- MDPI)
21	(Burks, 2022)	Historically Black College and University	United States	9	Performance Assessments	Journal of Microbiology & Biology Education
22	(Lovren & Jablanovic, 2023)	Serbian Secondary Education	Serbia	7	Formative	Sustainability (Switzerland- MDPI)
23	(Clark & Hsu, 2023)	Major Higher Education Accreditation Agencies	United States	7	Program Learning Outcomes	CBE: Life Sciences Education
24	(Guttilla Reed, 2021)	University of Saint Joseph	United States	5	Diagnostic Assessment	Biochemistry and Molecular Biology Education
25	(Arthur et al., 2018)	University of Western Australia	Australia	3	Diagnostic Assessment	Biochemistry and Molecular Biology Education
26	(Kabayiza et al., 2022)	Pittsford Mendon High School	United States	3	Technology-Enhanced	Crystals (Switzerland- MDPI)
27	(Sari et al., 2019)	Universitas Negeri Malang	Indonesia	2	Formative Assessments	AIP Conference Proceedings

No	Author	Education Level	Region	Cites	Assessment Types	Journal
28	(Van Stry et al., 2019)	Higher Education	United States	2	Feedback-Formative	American Chemical Society Symposium Series
29	(Fiedler et al., 2022)	Bavarian Fifth-Graders	Germany	2	Digital Nativity Assessment Scale	Sustainability (Switzerland- MDPI)
30	(Hidayat & Irdiyansyah, 2023)	Pakuan University	Indonesia	2	Self and Peer Assessments	European Journal of Educational Research
31	(Kushner, 2021)	Dickinson College Biology	United States	1	Performance Assessments	Biochemistry and Molecular Biology Education
32	(El Islami et al., 2022)	Schools in Indonesia, Thailand, Vietnam	Indonesia	1	Formative and Summative	Asia-Pacific Social Science Review
33	(Filice et al., 2023)	Michigan State University	United States	0	Formative and Summative	Evolution: Education and Outreach
34	(Roberts & Shell, 2023)	Undergraduate Laboratory Teaching	United States	0	Novel Assessments	Frontiers in Microbiology
35	(Labak & Blazetic, 2023)	Strossmayer University	Croatia	0	Self-Assessments	Journal of Education and e-Learning Research
36	(Gross et al., 2023)	Fisk University and Western Kentucky University	United States	0	Performance Assessments	Journal of Biological Education (Taylor & Francis)

Primarily, in this section, we managed to collect highly rigorously selected reviewer-reviewed data starting with the top publication by (Arneson & Offerdahl, 2018), originating from the United States and published in "CBE: Life Sciences Education," which has accumulated the most citations, 126. This is followed by the publication of (Rodríguez et al., 2019), from Spain with 109 citations in "BMC Medical Education (Springer Nature)." The third in the list of other works from the United States by (Wilton et al., 2019), published in the same journal as the first, has 73 citations. In summary, authors from the United States dominate the top research results on assessment methods used in biology education. Furthermore, Table 2 lists publications from different regions, including Australia, Germany, Canada, India, Ireland, Norway, Serbia and Indonesia, reflecting the diverse international contributions in the field of biology learning assessment. Journals covering a wide range of specializations in education and biology, such as "Biochemistry and Molecular Biology Education", "Journal of Science Education and Technology", "Journal of Biology Education", and more, demonstrating the interdisciplinary nature of this research.

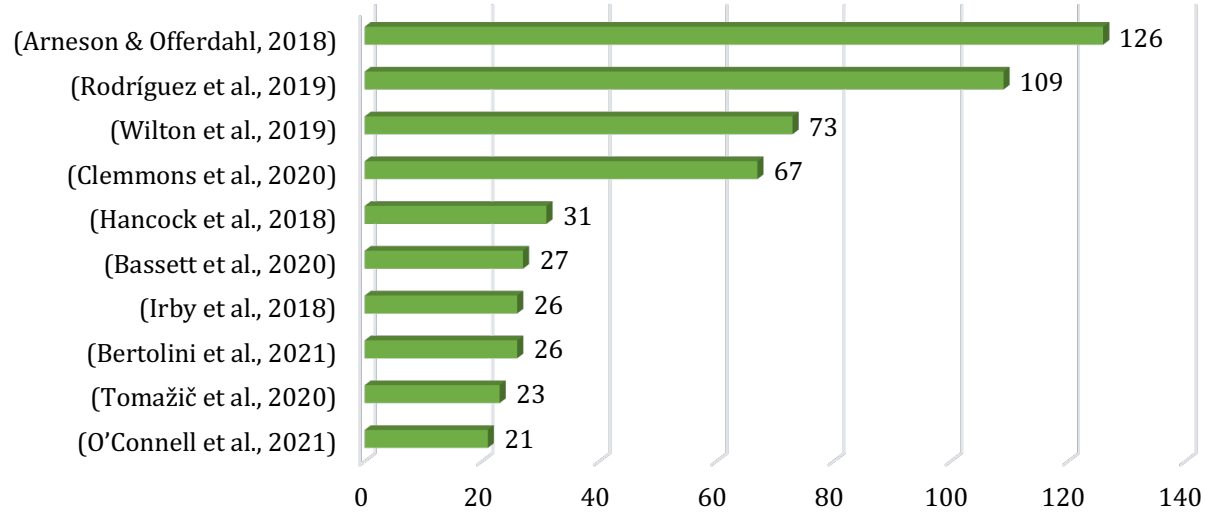

Figure 4. Top 10 articles by most citations in this study

The varying number of citations of some of the most cited publications indicates that the results of studies of various assessment methods are highly valued and frequently referred to in other research, especially in the context of the assessment of biology learning outcomes presented in the top 10 articles in Figure 4. On the flip side, some research results with fewer or no citations are due to several factors, such as the recency of the publication of new publications this year and the specific focus of the research. Overall, the overview of research has been influential in educational and biological assessment by highlighting key contributions in various assessment approaches. Further, identification is done on the research methods on biology learning outcomes that have been predominantly used over the past five years at various levels of education ranging from secondary school to higher education. In summary, the type of formative assessment dominated this study, as shown by 9 out of 36 articles that used formative assessment and were systematically reviewed.

The data presented in Figure 4 shows that at the secondary school level in Germany, most still use observational assessment to assess student behaviour (Fiedler et al., 2022; Tomažič et al., 2020). Meanwhile, self and peer assessment in India is becoming common in higher education, especially with student-centered teaching approaches (Kulkarni & Vartak, 2019). On the one hand, summative assessment is commonly used in the United States for end-of-semester evaluations (Arneson & Offerdahl, 2018; O'Connell et al., 2021), while formative assessment provides feedback throughout the learning process (Bassett et al., 2020; Hodges et al., 2021; Wilton et al., 2019). Performance assessments ask students to demonstrate specific skills, while technology-enhanced and diagnostic assessments are growing (Irby et al., 2018; Knutstad et al., 2021; Tahir et al., 2022). On the other hand, new assessments are being introduced in some universities with innovative evaluation approaches or criteria (Bertolini et al., 2021; Roberts & Shell, 2023). All these assessment methods aim to support student learning processes and outcomes, especially in biology education, with holistic programme evaluation.

Assessment of Biology Learning Outcomes in Education: Challenges and Opportunities

RQ3. *What are the primary challenges and opportunities educators face in implementing effective assessment methods for learning outcomes in biology?*

Implementing effective assessment methods for biology learning outcomes has challenges and opportunities for educators and students (Sakir & Kim, 2020; Yustina et al., 2020). The current main focus will discuss the main challenges in aligning the assessment methods utilized with the expected learning outcomes. Particulary, biology education covers a wide range of topics and skills, from molecular biology to ecology, which requires diverse assessment approaches to adequately measure students' abilities (Guttilla Reed, 2021; Hills et al., 2020; Kushner, 2021). Additionally, designing an assessment system that accurately and precisely reflects the complexity of biological concepts while being accessible to students with different backgrounds and abilities can be challenging. On the one hand, another challenge lies in integrating technology into assessment methods. While technology offers opportunities for innovative assessment approaches, such as virtual labs and online quizzes, educators must navigate issues related to digital literacy, access to technology, and ensuring the integrity of online assessments (Reen et al., 2021; Wilton et al., 2019). Henceforth, effective use of technology-enhanced assessment methods requires training and support for both educators and students.

Regardless of the present challenges, this research has significant opportunities for educators to implement effective assessment methods for biology learning outcomes, such as utilizing augmented reality technology (Weng et al., 2020). One opportunity is the advancement of interdisciplinary approaches to assessment (Burks, 2022). Biology education increasingly intersects with other fields, such as data science, bioinformatics, and environmental science (Clemmons et al., 2020; Labak & Blazetic, 2023; Stanja et al., 2023). By incorporating interdisciplinary assessment methods, educators can give students a deeper understanding of biological concepts and their real-world implementation. In addition, the growing emphasis on active learning and student-centered pedagogy creates opportunities for innovative assessment strategies (Carvalho et al., 2021; Suharti & Alen, 2021). Formative assessment techniques, peer evaluation, and project-based assessment empower students to take charge of their learning and engage more deeply with the subject matter (Guarracino, 2020; Hidayat & Irdiyansyah, 2023). These approaches are not limited to providing educators with

fundamental insights into student understanding but always encourage the ability for critical thinking, collaboration, and communication skills among students.

In conclusion, while implementing effective assessment methods for biology learning outcomes poses challenges for educators, it can provide opportunities for pedagogical innovation and student empowerment for the better. By overcoming challenges and capitalizing on opportunities, educators can create meaningful learning experiences, thus preparing students for success in biology education. By taking a holistic and sustainable approach to developing assessment methods, educators can ensure that assessments are not limited to measuring students' understanding of theoretical biology concepts but also encourage them to develop critical thinking skills, scientific reasoning, and a deep curiosity about the universe. Moreover, practical assessment can provide valuable feedback, helping students understand their strengths and weaknesses in learning biology and giving them clear directions for further improvement. Consequently, effective assessment methods are about assessing knowledge and facilitating students' growth and development as skilled and critical-thinking scientists.

Assessment of Biology Learning Outcomes in Education: Implications and Contributions

RQ4. *What are the implications and contributions of the changes of the last five years to future assessment methods in biology education?*

The changes in the last five years have significant implications for future assessment methods in biology education. One significant implication is the increasing integration of technology into assessment practices. The rapid advancement of digital tools and platforms offers opportunities to develop innovative assessment methods, such as virtual labs, simulations and online quizzes (Kabayiza et al., 2022; Reen et al., 2021; Tahir et al., 2022). These technology-enhanced assessments provide a more interactive and engaging learning experience for students and allow educators to collect real-time data on student performance, thus enabling more targeted interventions and feedback. Furthermore, an implication is the increasing recognition of the importance of assessing higher-order thinking skills in biology education. Traditionally, assessment in biology has focused heavily on factual recall and procedural knowledge (Cardozo et al., 2023). Nonetheless, there is a shift towards assessing students' ability to apply knowledge, analyze data, and solve complex problems (Rodríguez et al., 2019). Future assessment methods will likely emphasize assessing critical thinking, scientific reasoning, and inquiry skills, reflecting the broader goal of science education to foster science-literate citizens.

Subsequently, there is an increasing emphasis on equity, diversity and inclusion in assessment practices (Super et al., 2021). Educators recognize the importance of designing assessments that are accessible and culturally responsive to students from diverse backgrounds (Nortvedt et al., 2020; O'Leary et al., 2020) notably, in providing multiple means of representation, engagement, and expression in assessments to accommodate different learning styles, preferences, and needs. Future assessment methods are expected to prioritize fairness, validity, and inclusivity, ensuring all students have equal opportunities to demonstrate their understanding and proficiency in biology. Additionally, the COVID-19 pandemic has accelerated the adoption of distance and online learning modalities, leading to re-evaluating assessment practices in virtual environments (Anderton et al., 2021; Reen et al., 2021). Educators seek new ways to assess student learning remotely, utilizing technology and digital resources to design authentic and meaningful assessments that maintain academic integrity. Future assessment methods will likely continue to evolve to better suit the needs and challenges of online and hybrid learning environments, ensuring that assessment remains an adequate measure of student learning outcomes in biology education. Below is a percentage chart showing the development of the assessment of biology learning outcomes over the past five years, as shown in Figure 5.

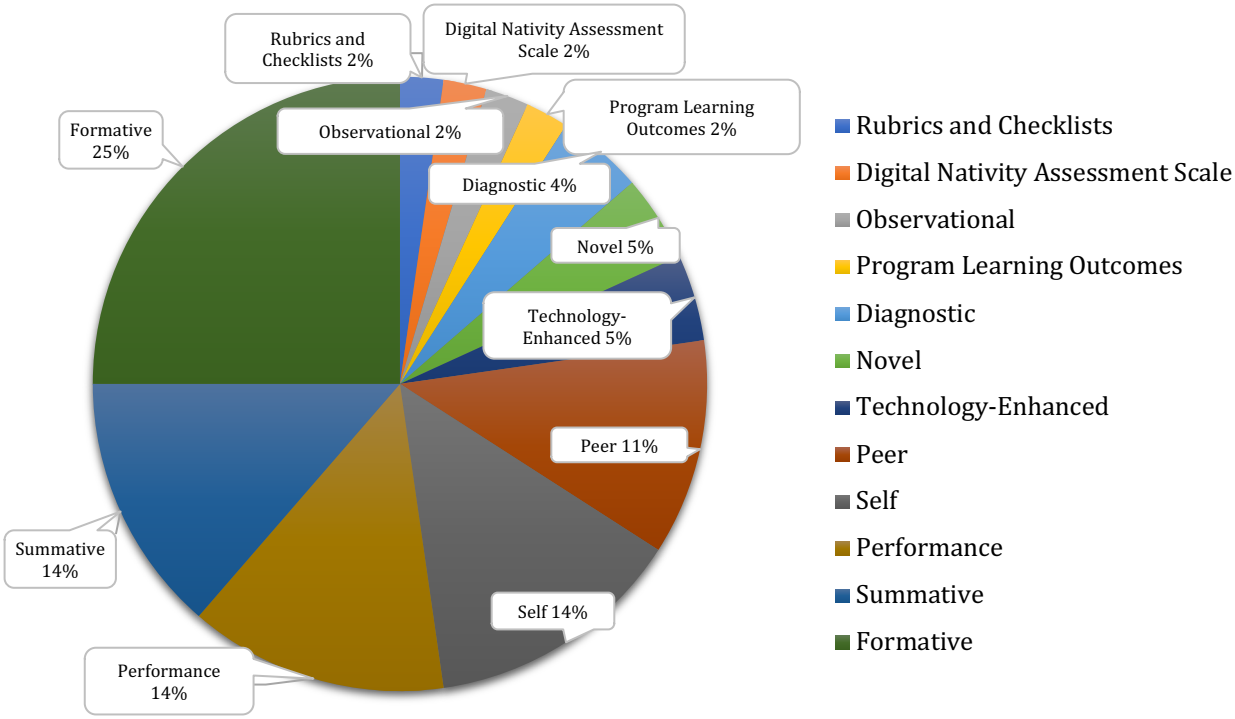

Figure 5. Percentage of Utilization of Assessment Methods from Various Publications in the Last 5 Years

The pie chart in Figure 5 shows the distribution of various assessment methods in education, with formative assessment dominating at 25%. This method involves continuous feedback throughout the learning process, allowing educators to customize their teaching approach according to students' individual needs. Other essential methods include self-assessment, performance assessment, and summative assessment, each accounting for 14% of the total, which supports self-reflection, evaluation of practical skills, and measurement of learning outcomes at the end of the course. Peer assessment, which accounts for 11%, prioritizes collaborative learning. Meanwhile, technology-enhanced assessment and novel assessment, at 5% each, integrate digital tools and innovative approaches in assessment. Diagnostic assessments that account for 4% help identify students' prior knowledge and misconceptions. Other methods such as observational assessment, digital rating scales, programme learning outcomes, rubrics, and checklists, although less dominant at 2% each, contribute significantly to a comprehensive assessment framework. This data demonstrates how a diverse approach to assessment can facilitate improved student learning outcomes.

In summary, the changes in the past five years have extraordinary implications and contributions to future assessment methods in biology education, encouraging innovation, equity and adaptability in assessment practices. By embracing technology, prioritizing higher-order thinking skills, promoting equity and inclusion, and responding to the evolving educational landscape, educators can develop assessment methods to meet the needs of students better and prepare them to become competent in the future biological sciences.

CONCLUSION

This research has offered a detailed analysis of the progression in assessment techniques of biology learning outcomes in education from 2018 to 2023. Utilizing the PRISMA approach and VOSviewer analysis on 36 articles from the Scopus database, the study identified the increasing use of technology in assessment and the dominance of formative assessment as the most prevalent method. The challenges educators face include the complexity of biological concepts and technology integration, while the emphasis on equity, diversity, and inclusion suggests a paradigm shift in assessment practices. Changes in the past five years, particularly the adoption of distance and online learning, have fueled innovation and adaptation in assessment methods, highlighting the importance of critical thinking, scientific reasoning, and inquiry skills. This research also highlights the importance

of interdisciplinarity and geographical diversity in assessment-related research contributions in biology education.

Limitations and Future Work

Although this study has provided valuable insights into the evolution of assessment methods in biology education and their influence on student learning outcomes, some limitations must be noted. Firstly, this study is limited to data obtained from the Scopus database and only includes articles in English-language journals, which may not include all relevant research conducted in other languages or published outside Scopus-indexed journals. Secondly, although the PRISMA approach has been used to ensure rigour in literature selection, the selection of keywords and inclusion criteria may have limited the scope of studies identified. Additionally, this study focused on assessing biology learning outcomes without considering in depth the socio-economic and cultural context in which biology education is delivered, which may affect the effectiveness of specific assessment methods.

For future research, the authors recommend expanding the literature coverage to include studies from other databases such as Web of Science, PubMed, ERIC, and others, and articles in multiple languages to gain a more global perspective. Similarly, further research examining the influence of socio-economic and cultural contexts on the effectiveness of assessment methods in biology education would be valuable, as it will help develop more inclusive and equitable assessment strategies that can be adapted to meet the needs of diverse student populations.

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