

The Evolving Landscape of Biochemistry and Molecular Biology Education: A Bibliometric Analysis of Trends, Omics Integration, and Future Directions

Bingli Wu ¹, Xinyue Tan¹, Zepeng Du ²

¹Department of Biochemistry and Molecular Biology, Shantou University Medical College, Shantou, 515041, People's Republic of China; ²Department of Central Laboratory, Shantou Central Hospital, Shantou, 515041, People's Republic of China

Correspondence: Bingli Wu, Email blwu@stu.edu.cn

Purpose: This study aims to comprehensively analyze the evolution of Biochemistry and Molecular Biology (BMB) education research from 2000 to 2025, with a specific focus on identifying global trends, research hotspots, term networks, and the integration of omics technologies into curricula. The goal is to understand the shifting educational landscape and address the attention needed in practical application and interdisciplinary approaches.

Materials and Methods: The analyses were conducted on 1237 English-language articles focusing on BMB education, which were retrieved from the Web of Science Core Collection database, covering publications from January 2000 to December 2025. Two visualization and clustering tools (CiteSpace and VOSviewer) were utilized to conduct the core analyses, including term frequencies, keyword co-occurrences, thematic clustering, and temporal timeline evolution analysis.

Results: Publication output has grown steadily, with a sharp spike post-2020, which indicates growing global attention in BMB teaching. Key journals including *Biochemistry and Molecular Biology Education* and *Journal of Chemical Education* have played a leading role in driving the dissemination of relevant research. Through co-occurrence network mapping and clustering analyses, prominent themes were identified, include “active learning”, “medical student education”, and “biochemistry course design”. The cluster “biochemistry course” dominated the timeline from 2000 to 2025, reflecting a sustained and strong emphasis on BMB instructional design. Our analyses further revealed a pivotal paradigm shift in the field: omics technologies (genomics, proteomics, and metabolomics) and associated bioinformatic tools have evolved from niche, emerging educational components to core pillars that bridge traditional BMB curricula and modern data-driven research practices.

Conclusion: The findings underscore significant progress in BMB education research, driven by technological advancements and interdisciplinary approaches. Despite the explosive growth of omics research and its wide applications across the life sciences, yet they remain significantly underprioritized in BMB education curricula. Future directions should prioritize technology-driven curriculum enhancements, cross-sector collaboration, and policy support to address evolving healthcare and scientific demands.

Keywords: biochemistry and molecular biology education, bibliometric analysis, educational research, omics curriculum

Introduction

Biochemistry and Molecular Biology (BMB) serves as a core foundational course in the life sciences, focusing on the structure, function, metabolism, and genetic information transfer of biological molecules.¹ As the new century progresses, life sciences and biotechnology, particularly BMB, have emerged as a global priority for research and development initiatives across numerous countries.^{2,3}

Omics technologies have evolved significantly over the past two decades, which has greatly improved our understanding of cellular and molecular processes within complex tissues and organisms. The representation of omics technologies in textbooks is crucial for students to gain a comprehensive understanding of these cutting-edge advancements. To achieve this, textbooks should include detailed chapters on each omics field, covering their principles, methodologies, applications, and the latest developments.⁴ Ouyang et al designed a genomics curriculum by incorporating the Presentation-Assimilation-

Discussion (PAD) pedagogy and providing students with opportunities for hands-on real data analysis.⁵ Brown et al conducted a survey among students in allied health disciplines at Texas Woman's University (TWU) to assess their understanding, attitudes, and perceived necessity for “omics” education in their future careers. The results revealed that approximately two-thirds to three-quarters of the respondents indicated a strong interest in gaining more knowledge and recognized the importance of omics in their disciplines, providing them a confidence to perform omics teaching in all allied health curricula.⁶

Bibliometrics is a valuable quantitative method for analyzing scientific research output by examining the information in the articles published in internationally peer-reviewed journals.⁷ As early as 2001, Wood carried out an analysis of the teaching methods for BMB over a span of 50 years, from 1950 to 2000.⁸ A bibliometric study of the Brazilian journal of Biochemistry Education (JBE) examined 117 articles published over 15 volumes from 2001 to 2017. This analysis revealed that only four articles focused on undergraduate courses, with 87.0% of the articles presenting methodological strategies for teaching biochemistry (51.3%) and laboratory exercises (18.8%), alongside other niche topics.⁹

While several bibliometric studies have mapped broad trends in BMB education, including curriculum design, pedagogical approaches, and student learning outcomes, none have specifically focused on the integration of omics technologies into BMB curricula.¹⁰ This study therefore aimed to perform a comprehensive bibliometric analysis of the scientific literature in the field of BMB education, to understand the overall landscape of BMB education trends and provide a view of omics application in BMB education.

Materials and Methods

Materials

The Web of Science (WOS) Core Collection is a recognized online database that offers a consistent and current dataset for scientific research and analysis. A general and a more specific literature search strategy were applied in this study, respectively. The first search query was employed: (TS=(“biochemistry and molecular biology” OR biochemistry OR “molecular biology”) AND TS=(“*omics” OR “multi-omics”) AND TS=(learn* OR teach* OR method* OR educat* OR skill* OR course* OR class* OR pedagog* OR curricul* OR assess*) AND PY=2000–2025 AND LA=English AND DT=Article) NOT DT=Review NOT TS=(clin* OR therap* OR medic* OR “patient education”). To find the specific articles about the omics teaching in BMB education, the second search strategy was applied: (TS=(“biochemistry” OR “molecular biology”) AND (“education” OR “pedagogy” OR “teaching”)) AND TS=(omics OR “genomics” OR “proteomics” OR “metabolomics” OR “transcriptomics”) AND PY=2000–2025 AND LA=English AND DT=Article) NOT DT=Review NOT TS=(clin* OR therap* OR medic* OR “patient education”). For these two research strategies, only records meeting the following criteria were included: document type limited to “article” and publication language restricted to English. Records categorized as “review”, “conference paper”, and “book chapter” were excluded from the analysis. Additionally, the search timeframe was set from January 1, 2000, to December 31, 2025.

To ensure rigorous retrieval quality, two independent authors conducted and verified the search queries and results through a dual-review process. Records focused primarily on clinical/therapeutic studies or patient education were excluded from the dataset.

A total of 1237 bibliographic records were retrieved via the first search strategy, and 57 via the second, all in the “full records” TXT format from the Web of Science (WoS) database. The extracted metadata included titles, authors, affiliated institutions, abstracts, country of origin, source journals, total citation counts, publication years, author-assigned keywords, and other relevant fields.

Terms and Keywords Visualization Analyses

Visualization plays a critical role in bibliometric analysis, as it enables intuitive observation of collaborative networks, research hotspots, and disciplinary evolution trends through visual maps. The retrieved data were imported into the CiteSpace (version 7.0.0) software¹¹ or VOSviewer (version 1.6.20) software,¹² to produce visualized maps to analyze frequent terms from title and/or abstract, keywords, respectively.

In this study, the CiteSpace parameters were configured as follows: time slicing was set from January 1, 2000, to December 31, 2025, with one year per slice; links defined by strength (cosine) and scope (within slices); selection criteria

based on the g-index with the k-value set to 25; and pruning methods including pathfinder, pruning of the sliced network, and pruning of the merged network.

The term source and node types were adjustable based on specific requirements. The analysis methods employed included co-occurrence, clustering, and burst detection. The visualization types produced included histograms, cluster views, timelines, and collinearity diagrams. All clusters were labeled using keywords, and the log-likelihood rate (LLR) served as the clustering algorithm. In bibliometric analysis, a modularity Q-value (clustering module value) greater than 0.3 is generally accepted as indicating a statistically significant clustering structure. For silhouette values, an S-value above 0.5 typically signifies reasonable clustering validity, while an S-value exceeding 0.7 denotes highly convincing, robust clustering. Additionally, synonymous terms were merged in the final analytical visualizations based on contextual relevance to ensure consistency in keyword representation.

Results

The Basic Statistics Analyses of the 1273 Papers in This Study

As shown in [Figure 1A](#), the number of published articles has shown a steady increase over the years. Starting with just one article in 2002, the count rose to 23 in 2003. A notable increase in publication metrics emerges every few years. In 2021, the number reached 93. In 2024, there was a substantial increase to 122 publications. There were 116 articles published in 2025, indicating continued growth in publication activity about BMB education.

The list presented the top 20 journals with the highest number of published articles ([Figure 1B](#)). Among them, “BIOCHEMISTRY AND MOLECULAR BIOLOGY EDUCATION” led with 269 articles, followed by “JOURNAL OF CHEMICAL EDUCATION” with 130 articles. Other notable journals included “CBE-LIFE SCIENCES EDUCATION” and “PLOS ONE”, each with 22 articles. As for other eligible academic journals in the biology and chemistry education domain, we identified 32 matching publications in CHEMISTRY EDUCATION RESEARCH AND PRACTICE, alongside 27 matching publications in AMERICAN BIOLOGY TEACHER.

[Figure 1C](#) shown the top 20 research areas based on the research fields of published articles, along with their respective counts. “Biochemistry & Molecular Biology; Education & Educational Research” was at the forefront with 269 articles, indicating a strong focus on both scientific inquiry and educational methodologies within this field. “Chemistry; Education & Educational Research” also had a substantial presence with 130 articles, suggesting a combined interest in chemical science and pedagogy.

The top 20 WOS categories by the number of published articles were indicated in [Figure 1D](#). “Biochemistry & Molecular Biology; Education, Scientific Disciplines” led with 269 articles, highlighting the academic community’s high willingness to publish relevant educational research on this subject. “Chemistry, Multidisciplinary; Education, Scientific Disciplines” and “Multidisciplinary Sciences” had 130 and 57 articles, respectively, indicating the academic community’s consistent emphasis on multidisciplinary-oriented educational research.

Visualization and Clustering of Terms from Titles, Abstracts, and Keywords in BMB Education Literatures by Citespace

Title Term Co-Occurrence Networks in BMB Education: Clustered by Citespace

To obtain the main idea from these education papers, their titles were analyzed and visualized by Citespace. In the center of the map ([Figure 2A](#)), the term “molecular biology” stood out prominently, connected by lines to other related terms such as “biochemistry course”, “active learning” and “teaching biochemistry”. The network of nodes and links visualized the co-occurrence relationships among these key terms in the literatures. The small squares scattered around the main network represented individual literature sources or nodes with less significant connections.

The visualization displayed several distinct clusters, each representing by a different color and labeled with a thematic keyword or phrase ([Figure 2B](#)). Cluster “biochemistry course” related to the curriculum of biochemistry, containing “central dogma” and “active learning”. Cluster “molecular biology” indicated a focus on instructional aspects of biochemistry, comprising “teaching biochemistry” and “biochemistry course”. These clusters illustrated different themes emerging from the title analysis.

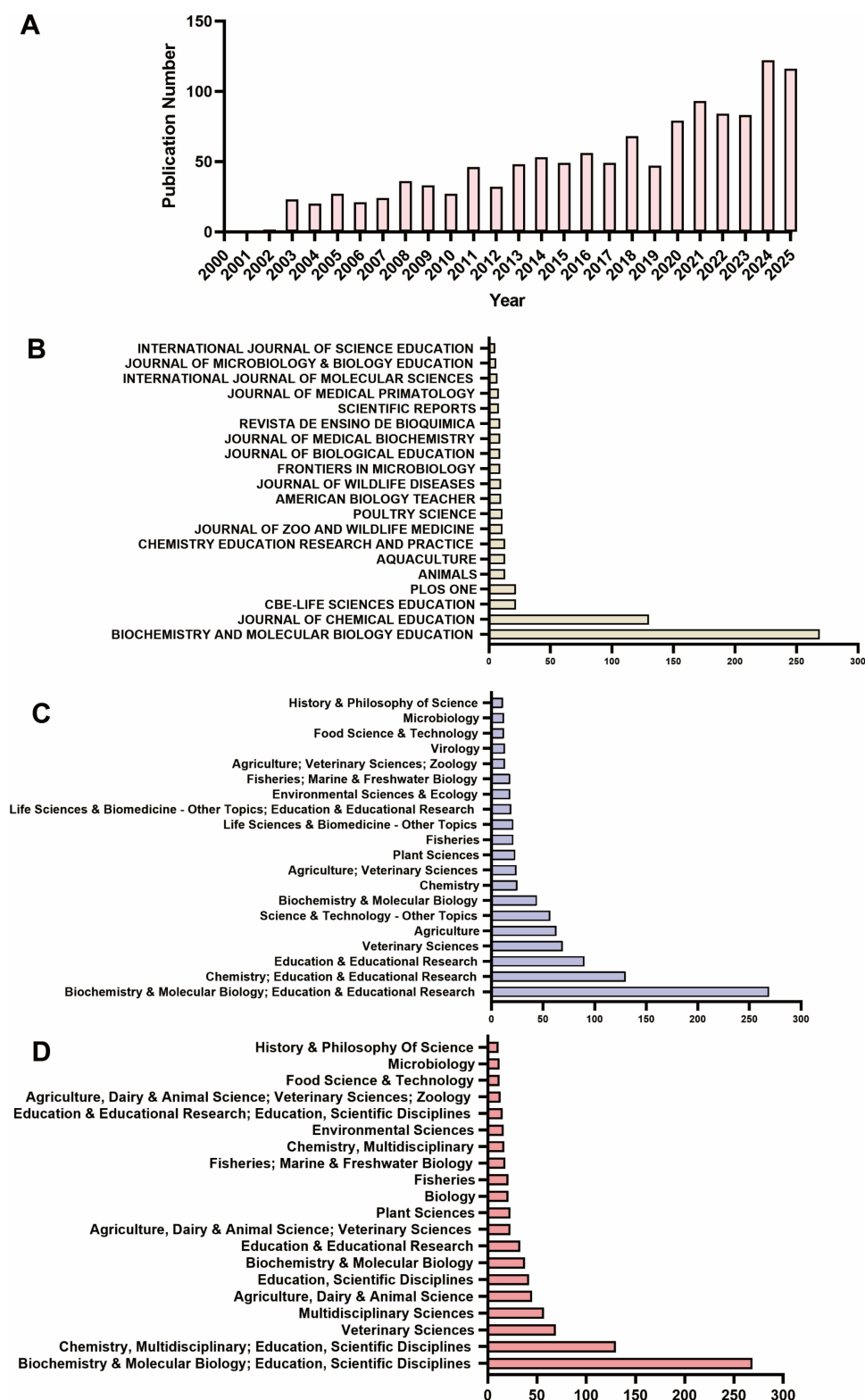


Figure 1 The basic Statistics analyses of the literatures in this study. **(A)** The number of published articles has shown a steady increase over the years. **(B)** The top 20 journals with the highest number of published articles. **(C)** The top 20 research areas based on the research fields of published articles. **(D)** The top 20 Web of Science (WOS) categories by the number of published articles were indicated.

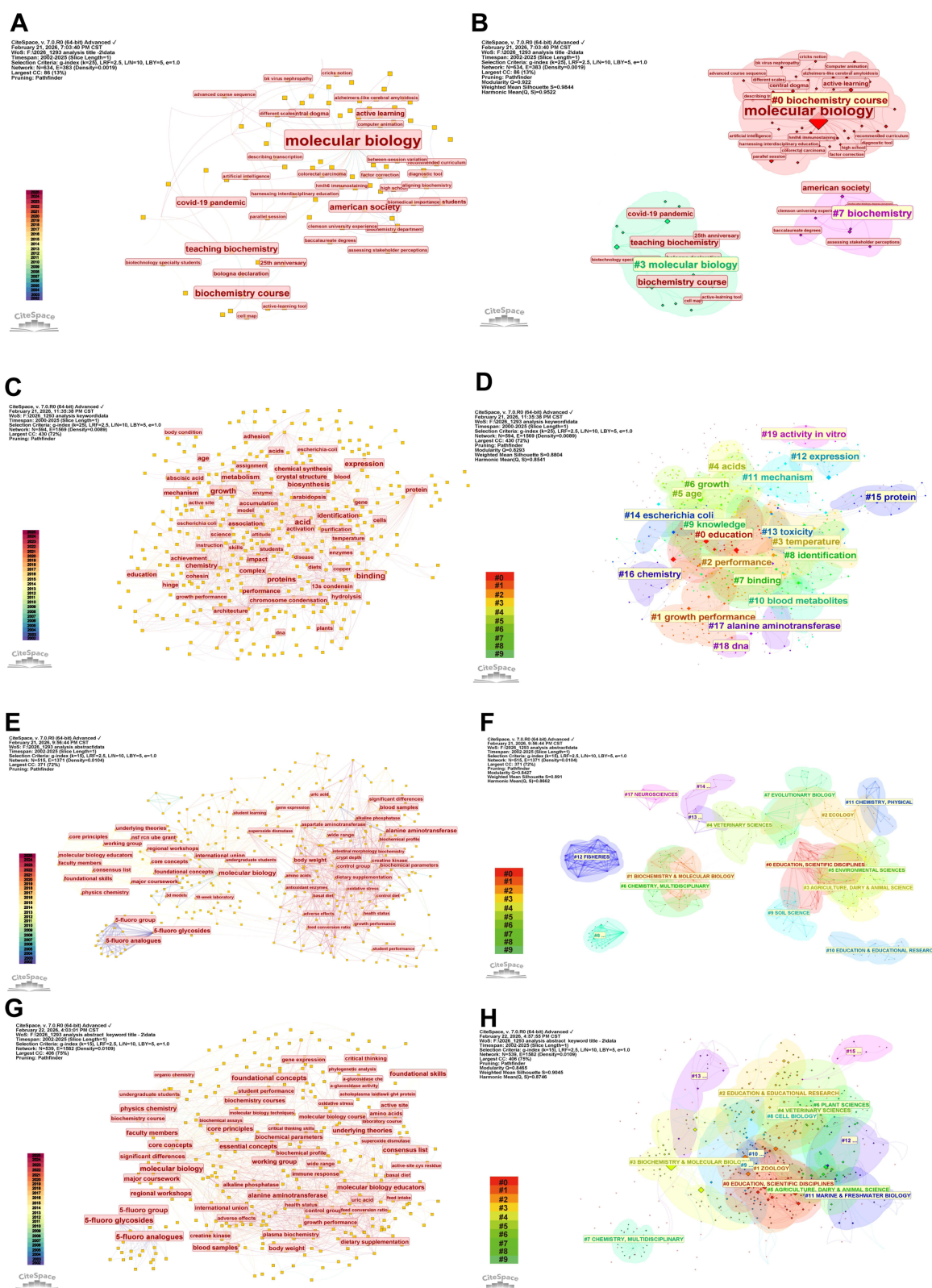


Figure 2 The terms in the titles, abstracts and keywords from the BMB education literatures were summarized and visualized by CiteSpace. (A) The network of terms from the titles. (B) The visualization displayed several distinct clusters for the title network, each represented by a different color and labeled with a number and a theme. (C) The visualization shown a network of keywords from BMB papers, with each keyword represented as a node. (D) The keyword network was generated containing 18 significant clusters. (E) Each node represented a significant concept or entity extracted from the abstracts. (F) The high frequency terms from literature abstracts were clustered. (G) Significant terms from the titles, abstracts, and keywords of the collected literatures. (H) The spectral clustering algorithm was employed to group terms in (G) to illustrate the research frontiers related to specific knowledge bases.

A timeline visualization was created by pinpointing burst keywords in the titles ([Figure S1A](#)). The timeline spanned from 2000 to 2025, with different colored lines representing various clusters. Each line shown the development and connection of related research topics over time, with nodes indicating key points or significant studies within each cluster. The cluster “biochemistry course” dominated the timeline from 2000 to 2025, suggesting a great emphasis on the instructional design of BMB in these years.

The CiteSpace time zone chart illustrated the research trends during various time periods and indicates the developmental trajectory over time, which can help forecast future advancements ([Figure S1B](#)). The vertical pink-shaded bars represented different time periods, ranging from 2000 to 2025. Each diamond-shaped node in the graph represented a key theme that has emerged in the literature over time. This visualization provided a comprehensive overview of how the research topics and themes have developed and interrelated over the specified time frame.

Keyword Co-Occurrence and Evolution in BMB Education

Usually, each article had its own key words when it was published. The visualization shown a network of keywords from BMB education papers, with each keyword represented as a node ([Figure 2C](#)). The nodes were connected by lines, indicating relationships or co-occurrences among the keywords. Prominent keywords such as “expression”, “metabolism”, “performance”, and “education” were clearly visible, suggesting their significance in the literature corpus. By employing the Pathfinder pruning method in CiteSpace, a keyword cluster was generated with 20 significant clusters ([Figure 2D](#)). Many clusters covered the major research topics in the field of BMB education, such as “#0 education”, “#2 performance”, “#12 expression”, “#15 protein”, and “#18 dna”.

The timeline is a rich tapestry of interconnected lines, each representing the temporal evolution and co-occurrence of different keyword clusters, indicating how they evolve over time. Each keyword cluster is distinctly labeled on the right by the order of frequency. We could observe the changes in research focus ([Figure S1C](#)). From 2000 to 2025, keywords “education” was dominant in these papers. In the keyword time zone diagram, research subjects show varying areas of emphasis at different times ([Figure S1D](#)). Some keywords appeared prominently, indicating their significant influence and frequent appearance in the literature during specific time periods.

Terms from BMB Literature Abstracts: Visualization, Clustering, and Temporal Dynamics Analyzed by Citespace

Next, we analyzed the abstracts of these education papers to understand what they have focused on. Each node represented a significant concept, keyword, or entity extracted from the abstracts, and their sizes vary according to their frequency of occurrence ([Figure 2E](#)). Many terms related to the education concepts of BMB were found, such as “molecular biology”, “foundational concept”, and “gene expression”. The links connecting these nodes were the invisible bridges that span the gaps between different concepts, revealing the intricate relationships and associations among them. By applying the g-index ($k = 25$) as the selection criterion, the high frequency keywords from literature abstracts were clustered ([Figure 2F](#)). The analysis of the keyword cluster map considered all keywords and organized them into 18 clusters, each with a unique color and label.

To gain a deeper understanding of how each keyword developed over time, a timeline model was performed, illustrating a network of keywords over time ([Figure S1E](#)). Clusters “#0 EDUCATION, SCIENTIFIC DISPLINES” had remained active over a long period for almost 20 years, underscoring the evolution of enduring research topics. The high frequency terms clusters were shown in a time zone model ([Figure S1F](#)). From 2010 to 2015, the field expanded to include educational and conceptual dimensions, with emerging topics such as “molecular biology educators”, “foundational concepts” and “regional workshops”, reflecting a growing emphasis on academic training and theoretical consolidation.

Visualization and Clustering of Terms from Titles, Abstracts, and Keywords in BMB Education Literatures by Citespace

Beyond these individual analyses, we also synthesized terms extracted from the titles, abstracts, and keywords of BMB education literature to mitigate bias and achieve a comprehensive understanding of the field’s core themes. [Figure 2G](#) presented the results of leveraging the titles, abstracts, and keywords of the collected literature, with front size indicating

the frequency of important terms. The network was dominated by educational and fundamental research topics, such as “biochemistry courses”, “core principles”, “molecular biology educators” and “foundational concepts”, highlighting a strong focus on academic teaching and theoretical construction in this research area. Other frequent molecular biology research hotspots are also highlighted, including “gene expression”, a fundamental concept in studying how genetic information is translated into functional proteins.

The spectral clustering algorithm was employed to group keywords to illustrate the research frontiers related to specific knowledge bases, while the log-likelihood rate (LLR) algorithm was utilized to identify keywords from citing articles for labeling the clusters (Figure 2H). Key foundational disciplines were also well-represented: “#3 BIOCHEMISTRY & MOLECULAR BIOLOGY” sit at the intersection of multiple clusters, highlighting its role as a fundamental pillar connecting fields like zoology, cell biology and chemistry, while “#2 EDUCATION & EDUCATIONAL RESEARCH” reflected the emphasis on academic training across these scientific domains. Peripheral clusters, such as “#7 CHEMISTRY, MULTIDISCIPLINARY” and “#11 MARINE & FRESHWATER BIOLOGY”, further illustrated the breadth of the research landscape, covering aquatic organism research and cross-disciplinary chemical applications in life sciences.

For this part, a timeline visualization was created, showcasing a rich tapestry of insights through clustering and a timeline-based visualization (Figure S1G). The most enduring and interconnected clusters were “#0 EDUCATION, SCIENTIFIC DISCIPLINES” and “#3 BIOCHEMISTRY & MOLECULAR BIOLOGY”, which have maintained continuous research activity since the early 2000s and show strong cross-cluster links, forming the core of the research landscape. In a time zone visualization, the area of the cluster and its intersections indicated the scale and connections of the cluster, while the word size of the nodes reflected their frequencies (Figure S1H).

Visualizing Title Terms in BMB Education Literatures by VOSviewer

Next, the terms in the titles from the education literatures in BMB were summarized and visualized by VOSviewer. At the network, terms like “effect” and “hematology” stand out prominently, surrounded by a plethora of related concepts (Figure 3A). The network was divided into several distinct clusters: one focuses on educational practice, marked by terms like “molecular biology course”, “biochemistry course”, “biochemistry student” and “learning”, highlighting the emphasis on academic teaching and training in the field. Another key cluster revolved around biochemical research and experimentation, featuring keywords such as “biochemistry”, “synthesis”, “experiment”, “purification” and “model”, which represent the fundamental experimental and analytical approaches in molecular biology studies.

These results were also illustrated by an overlay map (Figure S2A) and a density map (Figure S2B). The density map clearly visualized the core research hotspots: the brightest cluster centers on “molecular biology”, surrounded by closely associated terms including “biochemistry course”, “education” and “learning”.

Abstract Terms from the BMB Education Literatures: Co-Occurrence and Clusters Analyzed by VOSviewer

To eliminate the analysis bias from single software, another famous literature analysis software VOSviewer was also applied in this manuscript. Keywords from the abstracts were gathered to conduct a co-occurrence analysis (Figure 3B). The largest and most interconnected cluster (red) centered on educational research, dominated by core keywords like “student”, “learning”, “education” and “instruction”, alongside associated terms “approach”, “effectiveness”, “difficulty” and “technology”, highlighting a focus on teaching methods, learning outcomes and educational challenges. The green cluster represents outcome-oriented biochemical research, with key terms “effect” and “parameter” at its core, indicating studies focused on measuring and analyzing the results of biological and chemical processes, and its strong connections to the other two clusters show the integration of educational training and experimental practice with outcome assessment.

These results were also illustrated by an overlay map (Figure S2C) and a density map (Figure S2D). In the abstract’s density map, it clearly identifies two core hotspots: a large, dense cluster centered on educational and experimental keywords such as “student”, “learning” and “laboratory experiment”, and a smaller, distinct cluster for “effect” and “parameter”, which underscores the dual focus on educational methodologies and result-oriented research in this field.

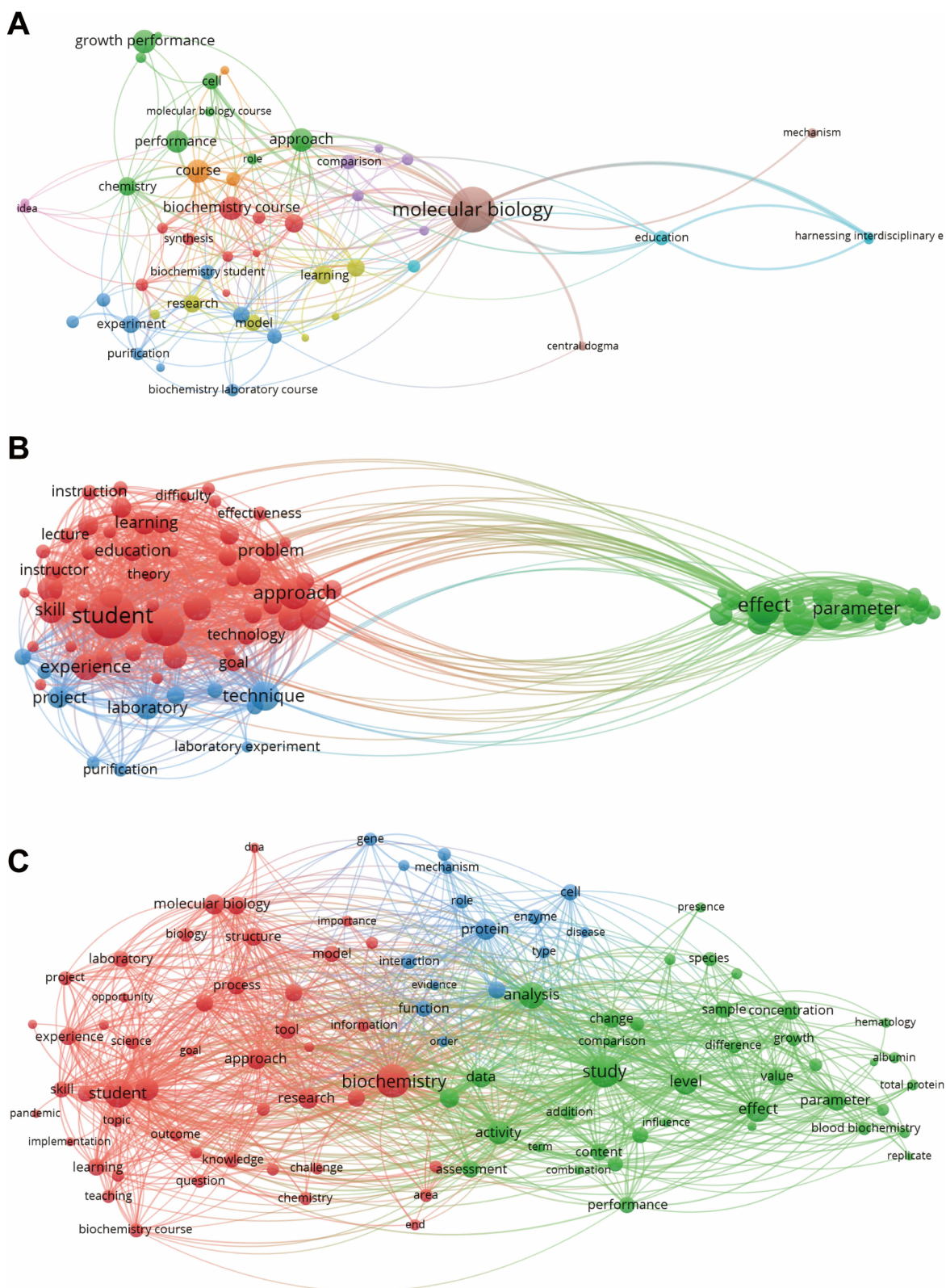


Figure 3 The terms in the titles, abstracts and both from the BMB education literatures were summarized and visualized by VOSviewer. **(A)** The terms in the titles were summarized and visualized by VOSviewer as a network. **(B)** Keywords from the abstracts were gathered to conduct a co-occurrence analysis. **(C)** The terms in both the titles and abstracts from the BMB education literatures collected were summarized and visualized by VOSviewer.

Network Visualization of Key Terms Derived from Titles and Abstracts in BMB Education Literature Using VOSviewer

To enhance visual impact, the terms from both the titles and abstracts from the education literatures in BMB were summarized and visualized by VOSviewer ([Figure 3C](#)). The red cluster, centered on “student” and “biochemistry”, is dominated by educational keywords such as “learning”, “teaching”, “biochemistry course” and “laboratory”, highlighting a strong focus on pedagogical approaches, laboratory training, and student learning outcomes in biochemistry education. The blue cluster revolved around fundamental biochemical research, featuring core terms including “molecular biology”, “protein”, “enzyme”, “mechanism”, and “analysis”, which reflected studies on molecular structures, biological functions, and underlying biochemical processes. The green cluster focused on applied biochemical assessment, with key terms like “study”, “effect”, “parameter”, “blood biochemistry”, and “sample concentration”, indicating research dedicated to measuring biochemical indicators, analyzing experimental results, and exploring practical applications in fields like hematology.

The cluster of frequent terms from title and abstract from BMB education literatures were also illustrated by an overlay map ([Figure S2E](#)) and a density map ([Figure S2F](#)). This density map identified two primary hotspots: a dense central cluster anchored by “student”, “biochemistry” and “study”, integrating educational elements (“teaching” and “learning”) with experimental and analytical terms (“laboratory” and “analysis”), and a secondary, smaller cluster focused on biochemical outcome assessment (“effect”, “parameter”, and “blood biochemistry”), which underscored the field’s growing emphasis on practical applications and result-driven research alongside educational and fundamental studies.

Mapping Topic Distribution in Omics-Related BMB Education Research by VOSviewer

Given that low-frequency omics-related keywords risked being overshadowed in the bibliometric analyses using our initial search strategy, we adapted a second, targeted search string to retrieve omics-focused BMB education papers, on which we then repeated keyword frequency analyses. [Figure 4A](#) was derived from title keywords, highlighting the initial integration of omics into educational frameworks, where terms like “genomics” and “bioinformatics” appear as emerging nodes linked to core educational keywords such as “biochemistry course”, “teaching”, and “biochemistry education”, signaling a growing focus on incorporating omics content into traditional biochemistry curricula. Built from abstract keywords ([Figure 4B](#)), this visualization significantly expands the omics landscape, featuring a dense cluster of specialized disciplinary terms, including “genomic”, “metabolomic”, “proteomics”, and “mass spectrometry”, which are interconnected with educational elements (“student”, “course”) and data analysis tools (“data”, “computer”, “python”), reflecting the depth of omics-related research methodologies and their integration into educational practice.

Merging title and abstract keywords, [Figure 4C](#) created a unified network where omics terms serve as critical bridges between education and research. Terms, including “genomics”, “metabolomics”, “bioinformatics”, and “mass spectrometry”, formed a cohesive sub-network linked to central educational hubs like “student”, “biochemistry”, and “approach”. These underscored the interdisciplinary nature of modern molecular biology education that combines traditional pedagogical strategies with advanced omics technologies and data-driven analytical techniques. The overlay and density model for [Figure 4](#) were also shown in [Figure S3](#).

Discussion

Several studies have indicated the challenges in teaching BMB, alongside the efforts made by researchers and educators to enhance content clarity and foster meaningful student learning.^{13–15} Bibliometric analyses offer a quantitative and statistical analysis of publications. Bibliometric visualization plays a significant role in bibliometric analyses because the collaborative networks, research hotspots, and trends of a new field can be intuitively observed through visualization maps. Furthermore, by synthesizing large datasets into knowledge maps, researchers can comprehensively analyze the development of a discipline and intuitively understand frontier trends.¹⁶

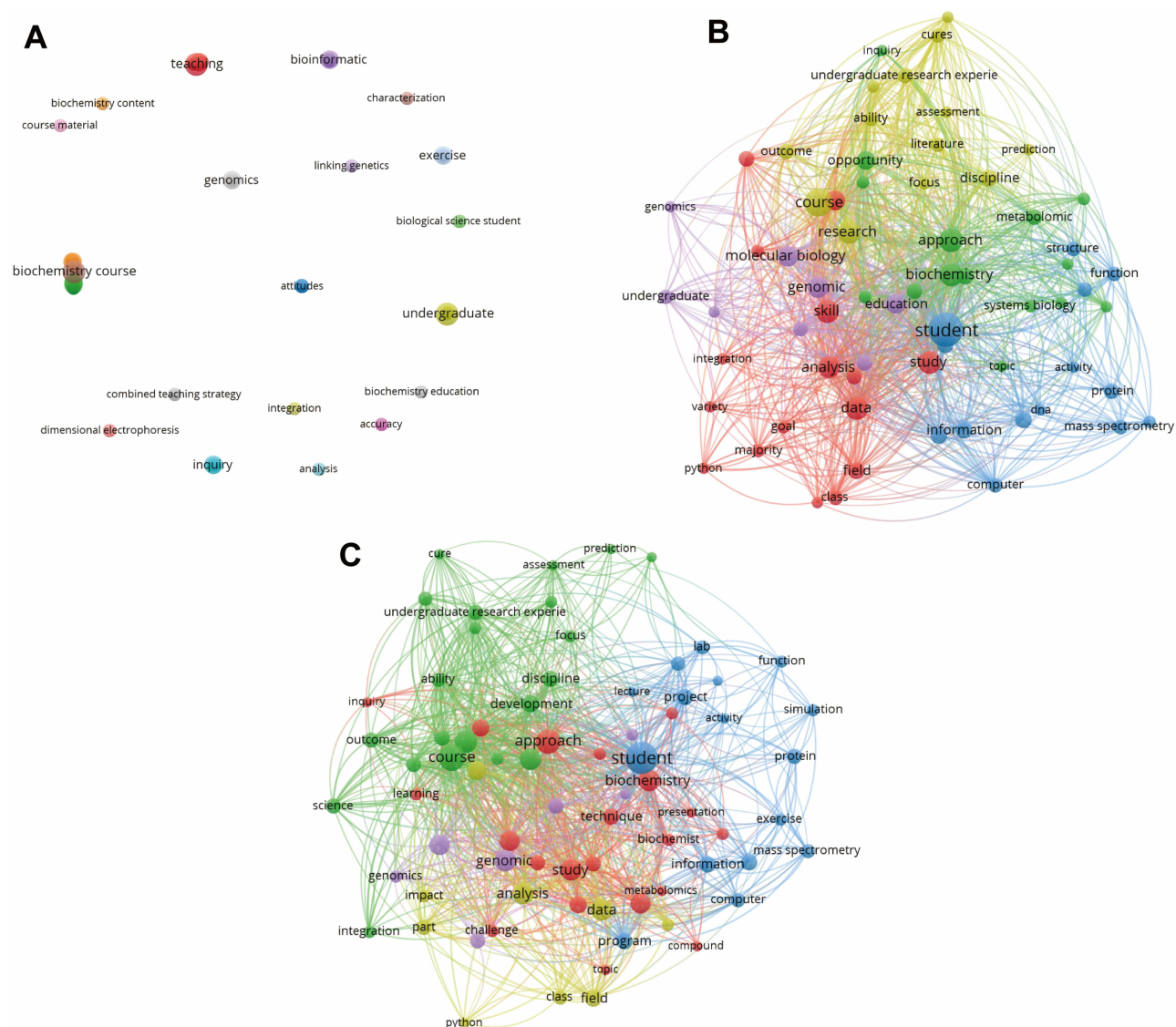


Figure 4 Term summarization and visualization for omics-specific BMB education literature by VOSviewer. **(A)** Title-only term network. **(B)** Terms from Abstract co-occurrence analysis. **(C)** Combined title-abstract term visualization.

Interdisciplinary Integration and Pedagogical Evolution in Modern BMB Education

Our findings align with the latest research progress in BMB education, reflecting the field's consistent focus on optimizing teaching practice and its dynamic adaptation to the evolving demands of scientific and medical education. "Active learning", a key term in title co-occurrence clusters, has become a mainstream instructional strategy in contemporary BMB education, with recent studies validating its effectiveness in improving learning outcomes and student engagement. Martin et al demonstrated that inquiry-driven active learning methodologies significantly enhance students' proficiency in molecular sequence analysis, a foundational BMB skill, by fostering hands-on data processing capabilities.¹⁷

Educational assessment, represented by the keyword “performance” in the co-occurrence network, has evolved toward a multidimensional and outcome-oriented model in recent research. The FEBS 2024 Education and Training Conference white paper emphasized formative assessment and self-regulated learning as critical directions for BMB education reform, advocating for assessment systems that evaluate both academic performance and practical skills.¹⁸

Interdisciplinary integration, a notable trend in the time zone visualization since 2018, has been extensively explored in recent studies, expanding the boundaries of BMB education. Morsink et al developed modular courses combining

BMB with metagenomics data analysis, responding to the demand for interdisciplinary talents in life sciences by integrating bioinformatics into traditional BMB curricula.¹⁹

Integrating Omics Technologies into Modern BMB Education

In the bibliometric analysis, concerns arose that low-frequency omics-related keywords would be overshadowed and insufficiently captured when we analyzed the occurrence frequencies of keywords in literature retrieved with the first set of search terms. Therefore, a second set of search terms was adopted to specifically retrieve papers focused on omics-related BMB education, and keyword analysis was subsequently re-conducted on this subset of literature. Our findings demonstrate that keywords, such as “genomics”, “proteomics”, and “bioinformatics”, have progressively migrated from specialized research contexts into core educational discourse, forming interconnected networks with pedagogical terms including “student”, “curriculum”, and “assessment”.

Omics integration has also driven innovation in BMB educational assessment, moving from single theoretical evaluation to competency-based assessment of bioinformatic and data analytical skills. Tapprich et al developed a validated assessment rubric for bioinformatics instruction, an essential omics-related skill, defining bioinformatics as an interdisciplinary field linking biology and computer science and providing a reliable framework for evaluating students’ ability to analyze omics-related biological data.²⁰ Similarly, a 4-week inquiry-driven modular course was developed using public Australian coral microbiome sequencing data, paired with bioinformatics, statistics training and hands-on fieldwork. This course enables students to master metagenomic data analysis skills, and gain practical experience of independent scientific discovery.¹⁹

Recent studies suggest that the integration of bioinformatics tools and next-generation sequencing data into undergraduate and graduate curricula can significantly enhance students’ analytical skills and scientific literacy.²¹ As a result, many institutions are revising their curricula to incorporate modules on big data handling, such as genomics and transcriptomics, aligning BMB education with the demands of modern life sciences research.²²

Obviously, omics has become an indispensable component of modern BMB education, reshaping curriculum design, experimental teaching and assessment systems. Our bibliometric results map the trajectory of this integration, while recent empirical research validates its effectiveness in enhancing students’ practical and research competencies. Future BMB education will need to further deepen multi-omics integration, particularly by combining omics technologies with AI and clinical research, to meet the demand for interdisciplinary talents in the omics era of life sciences.

Emerging Trends and Future Directions in BMB Education

Our results revealed a profound interdisciplinary integration trend, where omics technologies represented by genomics, metabolomics and proteomics have evolved from emerging educational elements to core bridges connecting traditional BMB curricula with modern data-driven research. This evolution not only reshapes the content system of BMB education but also drives innovations in pedagogical approaches, curriculum design and educational assessment, aligning with the latest practical explorations in contemporary BMB education and reflecting the field’s adaptation to the development of life sciences in the omics era.

Future BMB education should deepen omics integration beyond genomics/bioinformatics, incorporating advanced topics and data skills like Python. Strengthening teaching of core concepts (eg, gene expression, protein function) remains crucial. Embracing interdisciplinarity and connecting educational practice with advanced research methodologies is vital.

To implement these reform priorities, the future direction of this field may involve expanding the integration of computational biology and AI-assisted learning modules, such as large language models and AI teaching assistant, to meet the demands of modern scientific inquiry in BMB education.^{23,24} As the discipline continues to evolve, fostering adaptive and inclusive teaching practices will be a core priority for preparing the next generation of scientists. Rowland et al considered a radical shift from the content-based tradition is being driven by the “omics” information explosion in biochemistry teaching, which was in urgent need of a method for delivery of conceptual frameworks.²⁵

Limitations

This analysis has limitations inherent to bibliometric methods. Our results depend on specific algorithms (Citespace, VOSviewer) and parameters, potentially biasing network structures and clusters. Capturing niche topics like specialized omics (eg, metabolomics, proteomics) required targeted searches, indicating broader analyses might miss emerging trends. Relying on titles, abstracts, and keywords could overlook full-text nuances in educational approaches.

Conclusion

There is a need to assess the long-term impact of these changes on student outcomes, career readiness, and research productivity. As BMB education continues to evolve, it must remain responsive to the rapidly changing scientific landscape, ensuring that students are not only well-versed in molecular concepts but also equipped with the technical, analytical, and collaborative skills needed for the future of life sciences.

Data Sharing Statement

Data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethical Approval

Ethics approval was not required for this bibliometric paper.

Funding

This study was supported by Guangdong Basic and Applied Basic Research Foundation (No. 2024A1515011919).

Disclosure

The authors declare that they have no competing interests in this work.

References

1. Tansey JT, Baird T, Cox MM, et al. Foundational concepts and underlying theories for majors in “biochemistry and molecular biology”. *Biochem Mol Biol Educ*. 2013;41(5):289–296. doi:10.1002/bmb.20727
2. Hendrickson TL. Integrating responsible conduct of research education into undergraduate biochemistry and molecular biology laboratory curricula. *Biochem Mol Biol Educ*. 2015;43(2):68–75. doi:10.1002/bmb.20857
3. Caldwell B, Rohlman C, Benore-Parsons M. A curriculum skills matrix for development and assessment of undergraduate biochemistry and molecular biology laboratory programs. *Biochem Mol Biol Educ*. 2006;32(1):11–16. doi:10.1002/bmb.2004.494032010295
4. Garma LD, Osório NS. Demystifying dimensionality reduction techniques in the ‘omics’ era: a practical approach for biological science students. *Biochem Mol Biol Educ*. 2023;52(2):165–178. doi:10.1002/bmb.21800
5. Ouyang L, Zhang H, Zhang X, Wu H. Genomics course design and combined teaching strategy to enhance learning initiatives in classroom. *Biochem Mol Biol Educ*. 2019;47(6):632–637. doi:10.1002/bmb.21289
6. Brown HD, Boonme K, Imrhan V, Juma S, Vijayagopal P, Prasad C. Should “Omics” education be a part of allied health profession curricula? *Genomics*. 2020;112(1):169–173. doi:10.1016/j.ygeno.2019.01.009
7. Kokol P, Blažun Vošner H, Završnik J. Application of bibliometrics in medicine: a historical bibliometrics analysis. *Health Inf Libraries J*. 2020;38(2):125–138. doi:10.1111/hir.12295
8. Wood EJ. Biochemistry and molecular biology teaching over the past 50 years. *Nat Rev Mol Cell Biol*. 2001;2(3):217–221. doi:10.1038/35056600
9. Do Nascimento AS, de Oliveira FS, Bianconi ML. Bibliometric analysis of the brazilian periodical journal of biochemistry education. *Biochem Mol Biol Educ*. 2019;47(3):249–256. doi:10.1002/bmb.21220
10. Barbosa MLDO, Galembeck E. Mapping research on biochemistry education: a bibliometric analysis. *Biochem Mol Biol Educ*. 2022;50(2):201–215. doi:10.1002/bmb.21607
11. Chen C. Visualizing and exploring scientific literature with CiteSpace. Proceedings of the 2018 Conference on Human Information Interaction & Retrieval – CHIIR ‘18; 2018.
12. Bukar UA, Sayeed MS, Razak SFA, Yogarayan S, Amodu OA, Mahmood RAR. A method for analyzing text using VOSviewer. *MethodsX*. 2023;11:102339.
13. Cicuto CAT, Torres BB. Implementing an active learning environment to influence students’ motivation in biochemistry. *J Chem Educ*. 2016;93(6):1020–1026. doi:10.1021/acs.jchemed.5b00965
14. Milner RE. Learner differences and learning outcomes in an introductory biochemistry class: attitude toward images, visual cognitive skills, and learning approach. *Biochem Mol Biol Educ*. 2013;42(4):285–298. doi:10.1002/bmb.20658
15. Silva T, Galembeck E. Developing and supporting students’ autonomy to plan, perform, and interpret inquiry-based biochemistry experiments. *J Chem Educ*. 2016;94(1):52–60. doi:10.1021/acs.jchemed.6b00326
16. Huang C, Yang C, Wang S, Wu W, Su J, Liang C. Evolution of topics in education research: a systematic review using bibliometric analysis. *Educ Rev*. 2019;72(3):281–297. doi:10.1080/00131911.2019.1566212

17. Ortiz Martin I, Del Espino Perez A, Garcia Luque E, Viguera Minguez E. Using active learning methodologies to teach sequence analysis and molecular phylogeny. *Biochem Mol Biol Educ.* **2025**;53(1):21–32. doi:10.1002/bmb.21861
18. Villo L, Sincic N, Mello LV, et al. A white paper from the FEBS Education and Training Conference: challenges, opportunities, and action plans for transforming molecular life sciences education. *FEBS Open Bio.* **2025**;15(1):11–20. doi:10.1002/2211-5463.13916
19. Morsink MC, van Schaik EN, Bossers K, Duijker DA, Speksnijder A. Metagenomics education in a modular CURE format positively affects students' scientific discovery perception and data analytical skills. *Biochem Mol Biol Educ.* **2025**;53(3):311–320. doi:10.1002/bmb.21888
20. Tapprich WE, Reichart L, Simon DM, et al. An instructional definition and assessment rubric for bioinformatics instruction. *Biochem Mol Biol Educ.* **2021**;49(1):38–45. doi:10.1002/bmb.21361
21. Goller CC, Srougi MC, Chen SH, Schenkman LR, Kelly RM. Integrating bioinformatics tools into inquiry-based molecular biology laboratory education modules. *Front Educ.* **2021**;6. doi:10.3389/educ.2021.711403
22. Pucker B, Schilbert HM, Schumacher SF. Integrating molecular biology and bioinformatics education. *J Integr Bioinform.* **2019**;16(3). doi:10.1515/jib-2019-0005
23. Bolgova O, Shypilova I, Mavrych V. Large language models in biochemistry education: comparative evaluation of performance. *JMIR Med Educ.* **2025**;11:e67244. doi:10.2196/67244
24. Wang Y, Gu C, Ding B, Zhao J. Teaching innovation with AI assistants: application and impact evaluation in biochemistry education. *Front Digital Educ.* **2025**;2(1). doi:10.1007/s44366-025-0047-x
25. Rowland SL, Smith CA, Gillam EMA, Wright T. The concept lens diagram: a new mechanism for presenting biochemistry content in terms of “big ideas”. *Biochem Mol Biol Educ.* **2011**;39(4):267–279. doi:10.1002/bmb.20517

Advances in Medical Education and Practice

Publish your work in this journal

Advances in Medical Education and Practice is an international, peer-reviewed, open access journal that aims to present and publish research on Medical Education covering medical, dental, nursing and allied health care professional education. The journal covers undergraduate education, postgraduate training and continuing medical education including emerging trends and innovative models linking education, research, and health care services. The manuscript management system is completely online and includes a very quick and fair peer-review system. Visit <http://www.dovepress.com/testimonials.php> to read real quotes from published authors.

Submit your manuscript here: <http://www.dovepress.com/advances-in-medical-education-and-practice-journal>

Dovepress
Taylor & Francis Group