

 Review Article

Map and Trends in International Production on Biology Education

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Abstract

This study maps publications on biology education in the Web of Science database, aiming to understand its development and the most recent trends. A sample of 422 scientific articles was selected. Their metadata was bibliometrically analyzed using tools from the Bibliometrix statistical package. After reading the abstracts, the articles were categorized according to their type, research participants, thematic focus, and research design. It was found that publications on biology education have been growing, especially after 2014. The three main journals, the ten main authors, and the ten most impactful works in relation to the analyzed corpus are identified. The analyses showed that there is a small group of more prolific authors amidst a large mass of researchers with one or two publications, a proportion that suggests a dispersion of interest in the topic. The most important themes in the structure of academic production are related to “misconceptions” and “evolution,” which are among its motor themes, while descriptors such as “knowledge” and “concepts” stand out among the basic themes of the field. This suggests the importance of discussing the conceptual structure of biological knowledge, highlighting beliefs, attitudes, and the understanding of basic concepts. The thematic structure also reveals a concern with the training of biology teachers. The research reported is mainly survey-based, conducted with higher education students, and refers to teaching strategies or materials and psychological factors related to the teaching-learning process. Given the sample, research in the area is still dispersed among many authors who publish few works and cooperate little, which seems to indicate that the field is still seeking unity.

Keywords: Bibliometric Analysis, Biology Education, Literature Mapping, Research Trends

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Received
November 29, 2025

Accepted
March 1, 2026

Published
April 1, 2026

Citation: Matias, H. J. D., & Souza, B. O. (2026). The map and trends in international production on biology education. *Journal of Research in Mathematics, Science, and Technology Education*, 3(2), 128–145.

DOI: [10.70232/jrmste.v3i2.63](https://doi.org/10.70232/jrmste.v3i2.63)

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1. INTRODUCTION

The importance of Biological Sciences in today’s world is widely recognized, especially because of their role in articulating global problems and concerns, as well as providing answers and solutions demanded by the world we live in. Biology stands out in initiatives ranging from exoplanet science to discussions of climate and ecological challenges, including syntheses that integrate complex domains such as physics, chemistry, and computer science, as well as informing recent advances across many areas of medicine.

This prominence is directly associated with a long-standing effort to advance a parallel field of scientific and technological production: biology education. In fact, much has already been said about the implications of a new conception of biology for the 21st century (Labov et al., 2010), which significantly shapes biology teaching practices. This change has resulted in greater discipline-specific teaching and learning efforts, aligned with investigations carried out alongside other discipline-based education research fields that have also grown considerably in recent decades (Dolan et al., 2018). Research on biology education, as a defined field of investigation, is quite recent (Singer et al., 2013). As is the case with so many others, understanding this field largely depends on careful reflection through tools such as systematic

literature reviews, which highlight its theoretical approaches, conceptual frameworks, and other elements that characterize it (Luft et al., 2022).

Reflection on biology education has been underway for several decades and has accompanied numerous changes in the field. Two of the most influential journals in the area were established more than half a century ago: the *Journal of Biological Education* (1967) and *Biochemical Education* (1971, later renamed *Biochemistry and Molecular Biology Education* in 2000). Early in this scholarly reflection, two major challenges to the unity of biology education (both as theory and practice) emerged: the heterogeneity of biological knowledge and the institutional characteristics of biology teacher training (National Research Council, 1970). A long road to unification has been traveled (Rosenthal, 1990). Since the 1960s, observations suggest that biology education has increasingly aligned itself with the biological sciences, which have themselves become more mathematical, experimental, and predominantly focused on the microscopic level of biological phenomena. As a result, the distance between biological sciences and the public has widened (Jenkins, 2016).

Since the 1990s, research in the field has increasingly focused on several key areas, particularly: undergraduate teaching; a range of phenomena related to students' learning experiences (such as conceptual understandings, conceptual change, beliefs, and attitudes); the professional practice of educators (such as professional development and more effective instructional approaches); and more abstract themes (such as the nature of science) (Chang et al., 2010; Dirks, 2011). To a large extent, studies during this period relied on quasi-experimental designs, self-report data, and non-validated research instruments. However, research methodologies have diversified considerably, incorporating, in equal proportions, experiments, case studies, longitudinal studies, and other approaches (Reid et al., 2016).

A comprehensive study of the field, conducted by Gul and Sozibilir (2016), found that the most frequent thematic categories include topics familiar to biologists, such as environment, ecology, genetics, and biotechnology. The authors also sought to systematize these themes by grouping recurring phenomena in existing studies into broader analytical classes, with the aim of bringing greater coherence to their findings. For instance, "misconception" is part of the broader learning category. Other thematic focuses identified in their review include curriculum studies and teacher training (further divided into in-service training and pre-service training). Finally, the review also highlights the importance of computer-aided instruction as a recurring theme.

Gul and Sozibilir (2016) also report a greater prevalence of studies conducted at the secondary school level, followed by interest in higher education and, only then, in primary education. This represents an important shift in emphasis. The studies reviewed were predominantly empirical, with notable proportions of descriptive designs (17.8%), case studies (16.7%), quasi-experimental studies (9.1%), surveys (8.4%), and other comparative studies (8.1%). Lo et al. (2019) suggest that, in more recent years, there has been a decline in explanatory studies, those that produce clearer causal interpretations, and a corresponding increase in descriptive studies, which often generate more ambiguous findings. They also observe a broad predominance of mixed or quantitative approaches, along with a decreasing trend in qualitative studies. These patterns were already evident in earlier research.

In recent years, several emerging themes have gained prominence through systematic reviews examining their specific impact on biology education. These include topics such as biological literacy (Semilarski & Laius, 2018), assessment (Rahmi et al., 2025), the use of augmented reality (Permana et al., 2024), and other forms of educational technology applied to biology instruction (Nurdin et al., 2025; Sangur, Zubaidah, & Sulisetijono, 2025). Well-established themes continue to warrant systematic investigation as well, including misconceptions (Herak et al., 2025; Kadirhanogullari & Özyay Köse, 2024) and socio-scientific issues (Özel, 2024).

Understanding the terminology used to characterize current research in biology education is essential for identifying the field's prevailing trends and directions. It also supports the evaluation—and, when necessary, the refinement—of these directions. Comparing the characteristics of this research across different world regions and within distinct research traditions serves this same purpose.

For this bibliometric study, the Web of Science (WoS) database was selected to obtain the sample documents, given its comprehensive indexing of the main specialized journals in this area. WoS is certainly one of the most important databases globally, offering wide coverage of indexed journals. In addition, it is

a database known and appreciated for offering consistent metadata, bibliography, and citation network information, which are essential for impact analyses, thematic development, and relationships between authors. It offers advanced filtering tools and has broad institutional recognition.

However, it is necessary to take into account the biases identified by Mongeon and Paul-Hus (2016), who, while acknowledging the importance of WoS, note that the database tends to favor well-established journals within its areas of coverage and overrepresents English-language publications. Consequently, non-Anglophone journals and those from countries with more recent academic output are underrepresented. Furthermore, the authors also observe that WoS is comparable to other major databases, such as Scopus, with which it shares a high degree of coverage overlap. For this reason, they recommend exercising caution when making generalizations that compare different fields, institutions, or countries of origin among the publications analyzed. Similarly, Martín-Martín et al. (2018) identify a coverage bias that disproportionately affects highly cited publications in the humanities (28.2%) and social sciences (17.5%). Taken together, these considerations clearly limit the scope of any generalizations that may be drawn.

Despite these limitations, the WoS database has been widely used in bibliometric studies, including in the field of education, as illustrated by the works of Marín-Marín et al. (2021) and Sánchez Gómez et al. (2025). In the latter study, the authors argue that bibliometric analysis is an important tool for evaluating the dynamics of scientific production in education.

This study aims to map the international scientific production on biology education indexed in the Web of Science Core Collection between 2001 and 2023, identifying its thematic, methodological, institutional, and geographical characteristics. The WoS database was selected due to its rigorous indexing standards, stable citation metadata, and widespread recognition in bibliometric research. Furthermore, the use of a single, well-established database ensures internal consistency and enhances the reproducibility of the study, as it avoids the technical discrepancies often encountered when merging heterogeneous metadata from different platforms. The 2001–2023 period was selected for several reasons. Firstly, it allows for meaningful comparison with other existing bibliometric and review studies conducted in science and biology education. Secondly, this span is sufficiently broad to permit trend analysis while still capturing the most recent and representative phase of scholarly production. Finally, this period corresponds to a phase of greater stability in the indexing standards adopted by the Web of Science database.

2. METHODS

The documents comprising the corpus were obtained in July 2024 through a search employing the following parameters: (a) search terms “biology education” OR “biology teaching”; (b) applied to the “abstract” field; and (c) filtered by publication period (2001–2023) and document type (restricted to “articles”). To ensure analytical consistency and comparability, this study restricted the corpus to documents classified as “articles” in the Web of Science database. Articles typically represent complete, peer-reviewed research reports, offering greater methodological and conceptual detail than other document types such as reviews, editorials, or conference proceedings. Including heterogeneous document types could introduce analytical noise and affect the interpretation of publication patterns, particularly in relation to research design, thematic focus, and methodological reporting. Regarding the temporal scope, records published in 2024 were excluded from the analysis. At the time of data collection, the year was still ongoing, and the inclusion of incomplete annual data could distort trend analyses and longitudinal comparisons. This exclusion follows common practice in bibliometric studies, which typically rely on fully consolidated publication years to ensure the reliability of temporal patterns.

To enhance transparency in the data acquisition and filtering process, a flow diagram adapted from the PRISMA framework was employed to illustrate the stages of identification, screening, eligibility, and inclusion of records in the bibliometric corpus. Although this study does not constitute a systematic review, the use of a PRISMA-inspired flowchart allows for a clearer visualization of the applied inclusion and exclusion criteria and the progressive refinement of the dataset.

A total of 564 records were initially retrieved and subjected to a relevance screening process. Duplicate records were manually identified and removed. Subsequently, additional exclusions were applied to eliminate document types not aligned with the study’s analytical focus, including literature reviews not captured by the initial database filters, conference proceedings, and editorials. Records published in 2024

that had bypassed the temporal filter were also excluded to ensure dataset stability and consolidation. Finally, records only tangentially related to the topic of interest (false positives) were excluded following a title and abstract screening. The final corpus comprised 422 articles published across 125 distinct journals. All results reported below are based on the analysis of this consolidated dataset. The selection process is summarized in Figure 1.

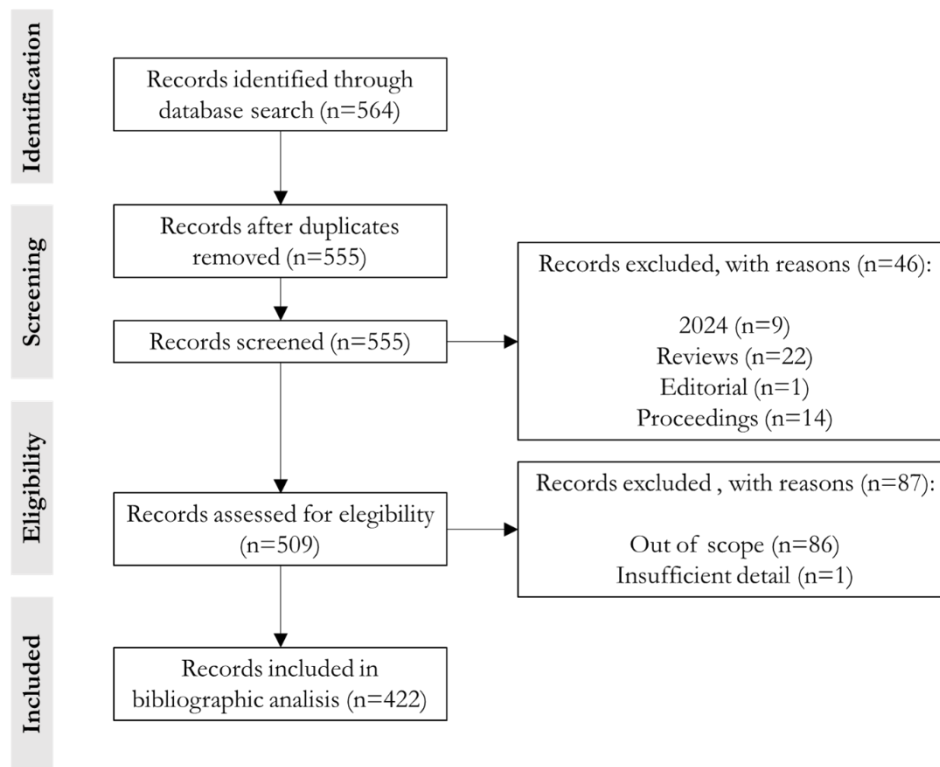


Figure 1. Flow Diagram Illustrating the Document Selection Process for the Bibliometric Analysis

Before analysis, the documents underwent additional preprocessing due to inconsistencies in the extracted metadata fields. These inconsistencies included: (1) the same author appearing under different name variants; and (2) descriptors being inconsistently recorded (e.g., multiple spellings for the same descriptor, such as “high-school”, “high school education”, and “high school”). All such metadata were therefore standardized. The resulting metadata were then analyzed using the Bibliometrix statistical package (Aria & Cuccurullo, 2017), with the aim of mapping the main characteristics of the corpus. The analyses were conducted using the Bibliometrix (version 4.2.1), which was the most recent stable release available at the time of data processing. The data analysis included an assessment of annual publication rates, the distribution of the most productive institutions and countries, the journals, authors, and documents with the greatest impact, as well as the predominant themes represented in the corpus.

Based on an analysis of the abstracts, the documents were categorized across four primary dimensions: article type, research participants, thematic focus, and research design (the latter applied only to documents classified as empirical).

Regarding article type, documents were mutually exclusively classified as: (a) empirical (presenting data collection and analysis); (b) descriptive (describing equipment, resources, teaching techniques, or similar elements); (c) essay (addressing a topic reflectively without primary data reference); or (d) methodological (presenting or discussing the usefulness of a particular research method). The classification of research participants identified which groups the study addressed: students, teachers, pre-service teachers, or others, with a single document potentially referring to more than one group. Empirical articles were further categorized by research design: survey, experimental, quasi-experimental, observational, documentary research, case study, or other. Finally, all documents were also categorized according to their educational scope: higher education, secondary education, primary education, early childhood education, or professional practice.

The final categorization identified the thematic focus of the analyzed documents, once again based on the reading of their abstracts. Unlike the previous categorization processes—which relied on predefined systems with some room for adjustment—this stage involved categories that emerged inductively from the corpus. Initially, categories were derived directly from the terms used in the documents themselves; however, they were later refined as conceptual associations among these terms became evident, yielding the consolidated set of thematic descriptors used in the final categorization. All categorizations were performed independently by two judges, who subsequently compared and discussed their initial classifications until reaching full consensus. This procedure ensured the internal consistency of the categorization process.

3. RESULTS AND DISCUSSION

The analysis reveals a significant, sustained increase in publications concerning biology education over the period under review. The average annual growth rate reached 16.5%, confirming the field's continued expansion. However, starting in 2014, the growth rate markedly accelerated, reaching 20.5% annually.

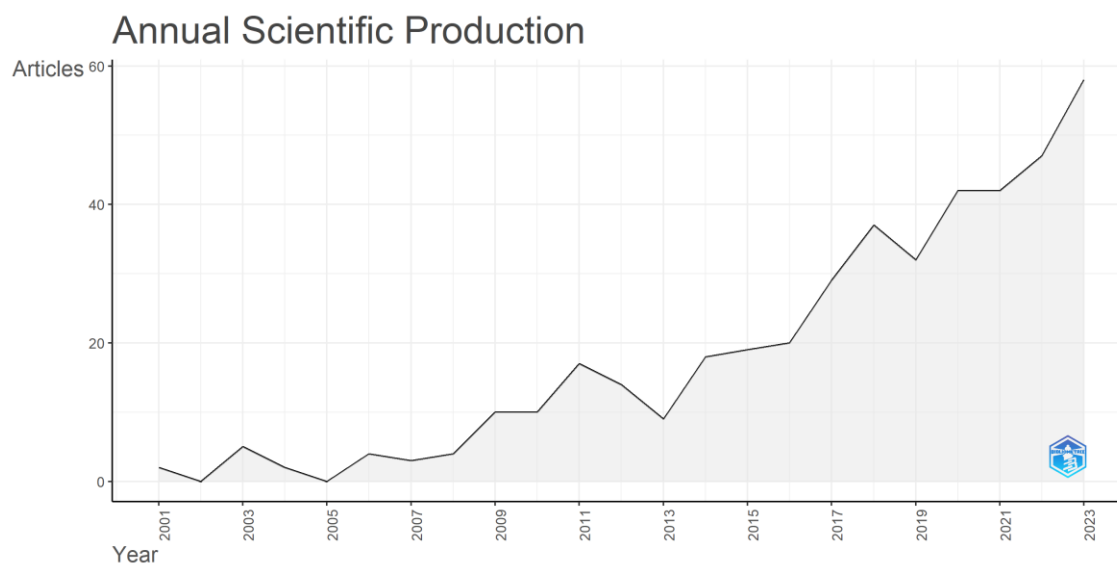


Figure 2. Annual Scientific Production on Biology Education

The surge observed in 2014 may be associated with broader global debates on pedagogical innovation, specifically marked by the consolidation of inquiry-based learning and by the emerging emphasis on scientific argumentation and model-based learning in major international science education frameworks — particularly those articulated in the NRC's *A Framework for K-12 Science Education* (2012) and operationalized in the NGSS (NGSS Lead States, 2013). These developments coincided with the growing incorporation of digital platforms and interactive technologies into science education, trends already observable before the widespread transformations triggered later by the COVID-19 pandemic (Sangur, Zubaidah, & Sulisetijono, 2025). In addition to these external influences, internal dynamics of the field — particularly publication patterns and thematic consolidation — may offer more robust explanations for this inflection in growth, as explored in the subsequent discussion.

One factor that helps explain the acceleration in publication growth relates to the journals through which these studies were disseminated. The most influential journals for disseminating research in biology education were identified and ranked according to Bradford's Law of Scattering, which organizes scientific output into core zones. We identified the journals with the highest concentration of publications in the field; the three most influential are listed in Table 1. These journals represent the core group that captures the majority of articles in the field and provide an essential reference point for researchers seeking to keep abreast of emerging trends. Two of these three journals are among the oldest in the field, suggesting continuity and institutional stability in sustaining scholarly discussions in biology education.

Bradford's Law underscores the principle that, in any scientific field, a small group of journals concentrates the most influential and frequently cited output. In the case of biology education, these core

journals play a central role in consolidating the discipline’s advances and structuring its editorial landscape. Following the principles of Bradford’s Law of Scattering, Table 1 reports only this core set of journals, which accounts for the highest concentration of publications in the field and functions as the primary editorial venues for biology education research. Extending the table beyond this core would yield diminishing analytical returns, as the remaining publications are dispersed across a wide range of peripheral journals, each contributing a relatively small number of documents to the topic. The prominence of articles focusing on innovative pedagogy, technology integration in science education, and the impact of contemporary educational approaches within these venues suggests that such topics retain high scholarly interest and continue to shape disciplinary debates.

Table 1. Journals with the Greatest Impact in the Field

	Journals	Start	Docs	Cit(T)	Cit(L)	H	G	M
1	CBE - Life Sciences Education	2002	62	1503	895	20	37	1.25
2	Journal of Biological Education	1967	44	430	354	12	19	0.50
3	Biochemistry and Molecular Biology Educ.	2000	24	239	116	9	14	0.64

As presented in Table 1, the journal with the largest number of documents in the collection, the highest Total Citations (Cit(T)), and the highest Local Citations (Cit(L)) is *CBE—Life Sciences Education*. It also exhibits the highest values across all local impact indices, including the H-index and its G- and M-index variants. Since its launch in 2002, the journal has served as a premier venue within the broader life sciences, and its wide disciplinary scope may have contributed to increasing the visibility of biology education research.

The analysis of the most cited authors, as presented in Table 2, highlights the researchers who exert the strongest influence within the corpus. These authors were ranked according to the Total and Local Citation counts accumulated by their publications. Their prominence in the citation ranking underscores the relevance of their theoretical, methodological, or practical contributions to the development of the field.

The most cited authors represent key contributors to the theoretical development of biology education. They have developed models, theories, or approaches that exert considerable influence within the corpus and, in some cases, across other WoS collections. This influence encompasses themes that guide educational practice, including research on students’ alternative conceptions, technology integration in the classroom, and student-centered instructional approaches. Identifying these authors helps guide future research agendas and supports the development of new studies grounded in established foundations of the field.

Table 2. Most Cited Authors in the Field

	Authors	Docs	Start	Cit(T)	Cit(L)	H	G	M
1	Tanner KD	7	2012	279	25	5	7	0.385
2	Brownell SE	5	2014	288	15	5	5	0.455
3	Coley JD	5	2012	257	23	4	5	0.308
4	Momsen JL	6	2010	120	11	4	6	0.267
5	Jungck JR	5	2010	125	7	5	5	0.333
6	Lo SM	6	2020	29	2	3	5	0.600
7	Cotner S	3	2021	20	0	3	3	0.750
8	Anderson TR	4	2015	26	2	4	4	0.400
9	Ballen CJ	4	2017	31	1	3	4	0.375
10	Wenderoth MP	2	2014	120	9	2	2	0.182

Ranking the most cited authors is not straightforward, as the ordering of the indicators used is not fully consistent across authors. Even so, identifying these citation patterns is crucial for mapping the dynamics of academic production and understanding scholars’ reciprocal influence within the investigated literature. Beyond highlighting those who exerted the greatest field-shaping impact, the table also shows that the majority of these authors (7 out of 10) began publishing in the area between 2010 and 2015—a period marked by a sharp increase in publication rates in biology education. This temporal overlap suggests a potential link between the rise of these authors and the broader expansion of interest in the field’s central

themes. Their contributions appear to align with, and possibly structure, the more recent trends in research and publication represented within this collection.

Nevertheless, some patterns stand out. The graph below shows the percentage of authors as a function of the number of documents published, indicating that most authors (approximately 75%) produced only one or two documents. The solid curve (Figure 2) represents the observed author productivity distribution, while the dashed line illustrates an expected trend. This pattern reveals that scholarly output in the field is concentrated among a relatively small cohort of prolific authors, while most researchers are represented in the corpus with only a limited number of contributions. Such an imbalance suggests that, within this dataset, the area has not yet consolidated a broad community of authors who publish consistently over time. However, the interpretation of this pattern must take into account the previously noted caveats regarding the potential biases inherent to the database used.

Building on previous debates, there is a long-standing discussion regarding the theoretical and practical unity of biology education (National Research Council, 1970; Rosenthal, 1990). An assessment of the problem suggests that the very nature of biology—a domain composed of epistemologically heterogeneous scientific traditions—bears implications for biology education (Kloser, 2012). We can also assume that biology education is also influenced by discipline-based structures, which tend to reinforce the fragmented character of the field. A similar argument is advanced by Nehm (2019), who notes that biology education exhibits fragmentation within its research program, likely due to the epistemological fragmentation that characterizes the organization of the life sciences across multiple academic disciplines and specialized departments, leading to institutional dispersion (societies, conferences, journals, etc.). In his view, conceptual and disciplinary fragmentation ultimately leads to educational fragmentation. Consistent with this diagnosis, he highlights the significant efforts to promote curricular cohesion, including initiatives led by organizations such as the American Association for the Advancement of Science, the National Research Council, and the National Science Foundation.

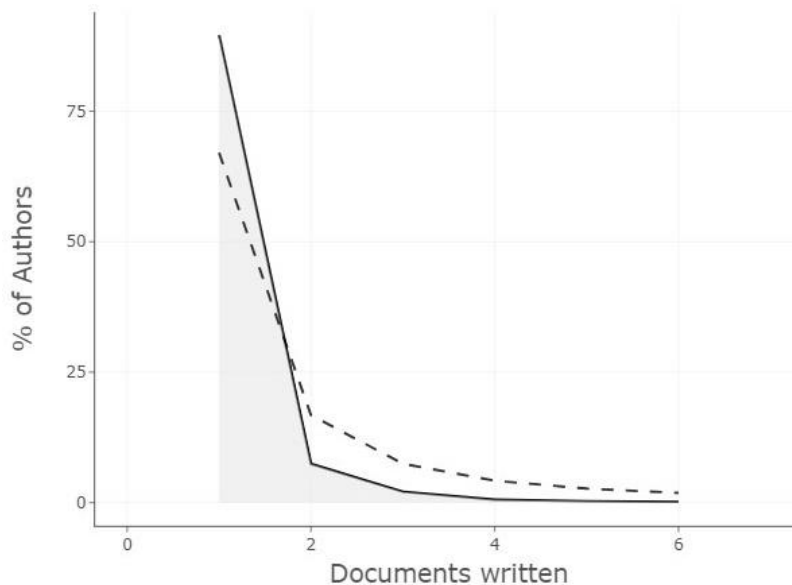


Figure 3. Distribution of the Number of Documents Written by Authors in the Area

Table 3 presents the most cited articles identified through the bibliometric analysis, listed with their complete references, local citations, total citations, and the LC/TC ratio. What stands out is the consistently low number of Local Citations (LC) when compared with the substantially higher Total Citations (TC). The LC/TC ratios vary widely, ranging from 2.91 to 12.77, indicating that the influence of these works is much stronger outside the analyzed collection than within it. In other words, even the most impactful articles in the field are only weakly absorbed by the specific literature mapped here. This suggests that research in biology education, as represented in this corpus, does not circulate primarily within a tightly interconnected community of authors and topics. Instead, it draws heavily from and contributes to broader areas in science education, scientific literacy, and cognitive research. Consequently, the literature on biology education, at least as captured by the selected descriptors, does not appear to form a cohesive or internally integrated

domain. This lack of internal consolidation may complicate efforts to delimit, describe, or systematically map the field.

Table 3. Most Cited Articles in the Field

	Documents	Cit(L)	Cit(T)	Cit/Year	LC/TC
1	Coley JD, Tanner KD (2012). Common origins of diverse misconceptions: cognitive principles and the development of biology thinking. <i>CBE—Life Sciences Education</i> , 11(3), 209-215.	9	96	7.38	7.29
2	Coley JD, Tanner KD (2015). Relations between intuitive biological thinking and biological misconceptions in biology majors and nonmajors. <i>CBE—Life Sciences Education</i> , 14(1), 1-19.	9	73	7.30	9.59
3	Brownell SE, Freeman S, Wenderoth MP, Crowe AJ (2014). BioCore guide: a tool for interpreting the core concepts of vision and change for biology majors. <i>CBE—Life Sciences Education</i> , 13(2), 200-211.	8	108	9.82	7.41
4	Maskiewicz AC, Lineback JE (2013). Misconceptions are “so yesterday!”. <i>CBE—Life Sciences Education</i> , 12(3), 352-356.	7	47	3.92	12.77
5	Leonard MJ, Kalinowski ST, Andrews TC (2014). Misconceptions yesterday, today and tomorrow. <i>CBE—Life Sciences Education</i> , 13(2), 179-186.	6	44	4.00	7.41
6	Lin CY, Hu R (2003). Students’ understanding of energy flow and matter cycling in the context of the food chain, photosynthesis, and respiration. <i>International Journal of Science Education</i> , 25(12), 1529-1544.	5	96	4.36	6.25
7	Catley KM, Novick LR (2008). Seeing the wood for the trees: an analysis of evolutionary diagrams in biology textbooks. <i>BioScience</i> , 58(10), 976-987.	5	54	3.18	9.26
8	Harrison M, Dunbar D, Ratmansky L, Boyd K, Lopatto D (2011). Classroom-based science research at the introductory level: changes in career choices and attitude. <i>CBE—Life Sciences Education</i> , 10(3), 279-286.	5	172	12.29	2.91
9	Smith JI, Combs ED, Nagami PH, Alto VM, Goh HG, Gourdet MAA, Hough CM, Nickell AE, Peer AG, Coley JD, Tanner KD (2013). Development of the biology card sorting task to measure conceptual expertise in biology. <i>CBE—Life Sciences Education</i> , 12(4), 628-644.	5	53	4.42	9.43
10	Holstermann N, Grube D, Bögeholz S (2010). Hands-on activities and their influence on students’ interest. <i>Research in Science Education</i> , 40, 743-757.	4	127	8.47	3.15

These results are consistent with those presented by Abdullah (2022). In his study, the three core journals highlighted here also appear prominently, alongside others that fall outside the scope of our analyzed corpus. Consequently, it is understandable that the sets of most influential articles do not fully overlap. Still, his top-five ranking exhibits a clear predominance of publications from the same period identified as most prominent in our findings, suggesting that both studies converge in identifying the 2010s as a highly productive and impactful decade for biology education research.

Another noteworthy point is the thematic pattern that emerges from the selected articles. Central topics in biology education—particularly misconceptions, intuitive reasoning, and practical aspects of biology teaching—appear with marked frequency. The relevance of these themes had already been demonstrated by Gul and Sozbilir (2016), whose study found this category to be the most frequent among those designating publication content within the learning group. In our results, four of the five highest-ranked articles focus on misconceptions, and nearly all of the top ten articles examine, in one way or another, issues related to students’ conceptions—including beliefs, naïve theories, and intuitive models. This pattern indicates that epistemological challenges, especially those framed in cognitive terms, constitute a defining feature of biology education research. As a result, they also represent central challenges for the biology teaching didactics.

DeHaan (2011) observes that Conceptual Change Theory has long served as one of the central theoretical frameworks in the field. According to diSessa (2022), the systematic study of conceptual change spans over four decades. The field of learning sciences owes many of its most important advances to the contributions of biology education research, which tackles some of the most conceptually challenging

domains, such as evolution and genetics. These theoretical and methodological contributions retain a decisive impact, and consequently, the topic remains salient in biology education studies.

This perception is supported by the findings of Kadirhanogullari and Köse (2024), who identified more than 400 publications from over 50 countries, distributed across more than 140 journals. However, since their survey spans publications from 1970 to 2022, this breadth helps explain why this theme appears as a well-established research sub-area. Herak et al. (2025) likewise show that misconceptions are investigated across a wide range of biological domains and learning difficulties, and that understanding these patterns can help guide effective teaching practices. However, this does not imply that the topic is still among the trending topics in the field. Indeed, as shown below, the articles addressing alternative conceptions in our sample are concentrated between 2010 and 2015.

One way to examine thematic interest trends is to analyze the occurrence and distribution of keywords (descriptors). In the figure below, the bars represent the annual recurrence of each theme across the corpus descriptors, while the circles—and their proportional sizes—indicate the cumulative frequency of each theme. Notably, the most recently incorporated themes include “COVID-19,” which emerged following the 2020 pandemic and has been widely discussed in biology education, as well as “inclusive teaching” and “STEM” (Science, Technology, Engineering, and Mathematics). The latter two themes suggest a rising attention within biology education to specific learner cohorts—particularly in the context of inclusive teaching—and to the field’s intersections with other knowledge domains, both of which introduce distinct conceptual and pedagogical challenges. Conversely, themes such as “conceptions” and “misconceptions” appear to be declining in prominence, evidenced by their decreasing annual frequency, despite their long-standing centrality in the field.”

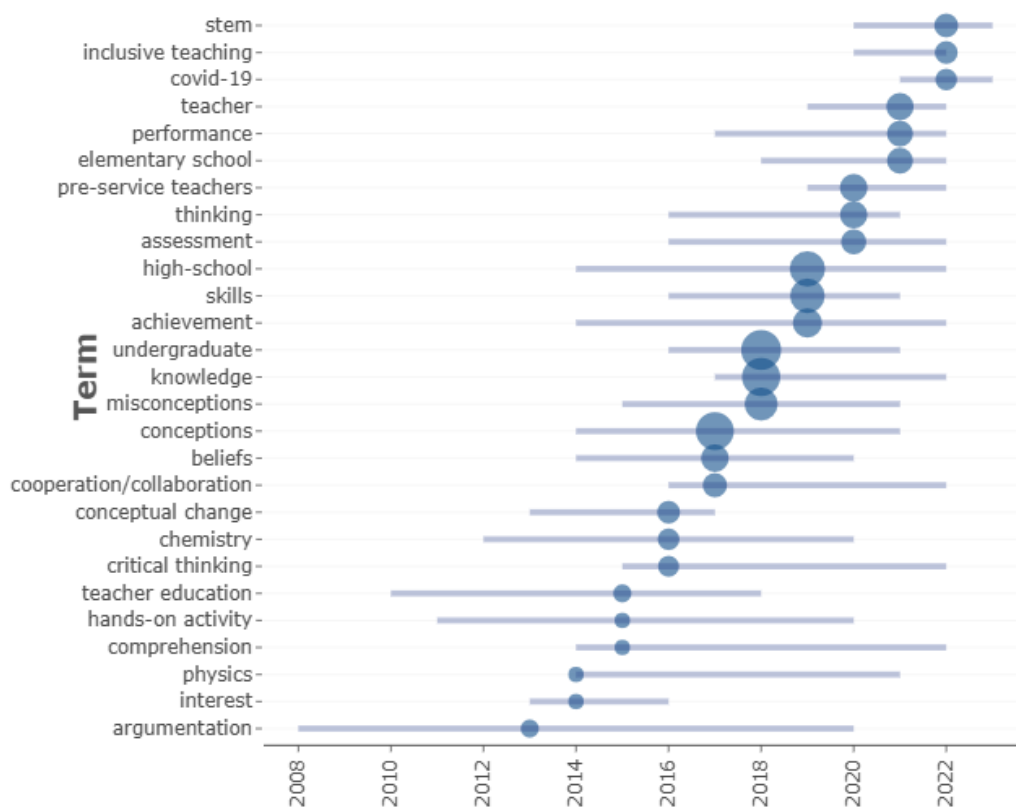


Figure 4. Thematic Development of the Field Based on Keyword Analysis (Trend Topics)

The analysis examines descriptor frequency and co-occurrence patterns, categorizing them based on two criteria: (a) Centrality—the intensity of association between a theme group and other groups; and (b) Density—the intensity of internal associations among themes within the same group. In the first spatial representation, labeled Niche Themes, we find themes characterized by strong internal cohesion but low association with other thematic groups. These themes are studied by specific interest groups and currently exert limited influence on the broader field. This block includes themes such as “CURE” (Course-based Undergraduate Research Experience—where students participate in original research and learn through this

experience), “STEM”, “laboratory”, and “inquiry-based education”. These niche themes reflect a perspective on biology education emphasizing learning through engagement in authentic scientific practices and the interdisciplinary connection between biology and other natural sciences and technology.

A second cluster of Niche Themes is positioned near the boundary of the quadrant representing more central themes. This cluster, including “achievement”, “motivation”, “gender”, and “inclusive teaching”, reflects interest in psychosocial variables of learning and attention to equity and specific student cohorts in biology education. This trend aligns with observations previously discussed. Jenkins (2016), in assessing the direction of biology education, noted that gender differences in student enrollment in biology courses have decreased over time. This increase in female participation, alongside broader social transformations, may have fostered attention to this niche theme. Jenkins (2016) also highlighted the necessity for biology education to incorporate topics focused on social, psychological, and health-related concerns. While some studies suggest these are emerging themes (Lo et al., 2019), a survey of participants at the Society for the Advancement of Biology Education Research (SABER) annual meeting (Hu et al., 2021) revealed that only a small proportion considers a deeper understanding of diversity and inclusion essential to the field’s core objectives. This supports the view that, for now, these topics remain niche themes.

Crucially, the high density of both niche clusters suggests they are highly specialized research programs. Should their Centrality—their connection to the rest of the field—not increase over time, they risk evolving into isolated subdisciplines, thus deepening the field’s fragmentation. This tension is further exacerbated by the nature of the other thematic quadrants: while the Motor Themes could offer identity and unity, their strong internal cohesion (high density) makes their dynamics close to those of the specialized Niche Themes. Conversely, the Basic Themes (lower quadrant) are generically fundamental, sharing broad curricular and conceptual concerns with other general and discipline-specific science education programs.

The remaining space comprises the Emerging or Declining Themes, which are neither highly central nor highly dense in the literature. By definition, these themes exhibit low centrality and limited internal cohesion, indicating a weak association with the core of the discipline. This cluster includes themes such as “active learning”, “biochemistry”, and new or weakly connected concepts. Notably, this group contains some of the most frequent themes, as indicated by the large proportional size of the corresponding circles, including “undergraduate” and “skills”. The presence of these high-volume themes in the peripheral quadrant suggests that although they generate a substantial number of publications, their current research does not significantly contribute to the field’s conceptual development or coherence (i.e., low Centrality and Density). The theme “COVID-19” represents a clear emerging theme; while it does not appear as a visible label in the figure due to its lower frequency during the analyzed period, its presence as a descriptor supports the assessment of new research concerns. Conversely, the theme “active learning” may signal a declining trend, which is noteworthy given its high recurrence in BER studies between the 1990s and 2010s (Dirks, 2011). Although active learning was a foundational element emphasizing effective instructional strategies since the inception of BER (DeHaan, 2011), its current position suggests it is no longer a primary driver of research growth or theoretical cohesion.

The themes situated in the space designated Basic Themes possess high centrality but exhibit relatively low internal cohesion (density). These basic themes also represent the most frequent topics, a fact visually confirmed by the proportional size of the corresponding bubbles in the figure. Visually, two main clusters emerge: one focused on epistemological and curricular concerns (e.g., knowledge, curriculum, genetics, models), and another on educational levels and professional training (e.g., high school, elementary school, pre-service teachers). This structural configuration suggests that curricular concerns applied to various educational levels constitute the fundamental core of biology education research, serving as the primary set of problems that other research themes attempt to illuminate. This structural centrality reinforces the perspective that epistemological concerns have historically been fundamental to BER. Furthermore, a bottom-up survey by Hu et al. (2021) found that two-thirds of practitioners and scholars view BER as concerned with classroom practices and teaching improvements, while three-quarters see the discipline from a student-focused perspective.

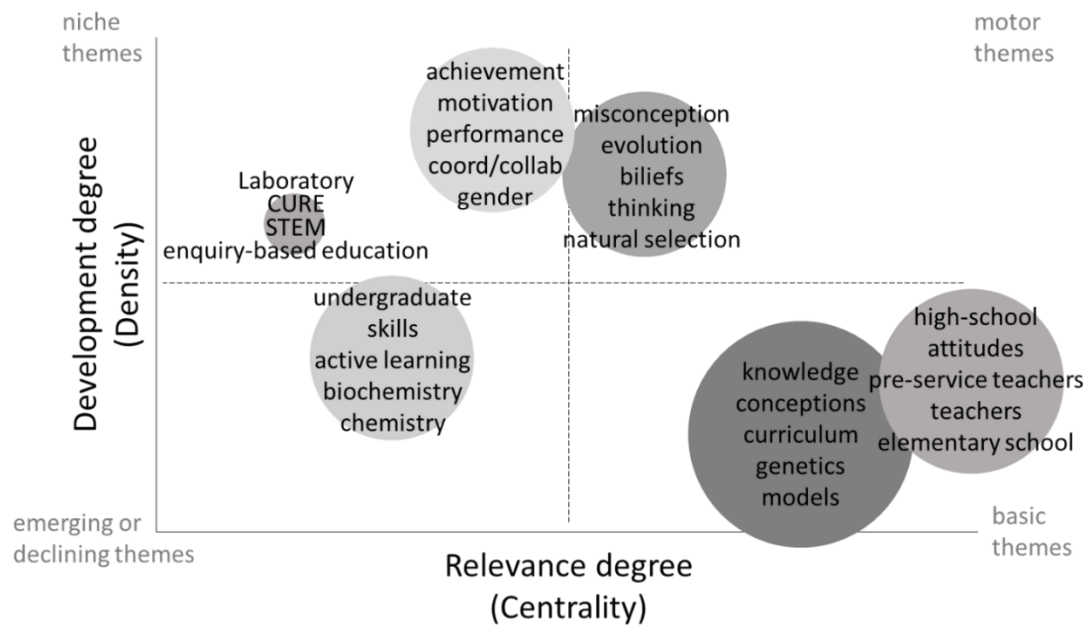


Figure 5. Thematic Map of the Field Based on Keyword Analysis

The Motor Themes correspond to the topics that currently drive and shape research in the field, characterized by a balanced association between high centrality and high density. This cluster encompasses “misconceptions” and related cognitive themes such as “beliefs” and “thinking”, alongside the core content of these conceptions: “evolution” and “natural selection”. Since these topics—particularly evolution and natural selection—are central to the modern organization of the biological sciences and their conceptual understanding is crucial, it is evident why these themes drive research within biology education. This assessment is endorsed by Gul and Sozbulir (2016), who found that both the biological themes (evolution and natural selection) and their associated “subject matter” (including “misconceptions”) are among the most frequent and research-mobilizing themes in the field.

Thus, the thematic map allows us to identify topics receiving the greatest research focus in the field, as well as those with which a novice researcher might initially engage, themes that are becoming saturated, those requiring further conceptual development, emerging trends, and areas where research gaps persist.

Additional characteristics of the analyzed documents were determined by examining their abstracts and categorizing them according to several parameters. The articles were classified by type, as previously described, and this classification is summarized in the table below.

Table 4. Types of Articles

Type of articles	Count	%
Empirical	287	68.0
Descriptive	85	20.1
Essayistic	49	11.6
Methodological	1	0.2
Total	422	100.0

As indicated, the majority of the analyzed articles are empirical studies, accounting for two-thirds of the total. This indicates a pronounced focus on investigating the practical reality of biology education, whereas opinion pieces or more theoretically oriented works represent only a small fraction, reflected in the low proportion of essayistic articles. Further evidence of this practical orientation is the proportion of studies presenting didactic-pedagogical techniques or resources, amounting to one-fifth of the articles (classified descriptively). This frequency may also reflect the editorial preferences of the leading journals in the field, which tend to favor, or exclusively publish, empirical studies.

Among the empirical studies, most provided sufficient information to classify the research design employed. In Table 5, the category “unspecified research design” represents 143 documents (33.9% of the

sample). This substantial proportion highlights a specific characteristic of the field’s production: a significant number of articles do not explicitly specify their research design or provide sufficient methodological detail in their abstracts to allow precise classification. As the present analysis is based on abstract-level information, such cases were conservatively grouped under this category to avoid misclassification. This finding suggests that methodological reporting in biology education research remains only partially standardized, which may limit the clarity, comparability, and cumulative potential of empirical studies. Consequently, the high percentage of studies with unspecified research designs reinforces the observation that the field is still seeking greater methodological cohesion and formal rigor in its scholarly communication. Notwithstanding these reporting limitations, the distribution of classified research designs reveals important patterns in the empirical orientation of the field.

As shown in Table 5, the categorization of research designs indicates a clear preference for survey studies, in which the primary aim is to gather descriptive information about specific groups or phenomena. This design typically involves describing group characteristics, establishing correlations between these characteristics, or relating them to contextual factors. Such a pattern may reflect a declining emphasis on explanatory studies, favoring research designs primarily oriented toward characterizing educational realities, a trend consistent with the observations of Lo et al. (2019). Questionnaires, interviews, and both standardized and non-standardized tests are common instruments in this type of research. Among empirical studies, it is also worth noting the prominent representation of designs with greater variable control, such as quasi-experimental and experimental studies, a finding also highlighted by Gul and Sozibilir (2016).

Table 5. Research Design of Empirical Articles

Design	Count	%
Unspecified research design	143	33.9
Survey	139	32.9
Quasi-experimental	49	11.6
Observational	21	5.0
Documental	16	3.8
Experimental	14	3.3
Case study	12	2.8
Other	28	6.6
Total	422	100.0

Table 6. Theme Frequency in Abstracts

Theme /Focus	Count	%
Teaching techniques	109	25.8
General competencies	94	22.3
[Metacognition, motivation, knowledge, learning, executive functions, reasoning, and problem-solving]		
Attitudes	56	13.3
Curriculum	47	11.1
Beliefs	46	10.9
Teaching materials	43	10.2
Teacher training	23	5.5
Assessment	17	4.0
Inclusion	10	2.4
General reflection on bioedu	8	1.9
Research	7	1.7
Gender	5	1.2
History: bioedu	3	0.7
Identity	2	0.5
Educational policy	1	0.2
Total	471	111.6

The themes explored in the analyzed corpus were previously examined through the survey of their descriptors. Table 6 presents the outcomes of the thematic categorization derived from abstract analysis. This categorization largely reflects characteristics previously noted, while also revealing significant nuances.

Unlike the previous categorization, documents could be assigned to multiple categories simultaneously (n=422), given that some works address more than one theme.

Approximately one-quarter of the works focus on teaching techniques, particularly classroom practices and their implementation in biology education, a finding consistent with Gul and Sozbilir (2016). This theme, together with works addressing teaching materials (47 occurrences), clearly highlights trends missed by keyword analysis, such as a pronounced interest in information technology and laboratory practices. This trend appears to corroborate the field perception reported in the survey by Hu et al. (2021). A second frequently addressed theme involves general psychological competencies (e.g., metacognition, motivation, knowledge, executive functions, learning, reasoning, and problem-solving), comprising slightly over a quarter of all occurrences. Among these, knowledge is the most frequent (55 occurrences). Other recurring psychological phenomena include attitudes and beliefs. These findings underscore the significance of educational and learning psychology research within biology education. They may reflect the theoretical influence of certain psychological perspectives on academic production and didactic reflection, as noted by Lo et al. (2019), who emphasize the pivotal role of cognitive psychology in shaping BER. Furthermore, these three themes—general competencies (including knowledge and reasoning), attitudes, and beliefs—likely correspond to the previously mentioned Motor Themes, which encompass critical curricular content (e.g., evolution) and associated challenges (e.g., misconceptions). To address these challenges, research on curriculum and teacher training, alongside teaching techniques, also occurs frequently.

Table 7. Distribution of Articles According to Participant Type

Participants	Count	%
Unspecified/not applicable	94	22.3
Students	249	59.0
Teachers	59	14.0
Pre-service teachers	35	8.3
Others	2	0.5
Total	439	104.0

The analyzed documents were also examined based on the participant groups involved in the research or discussion (Table 7). Among works with defined participants, a predominant focus on students as the primary group of interest is observed, accounting for more than half of the studies. This highlights the field's central concern with the learner's perspective, investigating how biological knowledge is acquired across different educational levels. Additionally, there is a significant emphasis on studies addressing teachers (both in-service and pre-service), reflecting the importance of professional development and pedagogical practice in the area. In Table 7, the category "Unspecified/Not applicable" represents nearly one-fifth of the documents. This group encompasses theoretical essays in which participants are not applicable, as well as empirical studies that do not provide sufficient information in the abstract to clearly identify participant groups. By grouping these cases, the analysis adopts a conservative approach, avoiding speculative classification and ensuring that the discussion remains focused on clearly identifiable trends that characterize the current landscape of biology education research.

Table 8. Distribution of Articles According to the Educational Level

Level	Count	%
Unspecified/not applicable	82	19.4
Higher education	198	46.9
Secondary (high school)	71	16.8
Professional	44	10.4
Primary (elementary and middle school)	35	8.3
Early childhood	1	0.2
Total	431	102.1

Finally, a notable characteristic of the documents is the focus of most research and reflections on higher education (see Table 8). Nearly half of the analyzed works address aspects of biology teaching at the higher education level, followed by a smaller proportion focusing on secondary education. This contrasts with the findings of Gul and Sozbilir (2016), who report a prevalence of secondary education, but aligns

with the results presented by Lo et al. (2019). Other factors likely account for the higher prevalence of studies at certain educational levels. Greater accessibility to participants and research sites in higher education likely accounts for its predominance, whereas secondary education is notably less represented. Primary and early childhood education, where biology education remains in its early stages and is less differentiated from other sciences, likely presents greater research challenges. This occurs despite the recognized importance of these stages, as highlighted by relevant studies. Again, the category “unspecified/not applicable” refers to records for which the analytical procedure is either not applicable (e.g., theoretical essays) or cannot be clearly identified based on the information provided in the abstract.

The analyzed literature can also be characterized in terms of its social and collaborative structure. This evaluation is enabled by metadata obtained from the consulted database, specifically through the examination of the spatial distribution of publications. The map presented below (Figure 5) provides preliminary insights for this assessment.



Figure 6. Geographical Distribution of Publications and Collaboration between Countries

Table 9. Distribution of Publications by Country

Country	Docs	TotCit	Mean(Cit)
USA	1° 173	1° 2903	5° 16.78
Indonesia	2° 30	4° 175	22° 5.83
Germany	3° 29	2° 378	9° 13.03
Turkey	4° 23	3° 242	11° 10.52
Brazil	5° 19	12° 59	28° 3.11
China	6° 17	5° 167	14° 9.82
Netherlands	7° 11	7° 131	10° 1.91
Serbia	8° 10	16° 38	26° 3.80
United Kingdom	9° 10	6° 155	7° 15.50
Sweden	10° 8	10° 65	17° 8.13

In this map, the intensity of shading for each country represents the relative number of publications. The lines connecting the countries, with thickness corresponding to collaboration intensity, indicate both the existence and the relative strength of international collaborations. The USA stands out as the leading country in both total publications and international collaborations. The most productive institutions in biology education research, according to this database, are predominantly based in the USA, including Northwestern University, Michigan State University, Purdue University, and the University of California (San Diego). However, publications remain largely isolated, with limited engagement in international

collaborations. Despite differences in absolute numbers, these data corroborate the findings of Abdullah (2022). It is important to note, again, the differences in scope between Abdullah's (2022) dataset and this study. Unlike Abdullah, this study excluded meeting reports and literature review articles. Nevertheless, the prominent role of countries such as Indonesia, Turkey, and Brazil — emerging economies gaining recognition in this field — remains evident. These patterns are further illustrated in Table 9.

A significant publication gap exists between the leading country (USA) and all others, with differences among the remaining countries being less pronounced. However, when applying impact metrics, such as total citations and average citations (calculated as the ratio of total citations to publication count), the country ranking shifts. This effect occurs for all high-output countries, as the impact of the most influential works is diluted by the total publication volume. However, this phenomenon appears more pronounced in peripheral countries, such as Indonesia, Serbia, and Brazil. While coverage bias partially explains this outcome, the fact that the vast majority of included works from non-Anglophone countries were published in English likely moderates this bias. Furthermore, given that English remains the lingua franca of international scientific publication, the relatively high impact metrics of non-English-speaking countries (e.g., Germany, Turkey, and Indonesia) carry distinct significance. This reflects the willingness of local journals to publish in English and their subsequent inclusion in internationally indexed databases. Strategies for emerging countries to mitigate this distortion have been discussed in the literature (Amarante et al., 2021; Meneghini & Packer, 2007).

5. CONCLUSION

Although constrained by the scope of the sample and the limitations inherent to the database, the analyses successfully reveal relevant elements of the overall landscape of biology education. Another key consideration is that, reflecting the nature of a bibliometric study, the analysis relies solely on metadata and abstracts. These constraints do not preclude generalizations within the study's objectives, although they limit certain comparative analyses, such as across thematic fields. Given the significant overlap of indexed works across major databases, we can assume that the sample provides a representative, albeit Anglophone-biased, snapshot of the field's thematic, methodological, and emerging trends.

The development of scholarly output in biology education, as traced through the analyzed database, involves at least two key historical milestones: (a) the launch of two of the three most influential journals (*CBE—Life Sciences Education* and *Biochemistry and Molecular Biology Education*) in the early 2000s, and (b) the publication of the field's most impactful works in the mid-2010s. Both milestones are relatively recent and partially account for the observed acceleration in the publication rate. Nevertheless, these works appear insufficient to consolidate a more cohesive field, as the growing number of publications remains dispersed among many authors who do not consistently engage in internationally visible collaboration, and whose work has yet to produce clearly consolidated disciplinary markers. Despite the long history of biology education as a research field and practice, and its substantial and continuous scholarly output, the centrifugal forces in the field appear to outweigh the centripetal ones.

Amidst a diverse thematic landscape that includes both specialized research niches and emerging/declining topics, the central theme and main driver of research in this field, highlighted in the most influential works, concerns students' alternative or erroneous conceptions that shape the teaching and learning of biological knowledge, along with associated epistemological perspectives. This theme continues to drive a substantial part of scholarly output, together with related Motor Themes, including psychosocial phenomena such as beliefs, knowledge, and attitudes, as well as core curricular content like evolution and natural selection. Research on these and other themes spans multiple educational levels and contexts, from elementary school to professional activity and continuing teacher training. However, it remains particularly concentrated in higher education, with a notable presence in secondary education.

The research conducted in the field is predominantly empirical, primarily utilizing survey designs, with quasi-experimental and experimental designs also notably represented. This pattern underscores a stronger methodological emphasis on descriptive rather than explanatory research. Many studies are descriptive in nature, focusing on presenting teaching techniques or instructional resources, notably including digital tools and authentic laboratory-based activities. This also reflects curricular priorities, particularly the effort to integrate pedagogical practices that mirror authentic scientific knowledge

production into biology education. Empirical research has further examined a wide range of psychological phenomena relevant to learning, employing diverse conceptual and epistemic models derived from the psychology of learning and education.

A key emerging trend from the analysis of thematic interests and contextual focus in biology education is the integration of biological knowledge with the epistemic practices of natural sciences, mathematics, and technology (STEM), particularly during the critical transition from secondary to higher education, a period crucial for familiarizing diverse student cohorts with professional biology. This points to a clear trend of integrating practical curricular and instructional reflection with theoretical epistemological reflection. Future research should therefore pursue longitudinal monitoring to examine whether this interdisciplinary integration will act as a catalyst for the structural unification of the field or whether biology education will continue to develop through relatively fragmented subdomains. Extending this bibliometric mapping to include regional and non-indexed databases would also be valuable in assessing whether the observed trends are consistent across different geographical and institutional contexts. Ultimately, tracking the evolution of key thematic clusters identified as motor themes in the present analysis will be essential for understanding how the field matures and progresses toward greater conceptual, methodological, and epistemic cohesion.

Acknowledgment. The author did not receive any specific grant, assistance, or support that requires acknowledgment.

Research Ethics: This study is a bibliometric research based exclusively on publicly available data and does not involve human subjects. In accordance with national regulations, ethical approval was not required.

Data Availability Statement. Statement. All data can be obtained from the corresponding author.

Conflicts of Interest. The author declares no conflicts of interest.

Funding. This research received no external funding.

REFERENCES

- Amarante, V., Burger, R., Chelwa, G., Cockburn, J., Kassouf, A., McKay, A., & Zurbrigg, J. (2021). Underrepresentation of developing country researchers in development research. *Applied Economics Letters*, 29(17), 1659–1664. <https://doi.org/10.1080/13504851.2021.1965528>
- Aria, M., & Cuccurullo, C. (2017). Bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of Informetrics*, 11(4), 959–975. <https://doi.org/10.1016/j.joi.2017.08.007>
- Chang, Y.-H., Chang, C.-Y., & Tseng, Y.-H. (2010). Trends of science education research: An automatic content analysis. *Journal of Science Education and Technology*, 19, 315–331. <https://doi.org/10.1007/s10956-009-9202-2>
- DeHaan, R. L. (2011). Education research in the biological sciences: A nine-decade review [Commissioned paper]. *Second Committee Meeting on the Status, Contributions, and Future Directions of Discipline-Based Education Research, National Research Council*. https://sites.nationalacademies.org/cs/groups/dbasseite/documents/webpage/dbasse_072581.pdf
- Dirks, C. (2011). The current status and future direction of biology education research. Paper presented at the *Second Committee Meeting on the Status, Contributions, and Future Directions of Discipline-Based Education Research*, held 18–19 October 2010, in Washington, DC. http://sites.nationalacademies.org/DBASSE/BOSE/DBASSE_071087
- diSessa, A. A. (2022). A history of conceptual change research. In R. K. Sawyer (Ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 114–133). Cambridge University Press. <https://doi.org/10.1017/9781108888295.008>
- Dolan, E. L., Elliott, L. S., Henderson, C., Curran-Everett, E., St. John, K., & Ortiz, A. P. (2018). Evaluating discipline-based education research for promotion and tenure. *Innovative Higher Education*, 43(1), 31–39. <https://doi.org/10.1007/s10755-017-9406-y>
- Gul, S., & Sozbilir, M. (2016). International trends in biology education research from 1997 to 2014: A content analysis of papers in selected journals. *Eurasia Journal of Mathematics, Science & Technology Education*, 12(6), 1631–1651. <https://doi.org/10.12973/eurasia.2015.1363a>

- Herak, R., Mahanal, S., Zubaidah, Z., & Novianti, V. (2025). Exploring misconceptions in biology learning: A systematic literature review. *Salud, Ciencia y Tecnología*, 5, 1743, 1-16. <https://doi.org/10.56294/saludcyt20251743>
- Hsu, J. L., Chen, A., Cruz-Hinojoza, E., Dinh-Dang, D., Roth-Johnson, E. A., Sato, B. K., & Lo S. M. (2021). Characterizing biology education research: perspectives from practitioners and scholars in the field. *Journal of Microbiology & Biology Education*, 22, e00147-21. <https://doi.org/10.1128/jmbe.00147-21>
- Jenkins, E. W. (2016). 50 years of JBE: The evolution of biology as a school subject. *Journal of Biological Education*, 50(3), pp. 229-232. <https://doi.org/10.1080/00219266.2016.1202484>
- Kloser, M. (2012). A place for the nature of biology in biology education. *Electronic Journal of Science Education*, 16(1), 1-21. <https://ejrsme.icrsme.com/article/view/10994>
- Konu Kadirhanoğulları, M., & Özay Köse, E. (2024). Bibliometric analysis of articles related misconception in biology by country and journal. *Science Insights Education Frontiers*, 22(2), 3567–3581. <https://doi.org/10.15354/sief.24.or580>
- Labov, J. B., Reid, A. H., & Yamamoto, K. R. (2010). Integrated biology and undergraduate science education: A new biology education for the twenty-first century? *CBE—Life Sciences Education*, 9(1), 10-16. <https://doi.org/10.1187/cbe.09-12-0092>
- Lo, S. M., Gardner, G. E., Reid, J., Napoleon-Fanis, V., Carroll, P., Smith, E., & Sato, B. K. (2019). Prevailing questions and methodologies in biology education research: A longitudinal analysis of research in CBE—Life Sciences Education and at the Society for the Advancement of Biology Education Research. *CBE—Life Sciences Education*, 18(1), ar9. <https://doi.org/10.1187/cbe.18-08-0164>
- Luft, J. A., Jeong, S., Idsardi, R., & Gardner, G. (2022). Literature reviews, theoretical frameworks, and conceptual frameworks: An introduction for new biology education researchers. *CBE—Life Sciences Education*, 21:rm1. <https://doi.org/10.1187/cbe.21-05-0134>
- Marín-Marín, J. A., Moreno-Guerrero, A. J., Dúo-Terrón, P., & López-Belmonte, J. (2021). STEAM in education: A bibliometric analysis of performance and co-words in Web of Science. *International Journal of STEM Education*, 8(41). <https://doi.org/10.1186/s40594-021-00296-x>
- Martín-Martín, A., Orduna-Malea, E., & López-Cózar, E. D. (2018). Coverage of highly-cited documents in Google Scholar, Web of Science, and Scopus: A multidisciplinary comparison. *Scientometrics*, 116, 2175-2188. <https://doi.org/10.1007/s11192-018-2820-9>
- Meneghini, R., & Packer, A. L. (2007). Is there science beyond English? *EMBO Reports*, 8(2), 112–116. <https://doi.org/10.1038/sj.embor.7400906>
- Mongeon, P., & Paul-Hus, A. (2016). The journal coverage of Web of Science and Scopus: A comparative analysis. *Scientometrics*, 106, 213-228. <https://doi.org/10.1007/s11192-015-1765-5>
- National Research Council. (1970). Biology and the future of man. In *The Life Sciences: Recent Progress and Application to Human Affairs* (pp. 427-470). The National Academies Press. <https://doi.org/10.17226/20497>
- National Research Council. (2012). *A framework for K-12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press. <https://doi.org/10.17226/13165>
- Nehm, R. H. (2019). Biology education research: building integrative frameworks for teaching and learning about living systems. *Disciplinary and Interdisciplinary Science Education Research*, 1(15), 1-18. <https://doi.org/10.1186/s43031-019-0017-6>
- NGSS Lead States. (2013). *Next Generation Science Standards: For states, by states*. The National Academies Press. <https://doi.org/10.17226/18290>
- Nurdin, A. M., Gofur, A., Sari, M. S., & Munzil, M. (2025). Technology-supported differentiated biology education: Trends, methods, content, and impacts. *EURASIA Journal of Mathematics, Science and Technology Education*, 21(3), em2598. <https://doi.org/10.29333/ejmste/16044>
- Özel, M. (2024). An analysis of research trends on socio-scientific issues in science education over two decades from 2004 to 2023. *Journal of Mathematics, Science and Technology Education*, 1(1), 69-83. <https://doi.org/10.12973/jmste.1.1.69>
- Permana, T. I., Husamah, H., Nurhamdani, M. I., Zaskia, A., Savitri, A., & Salsabila, D. A. (2024). Augmented reality in biology education: A systematic literature review. *Research and Development in Education*, 4(1), 630-652. <https://doi.org/10.22219/raden.v4i1.32636>

- Rahmi, S. N., Megawati, M., Alberida, H., & Fadilah, M. (2025). Assessment of biology learning outcomes in education: A systematic literature review. *Biosfer: Jurnal Pendidikan Biologi*, 18(1), 10-25. <https://doi.org/10.21009/biosferjpb.47179>
- Reid, J., Gardner, G. E., Carroll, P., Napoleon-Fanis, V., & Smith, E. (2016, November). *A history of biology education research from 2002 to 2015: A synthesis of methodological trends*. Paper presented at the Annual Meeting of the Mid-South Educational Research Association, Mobile, AL, United States.
- Rosenthal, D. (1990). What's past is prologue: Lessons from the history of biology education. *The American Biology Teacher*, 52(3), 151-155. <https://doi.org/10.2307/4449067>
- Sánchez Gómez, M. C., Cabanillas García, J. L., del Brio Alonso, I., & Verdugo Castro, S. (2025). Métodos de investigación en el área educativa. Análisis bibliométrico: estudio comparativo entre Scopus y WoS. *Revista Española de Educación Comparada*, 46, 141–172. <https://doi.org/10.5944/reec.46.2025.40201>
- Sangur, K., Zubaidah, S., & Sulisetijono (2025). A systematic literature review of mobile learning trends in biology education over ten years. *Social Sciences & Humanities Open*, 11(1), 101429, 1-26. <https://doi.org/10.1016/j.ssaho.2025.101429>
- Semilarski, H., & Laius, A. (2018). Exploring biological literacy: A systematic literature review of biological literacy. *European Journal of Educational Research*, 10(3), 1181-1197. <https://doi.org/10.12973/eu-jer.10.3.1181>
- Singer, S. R., Nielsen, N. R., & Schweingruber, H. A. (2013). Biology education research: Lessons and future directions. *CBE—Life Sciences Education*, 12(2), 129-132. <https://doi.org/10.1187/cbe.13-03-0058>