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Publication Trends in Biology Education: A Bibliometric Review of 63 Years

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ABSTRACT
Biology is a vital and relevant branch of science that has a significant impact on daily life and the overall development of societies. Many advances in biology education have transformed much pedagogy, particularly learning in the more substantial part of higher education contexts. Thus, bibliometrics can be used to depict and analyze publication trends in updating scientific datasets and knowledge in this field. This bibliometric review scrutinized the progress, trends, and updates in the Scopus database for biology education publications. The total number of publications, citations, and publication patterns over 63 years are among the bibliometric parameters examined in this review. The obtained publication lists were analyzed using VOSviewer software, which displayed the bibliographic data graphically. The current study portrayed that the number of publications on biology education has increased in recent years. This inclination is probable to continue, as evidenced by the current peak of publications trajectories. The examining publications and research areas reveal that efforts to improve biology education cover miscellaneous topics and disciplines. Researchers and educators in biology education may benefit from this bibliometric review because it provides information, concepts, thoughts, and intuitions that can be used to strengthen their theories and practices.

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Introduction

Biology is an eminent and influential science that has a tremendous impact on our lives and plays a significant role in developing societies (Özalemdar, 2019; Wallis, 2012). A wide variety of cognitive science has shown that people perceive the biological world intuitively and effectively in nuanced and systematic ways (Bustami et al., 2021; Coley et al., 2017). Cognitive science studies have exposed the nature of learning in the last half-century, in which students also build their knowledge from previous ideas and experiences (Carrió et al., 2016; Gloria et al., 2019). This happens as learning is a social activity arising from negotiating meanings between peers and teachers (Vygotsky, 1978). Therefore, biology education has ramifications for growing science awareness, delivering high-quality science, technology, engineering, and mathematics (STEM) education, and leading to significant research advancements (Driessen et al., 2020). Furthermore, biology education is a discipline of medical and veterinary education that teaches students about physiology, biochemistry, and genetics while also practicing in actual conditions (Ankhi et al., 2019; Arslan et al., 2020). Thus, new technologies must be more adequately adapted for classroom use than standard laboratory settings.

At least over the last 25 years, the many advances in biology education have transformed much of the pedagogy and learning in the most higher education context. This has been mainly mooted by a burgeoning, disciplined educational research group that has resorted to employing evidence-based teaching practices propelled by research findings (Aikens, 2020; Antonio & Prudente, 2021). Higher education is at the juncture of enabling students with a higher degree of critical thought besides proven decision-making abilities or skills (Narguizian, 2020). In line with this, biology courses must provide more than curriculum content to assist learners in acquiring relevant skills (Reiss, 2020). It is also critical in developing higher-level necessary thinking skills while also enhancing their creative and critical thinking abilities (Asniza et al., 2021; Mataniari et al., 2020). This has become ever so important as we cope with escalating environmental challenges that directly impact our lives. A case in point would face the humungous issues in this unprecedented Covid-19 pandemic. Therefore, the publication of innovative teaching materials in peer-reviewed journals by biology instructors is urgently needed to test students' knowledge of a range of biology concepts, determine student learning outcomes through interactively planned exercises, and publish results (Smith, 2018).

Recent research on biology education also calls on researchers to exploit learning theories and methodologies from other disciplines to investigate mechanisms through which students create sophisticated ideas (Parmin & Sajidan, 2019; Scott et al., 2020). At the turn of the nineteenth and early twentieth centuries, considerable attention was paid to the quality of science teaching and learning, which sparked initiatives toward discipline-based education study (Şeyda & Sözbilir, 2016). This then pivoted biology scholars to exhaustively study the complexities and vital aspects of teaching and learning in the discipline, referred to as biology education researchers (Anatürk Tombak & Ateşkan, 2019; Singer et al., 2013).

The instruction process of formal education is planned and in a changing method following the needs (Çobanoğlu & Şahin, 2009). Therefore, many reforms in biology education by teaching students to coordinate their conceptual knowledge as experts have been made through concerted efforts but methods that seek to quantify this initiative are insignificant in numbers (Bissonnette et al., 2020; Haviz et al., 2020). Consequently, critical thinking should be essentially developed to promote effective 21st-century learning, but it cannot be denied that the constructive development of essential thinking skills is still very negligible (Budiarti & Harlis, 2020). Thus, it is vital to comprehend biology education research regarding its signs of progress and current status. A likely reason is that students' interests, objectives, attitudes, concerns, and motivation all directly affect academic achievement and learning and their behaviour, which significantly impacts what students learn in biology classes (Derman, 2017; Yener et al., 2020). Access to prominent scholarly journals and publication awareness paves the way for novice researchers to consider science education extensively (Şeyda & Sözbilir, 2016). Therefore, it can be reiterated that researchers could be helped to explore the current status and future trends in this field of studies through bibliometric reviews of biology education.

The scientific community regards bibliometric analysis as a valuable and indispensable field of study since the volume of publications in most study areas has aided scholars' persuasive arguments for obtaining relevant data (Abdullah, 2021). Thus, bibliometric analysis has developed into a widespread research trend that enables the identification and classification of such analyses to produce the most remarkable results (Merigó et al., 2015). The bibliometric analysis delivered a valuable statistical and mathematical method for analyzing printed information sources and other modes of communication. Additionally, it entails a systematic assessment of specific publications or documents, including their authors, subjects, publication summaries, references, and related material.

Bibliometrics is appropriate to all research fields, and the use of bibliometric data and its implications for scientific communication necessitates extensive research. The approach described has been used in numerous research themes, including knowledge management (Gaviria-Marin et al., 2019), marine safety (Abdullah, 2021), and sports nutrition (Abdullah et al., 2022). Bibliometric analyses have also been conducted in education, for instance, augmented reality in science education (Arıcı et al., 2019), gamification in education (Swacha, 2021), chemistry education (Draman & Mohd,

2021), and physics education (Bitzenbauer, 2021). Yet, comprehensive and current bibliometric research on biology education is necessary and urgent.

This study was designed to elicit knowledge about biology education through a bibliometric review by perceiving (i) the progression of publications, (ii) influential countries, (iii) productive source titles, (iv) highly-cited papers and productive authors, (v) high-yielding publications by institutions, (vi) analysis of research areas, and (vii) mapping of biology education research. The Scopus database is used to conduct a bibliometric review of biology education publications in the current study. The investigation was performed using a document examination approach within a descriptive analysis context.

Methodology

Data Collection Process

On November 3, 2020, the Scopus database was searched for the term "biology education" in the title, abstract, and keywords. The Scopus database combines the best features of PubMed and Web of Science into one comprehensive resource. Likewise, Scopus is the only database that combines a comprehensive, expertly curated abstract and citation database with enriched data and cross-referenced scholarly literature from multiple disciplines. As a result, between 1957 and 2020, 1028 publications on biology education were discovered. The author has not determined the initiated year in this study. It is possible to divide the 1028 publications into 846 journal articles, 154 conference papers, 19 books, and nine-book series. There are 996 English-language publications, but fewer than ten in other languages, including Turkish, Bulgarian, and German. Language is irrelevant in bibliometric analysis because the analysis is attentive to publication patterns that do not require an in-depth reading of an article, as in conducting systematic literature reviews or scoping reviews.

Data Analysis

The data analysis began with the export of the data in Comma-separated Values (CSV) and Research Information Systems (RIS) formats from the Scopus database to Microsoft Excel, Publish or Perish (PoP), and VOSviewer software. The author's name, the document's source, the year of publication, the title, the country, the journal, the subject area, and the type of article were all included in the retrieved data. The VOSviewer software, developed by Van Eck and Waltman (2010), made it possible to conduct a bibliometric review and map of publications in biology education research. Visual elements in VOSviewer were consequential from mapping techniques that convert CSV data into diagrams or clusters (Van Eck & Waltman, 2010; 2019). These mapping techniques could aid researchers in analyzing specific data points such as author, location, institution, citations, and additional refining features.

Results and Discussion

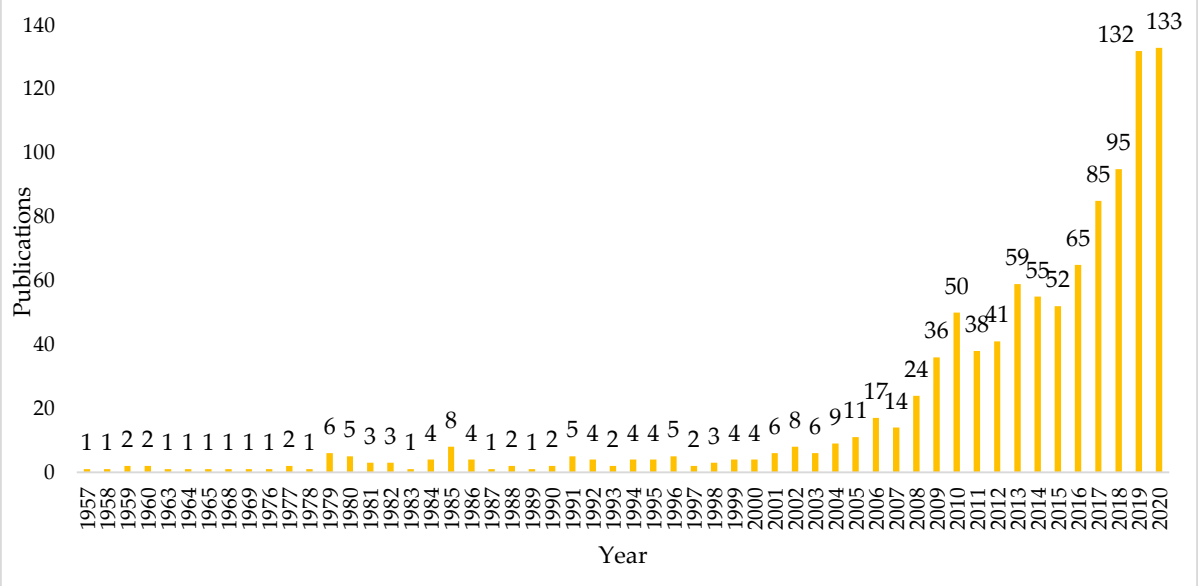
The Progression of Publications

Figure 1 shows that the number of publications in biology education increased by more than ten in 2005. More precisely, after three decades, biology education publications started to progress, accounting for 89.11% of total publications. In 2010, the number of publications upsurged by more than 50 documents, but the number of publications declined marginally in 2011 and 2012, with 38 and 41 publications, respectively. Though there were only 53 documents in 2013, by 2020, the number of publications had grown steadily with 133 publications. After six decades, it is depicted that 2020 has been a significant publication year for biology education. The higher numbers indicated are primarily a result of the rising keenness in biology education. This is because currently, our world's extinction

rate is between 100 to 1000 times higher than expected due to human effects on the environment, namely habitat alteration and degradation (Reiss, 2020). Also, biology education plays a vital role in responding to the current and future crises, for example, the Covid-19 pandemic. An additional compelling argument is that researchers' wide-reaching and the growing number of publications in the Scopus database on biology education influence the number of publications in this field. Hence, the ever-increasing number of articles devoted to biology education can be elucidated as evidence that this discipline is essential and well-regarded among academics.

Figure 1

The Progression of Publications



Influential Countries

In this topic, citation network analysis implemented a classification of the authors' countries that contributed most to biology education. As illustrated in Figure 2, the citation network spans 32 countries and is congregated into nine clusters; the countries are represented by nodes, with a greater number of nodes indicating a more significant number of publications. The link strength denotes the lines among the countries. This study revealed that the United States of America has more significant nodes with 4908 citations concerning citation networks. The United Kingdom is ranked second with 791 citations, and Australia is ranked third with 785 citations. These countries have established a critical role in fostering scientific collaboration in biology education and serving as a conduit for information.

The top ten productive countries are shown in Table 1. With 382 publications in biology education, the USA became the most productive country for 63 years. By comparison, Indonesia is the second most productive country, producing 159 publications, followed by Germany, which published 63 documents. According to this study, Indonesia is the only Asian country in the top ten that has published a substantial number of biology education. The Indonesian government is working hard to provide in-service teachers and governmental and non-governmental groups with professional development opportunities to consider teachers' needs when planning biology education content (Faisal & Martin, 2019). Yet, Indonesia received 198 citations in total, less than Germany. This discovery will aid future researchers in determining the most effective strategies or measures for increasing the citations of biology education publications by Indonesian authors.

Figure 2

The Nexus of Citation among the Countries

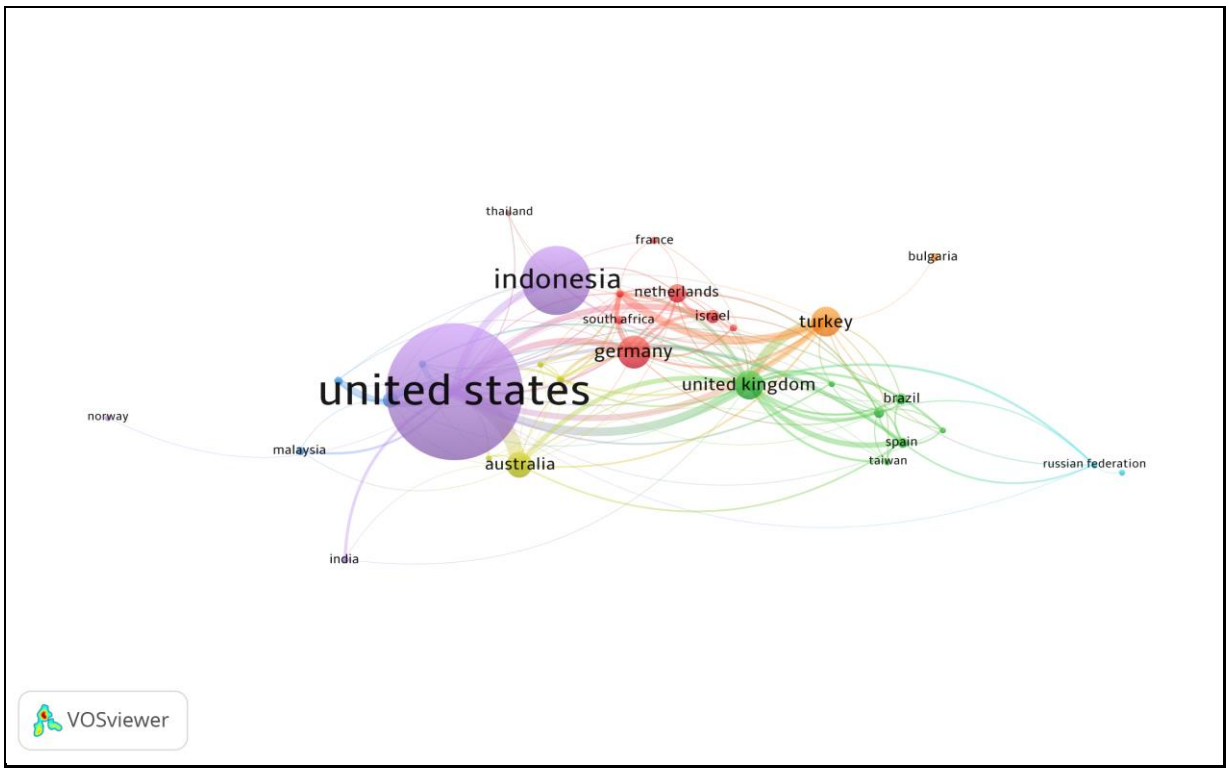


Table 1

Ten Most Influential Countries to Publish Biology Education Research

Rank	Country	Publications	Citations	Total Link Strength
1	USA	382	4908	157
2	Indonesia	159	198	21
3	Germany	63	711	59
4	Turkey	54	444	68
5	United Kingdom	53	791	106
6	Australia	46	785	54
7	Netherlands	30	272	26
8	Canada	25	291	27
9	Israel	20	338	31
10	Brazil	17	125	14

Productive Source Titles

In the design of a publication, one of the essential variables to consider is productivity. Table 2 shows a ranking of the most frequently published titles in the field of biology education. A list of 38 source titles with at least four publications is presented. CBE Life Sciences Education and the Journal of Physics Conference Series became the most fruitful journals in this field, with 88 publications. Surprisingly, conferences are vital for scientific communication pertinent to biology education. It is confirmed that conference proceedings must be considered when evaluating research in biology

education. The Journal of Biology Education is ranked second, and the American Biology Teacher is positioned at the third.

This study found that CBE Life Sciences Education obtained the most citation (1699) in the last six decades, followed by the Journal of Biological Education (929 citations) and the International Journal of Science Education (863 citations). Consequently, these journals have contributed advantageous knowledge to enable prospective researchers to source them for future biology education studies. It is worth noting that even the Journal of Turkish Science Education published four research papers in biology education from 2009 to 2020. However, this journal has a progressive development and continuous improvement with the best of quartile in 2019 being Second Quartile (Q2); SCImago Journal Rank (SJR) is 0.588, Cite Score is 2.8, and Source Normalized Impact per Paper (SNIP) is 1.821 (Scopus preview, 2020). It is indicated that the Journal of Turkish Science Education is among the leading biology education publications, one of which is being reviewed in this study.

Table 2

Productive Source Titles in Biology Education

Rank	Source Titles	Publications	Citations	Total Link Strength
1	CBE Life Sciences Education	88	1699	83
	Journal of Physics: Conference Series	88	45	14
2	Journal of Biological Education	85	929	74
3	American Biology Teacher	75	268	23
4	Biochemistry and Molecular Biology Education	63	244	17
5	International Journal of Science Education	62	863	61
6	Research in Science Education	28	495	40
7	Evolution: Education and Outreach	17	132	24
8	Eurasia Journal of Mathematics, Science and Technology Education	16	201	32
9	AIP Conference Proceedings	15	13	2
	Bioscience	15	227	18
	International Journal of Instruction	15	52	3
	Journal of Baltic Science Education	15	68	18
10	Jurnal Pendidikan IPA Indonesia	14	41	5
11	Cell Biology Education	11	138	10
12	Education Sciences	10	26	17
	Journal of Microbiology and Biology Education	10	10	11
	Journal of Research in Science Teaching	10	175	12
13	Science Education	8	109	16
14	Journal of Science Education and Technology	7	31	11
	Science and Education	7	112	12
15	Bulletin of Mathematical Biology	6	4	2
	Chemistry	6	3	2

	International Journal of Science and Mathematics Education	6	94	10
	Procedia - Social and Behavioral Sciences	6	22	0
16	Asia-Pacific Forum on Science Learning and Teaching	5	3	1
	Biochemistry and Molecular Biology Education: A Bimonthly Publication of The International Union of Biochemistry and Molecular Biology	5	20	1
	International Journal of Environmental and Science Education	5	42	8
	IOP Conference Series: Materials Science and Engineering	5	4	0
	Molecular Biology of The Cell	5	4	6
17	Biotechnology and Biotechnological Equipment	4	12	3
	Cultural Studies of Science Education	4	33	0
	Energy Education Science and Technology Part B: Social and Educational Studies	4	72	3
	Hacettepe Egitim Dergisi	4	11	0
	Journal of Turkish Science Education	4	1	5
	PLOS Computational Biology	4	19	1
	PLOS One	4	39	1
	Soviet Education	4	1	0

Highly-cited Papers and Productive Authors

The next step in this study is to identify the papers that have received the most citations in biology education. It is shown in Table 3 that five of the most frequently referenced documents are included to illustrate the findings. Although various factors contribute to the critical importance of a paper, the number of citations is generally regarded as a fair representation of their work's influence and popularity within the scientific community (Merigó & Yang, 2017).

As indicated in Table 3, the most cited work was taken up by Palsson (2006), with 569 citations for an article entitled "Systems biology: Properties of reconstructed networks". The second-ranked is a publication written by Auchincloss et al. Their paper was published in 2014, with 251 citations for an article entitled "Assessment of course-based undergraduate research experiences: A meeting report". Significantly too, as per the citations rate per year, an average of 41.83 citations per year was dominated by Auchincloss et al. (2014). The insights provided by the preceding two publications aided in identifying the most prominent biology education researchers for consideration in future studies.

Another critical bibliometric analysis is defining the most productive authors. Table 4 reflects seven authors with at least ten publications related to biology education. The most productive author found in this study is Dolan, E. L. He is affiliated with the University of Georgia, Athens, USA. He had published 12 publications. The second-ranked goes to Rahmat, A., affiliated with Universitas Pendidikan Indonesia, Bandung, Indonesia, with 11 academic works. The third-ranked with ten publications was shared with five authors, namely (i) Bogner, F. X. from Universität Bayreuth, Bayreuth, Germany, (ii) Prokop, P. from Slovak Academy of Sciences, Bratislava, Slovakia, (iii)

Redjeki, S. from Universitas Pendidikan Indonesia, Bandung, Indonesia, (iv) Reiss, M. J. from UCL Institute of Education, London, United Kingdom, and (v) Zubaidah, S. from Universitas Negeri Malang, Malang, Indonesia. It is noteworthy that over the last 63 years, Indonesian authors associated with Universitas Pendidikan Indonesia have been the most active authors in biology education.

Table 3

The Top Five Documents Most Often Cited

Rank	Authors	Year	Title	Source	Citation	Cites Per Year
1	B.Ø. Palsson	2006	Systems biology: Properties of reconstructed networks	Systems Biology: Properties of Reconstructed Networks	569	40.64
2	L.C. Auchincloss, S.L. Laursen, J.L. Branchaw, K. Eagan, M. Graham, D.I. Hanauer, G. Lawrie, C.M. McLinn, N. Pelaez, S. Rowland, M. Towns, N.M. Trautmann, P. Varma-Nelson, T.J. Weston, E.L. Dolan	2014	Assessment of course-based undergraduate research experiences: A meeting report	CBE Life Sciences Education	251	41.83
3	S.E. Brownell, K.D. Tanner	2012	Barriers to faculty pedagogical change: Lack of training, time, incentives, and tensions with professional identity?	CBE Life Sciences Education	221	27.63
4	G.L. Moseley, D.S. Butler	2015	Fifteen Years of Explaining Pain: The Past, Present, and Future	Journal of Pain	198	39.6
5	P. Sengupta, J.S. Kinnebrew, S. Basu, G. Biswas, D. Clark	2013	Integrating computational thinking with K-12 science education using agent-based computation: A theoretical framework	Education and Information Technologies	179	25.57

Table 4

Seven Most Productive Authors in Biology Education

Author	Affiliation	Publications
Dolan, E.L.	University of Georgia, Athens, USA	12
Rahmat, A.	Universitas Pendidikan Indonesia, Bandung, Indonesia	11
Bogner, F.X.	Universität Bayreuth, Bayreuth, Germany	10
Prokop, P.	Slovak Academy of Sciences, Bratislava, Slovakia	10
Redjeki, S.	Universitas Pendidikan Indonesia, Bandung, Indonesia	10
Reiss, M.J.	UCL Institute of Education, London, United Kingdom	10
Zubaidah, S.	Universitas Negeri Malang, Malang, Indonesia	10

High-yielding Publications by Institutions

Table 5 offers a list of institutions with at least ten biology education publications. The findings of this study were fascinating because two Indonesian universities, Universitas Pendidikan Indonesia and Universitas Negeri Malang, were among the top performers. Universitas Pendidikan Indonesia had 35 publications and heads as the most prominent institution in biology education. Universitas Negeri Malang had 23 publications. These universities were ranked over the top universities in the USA, such as Purdue University, the University of Wisconsin-Madison, and the University of Georgia. The relationships between the most productive authors and influential institutions were verified using Table 4 and Table 5. Captivatingly, in this study, there are two outstanding researchers in biology education; they are Rahmat, A. and Redjeki, S. The authors are Indonesian researchers associated with Universitas Pendidikan Indonesia, Bandung, Indonesia. Another eminent author is Zubaidah, S., an Indonesian researcher attached to the Universitas Negeri Malang.

Table 5

Ranking of the Institutions with a Minimum of Ten Publications

Institution	Publications
Universitas Pendidikan Indonesia	35
Universitas Negeri Malang	23
Purdue University	17
University of Wisconsin-Madison	17
University of Georgia	16
University of Colorado Boulder	15
Utrecht University	14
Stanford University	13
University of Melbourne	13
University of Minnesota Twin Cities	12
Universitas Negeri Yogyakarta	12
University of California, San Diego	11
Monash University	10
Universität Bayreuth	10
San Francisco State University	10
North Dakota State University	10

Analysis of Research Areas

It is also critical to conduct a literature review of relevant studies. This method aids in the identification of the vital disciplines under which biology education research has been undertaken. Table 6 lists 14 subject areas in which there are at least ten Scopus-classified publications on biology education.

Table 6

The 14 Research Areas Pertinent to Biology Education

Rank	Subject Area	Publications
1	Social Sciences	668
2	Agricultural and Biological Sciences	248
3	Biochemistry, Genetics and Molecular Biology	240
4	Physics and Astronomy	114
5	Computer Science	73
6	Engineering	50
7	Mathematics	50
8	Psychology	39
9	Environmental Science	30
10	Immunology and Microbiology	25
11	Medicine	25
12	Arts and Humanities	21
13	Neuroscience	20
14	Materials Science	10

With 668 publications in biology education, the discipline of "Social Science" has been discovered to be the most extensively researched area. Due to the fact that the subject of this review is relevant from a social science perspective, which focuses on the relationship between humans and their social interactions, this result was expected. The second field of study is "Psychology," which has produced 39 publications. As a result, both fields are concerned with studying human behaviour in addition to having a significant impact on students' learning processes. Another related research area is "Agricultural and Biological Science," with 248 publications. Indeed, "Agricultural and Biological Research" is one of the many biology education areas that has been taught in the biology education syllabus.

Mapping Biology Education Research with VOSviewer

This section provides a visual depiction of the conclusions drawn in the preceding sections. The VOSviewer software evaluates co-citation, bibliographic coupling, and the author's keyword's co-occurrence. The co-citation examines how two documents are cited in conjunction with other documents. Two publications are considered co-cited if a third publication mentions both of them. The results of a co-citation analysis conducted by various journals are depicted in Figure 3. The criteria for inclusion in this section is that the number of citations exceeds 20. As a result, 19 source titles satisfy this requirement. Before beginning this analysis, the source's title's similar name was thoroughly examined and edited in thesaurus files. This step is critical to avoiding duplication of sources with similar titles.

With a total link strength of 6942, the International Journal of Science Education is the most-cited journal. It was grouped in a similar cluster with the Journal of Research in Science Teaching, the Research in Science Education, Science and Education, and the Journal of Biological Education. However, concerning the frequency of being published, the International Journal of Science Education was fifth-ranked.

Additionally, it is worthwhile to investigate how an institutional bibliographical coupling connects the most productive institutions. Bibliographic coupling occurs when two documents both

cite one or more other credentials. The greater the number of references shared by two publications, the stronger the bibliographic coupling between them (Van Eck & Waltman, 2019). In this review, the bibliographic coupling of the most prolific institutions in biology education is shown in Figure 4. A bibliographic coupling analysis was conducted using four minimum numbers of publications and four citations. Additionally, seven institutions have chosen to collaborate on this bibliographic coupling. It is indicated that there are three clusters: blue, representing the Department of Biology Teaching, the University of Minnesota in the USA, Red represents two universities, the Department of Science Teaching, the Weizmann Institute of Science, Israel, and the Department of Biological Sciences, Purdue University, USA. Finally, the green cluster represents the Department of Biology, San Francisco State University in the USA, and the University of Trnava, Slovakia. Accordingly, these two institutions in the USA are the driving force behind both internal and external networking in the USA.

The VOSviewer made it possible to examine the keywords that appeared the most frequently in a collection of publications. The keywords used in this study were mapped by means of VOSviewer. The VOSviewer topographies such as colour, node sizes, font sizes, and the thickness of the connecting lines in Figure 5 are used to show the relationship between keywords. In Figure 5, the keyword "biology education" in a green cluster is the most frequent keyword. The keywords "biology", "education", "science education", and "evolution are the other highly frequently used keywords in terms of co-occurrence. From now, it could be confirmed that research on biology education has an interdisciplinary perspective. It inter-relates with a considerable array of other fields: evolution, nature of science, environmental education, curriculum development, and bioinformatics.

Figure 3

Co-citation among Biology Education Journals

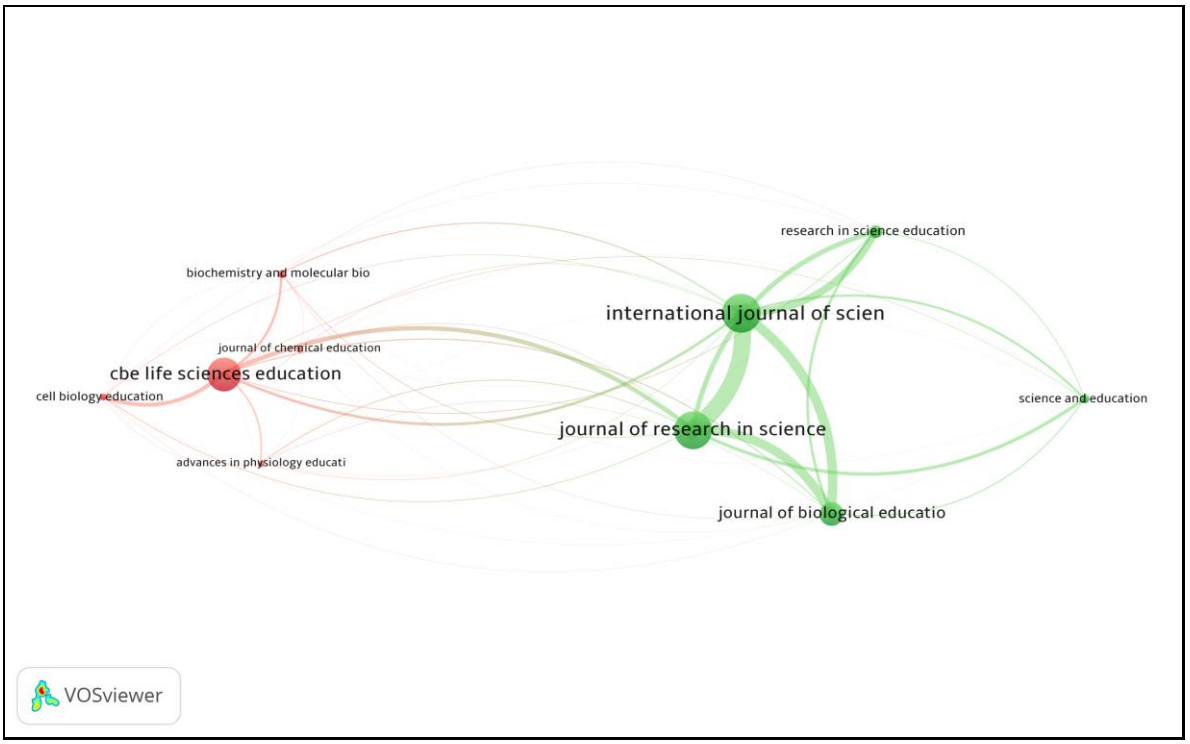


Figure 4

Bibliographic Coupling of the Most Productive Institutions

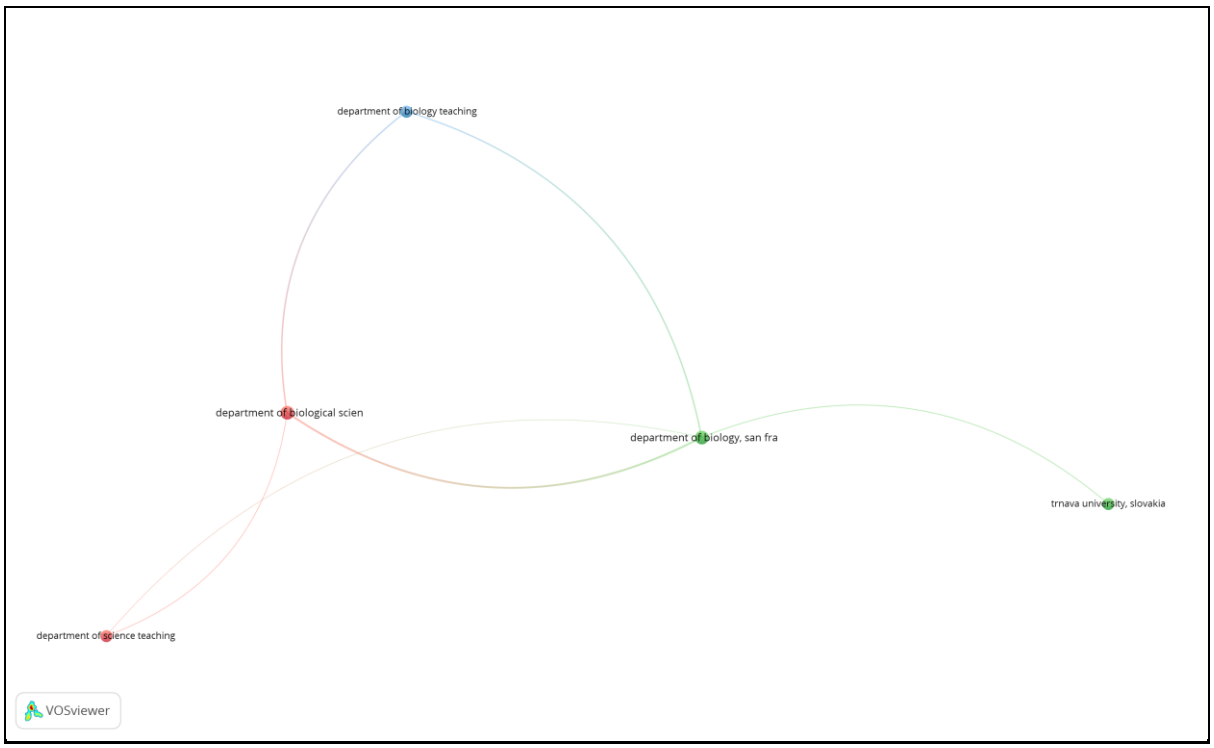
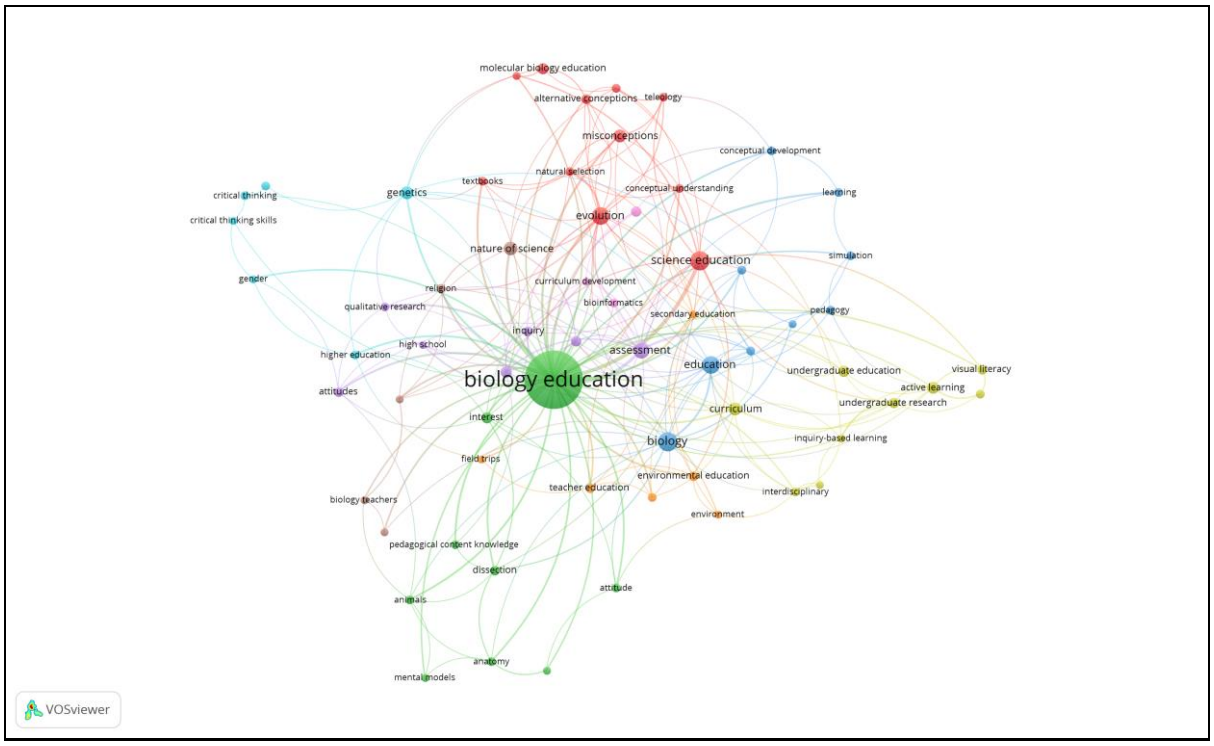


Figure 5

The Nexus of Authors' Keywords



Conclusion

This bibliometric review aims to promote the examination and integration of established directions in biology education research in light of emerging trends. Following a bibliometric review of 63 years of biology education, the researcher discovered the following data for readers, educators, and researchers:

1. Publications in the field of biological education have steadily increased over the last six decades, reaching a record high of 133 publications in 2020.
2. The USA, Indonesia, and Germany were the most productive countries, followed by Turkey. Also noteworthy is that Indonesia has been identified as one of the developing countries actively engaged in biology education research.
3. The CBE Life Sciences Education and the Journal of Physics Conference Series seem to be the most influential journals in biology education. Interestingly, even the Journal of Turkish Science Education has published four articles in biology education. However, the Journal of Turkish Science Education is among the leading biology education publications, one of which is being reviewed in this study
4. This study's leading institutions were the Universitas Pendidikan Indonesia and the Universitas Negeri Malang, both ranked first and second, respectively. The Universitas Pendidikan Indonesia had 35 publications to its credit and was the leader of the most prestigious institutions in biology education.
5. Dolan, E.L. affiliated with the University of Georgia, Athens, USA, is the most productive author with 12 publications.
6. "Social Science" became the most researched area, with 668 publications in biology education. Also, research on biology education has an interdisciplinary perspective. It is inter-related with a considerable array of other fields: evolution, nature of science, environmental education, curriculum development, and bioinformatics.

Bibliometric studies make it possible to project or provide insights into the state of the art of a particular field or subject. Nonetheless, some constraints related to the analysis approach used and how records were classified must be considered. In this regard, it is essential to note that other databases, such as the Web of Science (WoS) or Google Scholar, could have been used for the bibliometric review. Also, the essence of a bibliometric review per se is minimal. Only publications that meet the search criteria and refining specifications set out in the methodology ("biology education") have been included. This is the main shortcoming of this study, limiting empirical findings and not allowing various organizations to fully understand biology education. Further studies should be conducted to determine the trend of biology education publications in a tangible context, such as biology education programs or interventions and biology education based on specific targeted groups, academic content or program syllabus, educational pedagogy, teaching personnel, resources, and assessment.

It is unquestionably necessary to implement progressive biology education to promote and develop critical biological knowledge and skills. This is critical in reinforcing the fundamental understanding of biology education that will benefit individual lives. To that end, this bibliometric review provided information, concepts, thoughts, and intuitions that can be used to strengthen biology education theories and practices. Consequently, future researchers and educators will better understand how to identify critical information for evaluating or investigating in-depth biology education.

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