RESEARCH ARTICLE

Standardizing Biology Labs in Health Education Curriculum

Standardizing Biology Laboratory Curriculum in Health Education: A Blueprint for European Undergraduate Programs

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ABSTRACT

Current trends in education advocate for the development of skills alongside knowledge. Biology laboratories serve as essential platforms for developing practical skills and competencies such as data analysis, scientific inquiry, critical thinking, and problem-solving that are crucial for health science students. This paper aims to identify a standardized, competency-based biology laboratory curriculum aligned with international educational frameworks. The curriculum may be integrated into undergraduate health curricula across European universities to ensure consistent and high-quality education. A systematic search of university curricula was conducted across 28 European countries and included 138 universities. Eligible programs included medicine, pharmacy, nursing, biology, biomedical sciences, and others. Of the 432 syllabi identified, 290 were retrieved, and about half included a laboratory. Course outlines were analyzed for laboratory content and extracted data were summarized. The most frequently integrated laboratories were Microscopy, Isolation of DNA and PCR, Agarose Gel Electrophoresis, Cell Division, Cell Structure and Function, Lab Safety, and Using Basic Lab equipment. Learning objectives for foundational and advanced biology laboratories are presented. The proposed two-semester curriculum maps to the European Tuning and Vision and Change to provide a structured progression from foundational to advanced laboratory techniques. It utilizes digital tools, such as virtual labs and AI, to enhance accessibility and modernize laboratory education. In conclusion, the proposed curriculum provides a practical framework for implementing biology labs providing the foundational knowledge and competencies to prepare students to progress to more advanced topics in other disciplines, including physiology. It ensures consistent skill development across geographical locations, enhancing education quality and preparing students to address global health challenges.

NEW & NOTEWORTHY

This study identifies the most frequently used biology laboratory topics in health-related undergraduate programs across 28 European countries. We propose a standardized two-semester curriculum that strengthens foundational biology skills and advanced molecular methods, grounding students in physiology education. This framework reduces disparities in laboratory training, fosters competency, and prepares students for global health challenges.

Keywords: Biology laboratory; Curriculum standardization; Health education; Undergraduate education;

INTRODUCTION

In an increasingly interconnected world, the globalization of health education has become a critical priority. The World Health Organization (WHO) has emphasized the need for harmonized health education standards in their "Global strategy on human resources for health: Workforce 2030" report (1). The current trend in internationalization and sharing of curricula in transnational collaborations lead to the need for a unified curriculum across universities and countries to ensure that all students receive a consistent and high-quality education, regardless of their geographical location (2). A transformative approach to health education prepares professionals to meet the challenges of the 21st century including improved quality assurance and the facilitation of international student and faculty exchanges (2,3). This is a gradual and on-going process that requires careful planning and consideration for cultural nuances (4).

A good starting point would be Biology, as it plays a crucial role in health education, and often serves as a foundational course in health-related curricula including physiology, medicine, pharmacy, molecular biology, nursing and other undergraduate curricula. Biology provides the essential knowledge base for understanding the complexities of human health, disease mechanisms, and the biological interactions that underpin medical science. Biology laboratories, in particular, are integral to the learning process as they allow for the theory to take shape and for knowledge and understanding to become one. They provide hands-on experience and practical skills that are vital for understanding theoretical concepts. Laboratory work fosters critical thinking, problem-solving, and the application of scientific methods (5). It also allows students to engage in experiential learning, which is crucial for retaining complex information and developing technical proficiency. This is integral as educational trends highlight the significance of skills development alongside knowledge. A standardized approach to biology labs can ensure that all students, regardless of their institution, receive the same high-quality practical training. Biology laboratories may be taught as part of a standalone course or incorporated under specific topics in integrated curricula. By aligning essential laboratory techniques with core physiology concepts, these foundational experiences help students connect molecular interactions to broader organ-system functions, reinforcing their readiness for advanced health education.

The rationale behind this study is rooted in the need for standardization in health education to ensure that all students, irrespective of their geographical location, receive a consistent and high-quality educational experience. This is particularly crucial in the field of health sciences, where the practical skills and theoretical knowledge transmitted through laboratory work are fundamental to the professional competencies of future health practitioners (1).

At present, there is no information regarding the frequency of delivery of Biology laboratories in Health-related undergraduate curricula. In this study, we set out to determine the most commonly delivered biology laboratories in health-related courses at leading European universities. We rigorously analyze the pedagogical content of the laboratory courses and the insights gained from this comparative analysis enabled us to propose a standardized laboratory curriculum that may be adopted across health science undergraduate programs. This systematic mapping of laboratory content provides educators and administrators with actionable insights for curriculum refinement, allowing them to adopt or adapt the proposed framework to their institution's pedagogy.

MATERIALS AND METHODS

Study Design

The current study is a systematic search of university curricula across 28 European Countries (Supplemental Table 1). The search was conducted between February - May 2024. We focused on the top three universities in each country, as determined by Times Higher Education (THE) World University Rankings (6). If fewer than two suitable course outlines were identified, the search was expanded to include additional universities (>3 to as many needed) to ensure sufficient data.

Selection of Relevant Programs

The study concentrated on programs that might include one or more Biology courses with potential laboratory components. These included medicine (mostly 6-year programs), pharmacy, nursing, biology, human biology, biomedical sciences and other relevant programs that may potentially offer Biology as a foundation course in undergraduate curricula. Within these programs, course titles such as "General Biology," "Principles of Biology," "Cell Biology," "Molecular Biology" (if offered at an introductory level) "Biology and Genetics" and others were examined to determine whether they included dedicated lab sessions. For Problem-Based Learning (PBL) integrated curricula, we examined course modules and identified biology laboratory components within PBL cycles.

Data Extraction and Analysis

A comparative framework was developed to examine course content, structure, and pedagogical approaches, with particular attention to laboratory-based teaching. Specifically, all researchers used a shared Excel spreadsheet to gather consistent information from each university's website. Data extracted included: country, University name, relevant program(s) of study, course title, outline availability, laboratory inclusion, and any additional comments. In cases where full syllabi were offered in languages other than English, Google Translate was used to identify and interpret any mention of laboratory requirements or scheduled practical sessions. Any standalone or integrated lab components were also noted.

All collected syllabi underwent a full review for laboratory content, focusing on the presence and frequency of specific laboratory techniques. To ensure consistent categorization, labs with overlapping or synonymous titles were grouped together, and their occurrences were tallied to produce an overall frequency count. The laboratories were then ranked according to how often they appeared in the syllabi. From these aggregated findings, a proposed two-semester curriculum (16 laboratory topics) was developed to guide standardization, reflecting the most frequent and pedagogically relevant lab topics across institutions. These topics represent fundamental principles and skills in the biological sciences and were chosen to provide a structured foundation for students.

Development of Learning Objectives and Outcomes

The development of the learning objectives and outcomes was informed by the course syllabi as well as by multiple educational frameworks, including the Bologna Process, Tuning Educational Structures in Europe, and Vision and Change (7-10). These frameworks collectively emphasize essential proficiencies in technical laboratory skills, data interpretation, and interdisciplinary integration. Action verbs from Bloom's revised taxonomy were systematically used to ensure clarity and progression in student skill development. The learning objectives are further placed in three categories: A. Knowledge and Understanding, B. Practical Skills and C. Transversal Skills (also known as transferable skills). This approach ensures the inclusion of both technical and analytical competencies for comprehensive student training in laboratory sciences.

RESULTS

Universities from 28 European countries were systematically searched to identify whether they offered health-related undergraduate programs that would include Biology. 78% (n = 108) of universities were further investigated as they offered health-related programs which may incorporate Biology laboratory curricula. In total 432 syllabi courses were identified. Of those 290 were available online and were retrieved (67.13%) and of those about half had a laboratory component (46.90%). An overview of the process is shown in Figure 1.

272 relevant health-related undergraduate programs were identified. The most common were Medicine (n = 65), Biology (n = 49), Nursing (n = 29), Pharmacy (n = 27) and Biomedical Sciences (n = 9). From those and as expected, all undergraduate Biology program included basic Biology courses, so did most Pharmacy, Medicine and Biomedical Sciences degrees while nursing incorporated basic Biology in about half their curricula (Figure 2). Of the courses that incorporated Biology in Medicine less than half incorporated a laboratory (Figure 2C). 50% of Biology and Pharmacy undergraduate degrees included labs, while in Nursing and Biomedical Sciences about a quarter of the courses also included a laboratory component (Figure 2C).

The biology laboratory curriculum

The retrieved syllabi showed diverse course naming conventions that incorporated basic Biology and also included a laboratory component. The majority were found under Cell Biology titles followed by some sort of variation in Biology and Molecular Biology titles (21.3 % and 20.6%) (Table 1). 87 different laboratory titles were identified and their frequency was recorded. Detailed information is provided in Supplemental Table 2.

One important aspect of this endeavor was to make sure that the identified curriculum made practical sense. In a Semester in an undergraduate program, one would expect to cover about 7-10 laboratories. The 16 most frequently identified laboratories were selected and arranged in a pedagogically logical sequence. These topics represent fundamental principles and skills in the biological sciences and were chosen to provide a structured foundation for students. The chosen laboratories were then cross-referenced with core competencies outlined in the European Tuning and Vision & Change frameworks and are shown in Table 2 (7,8,10). The proposed rearrangement of the biology labs across two semesters is designed to ensure a logical progression of skills and knowledge for undergraduate students. In the first semester, the sequence begins with lab safety, which is crucial for establishing a foundation of proper safety protocols and equipment handling. This is followed by an introduction to basic lab equipment, ensuring students are proficient in essential techniques that will be used throughout the semester. Light microscopy is introduced early to help students develop observational skills and understand cell structure, which are fundamental for many biological studies. Building on these skills, the lab on cell structure and function through osmosis provides a deeper understanding of cell biology. The identification of biomolecules is then covered, providing essential biochemical knowledge that is foundational for studying metabolism and other cellular processes. The labs on enzyme activity, focusing on the effects of pH and temperature, introduce students to metabolic processes and enzyme kinetics. The semester concludes with electron microscopy, allowing students to compare and contrast it with light microscopy, thereby deepening their understanding of cellular components.

In the second semester, the sequence begins with the study of cell division through mitosis and meiosis, preparing students for more advanced genetic studies. An introduction to biostatistics, follows next, equipping students with the necessary skills to analyze experimental data, which is crucial for understanding and interpreting results from subsequent labs. The study of Mendelian genetics and genetic problems builds on the concepts of cell division and introduces genetic principles, preparing students for molecular biology techniques. The lab on microbial culture and growth provides practical skills and knowledge essential for studying microbiology and related fields. Following this, the isolation of DNA and PCR techniques are introduced, preparing students for more advanced molecular biology experiments. The subsequent lab on restriction endonuclease digestion of DNA teaches students molecular biology techniques for analyzing DNA, providing a deeper understanding of genetic manipulation. The separation of DNA by size using agarose gel electrophoresis complements the previous DNA labs by teaching students how to analyze DNA fragments. The semester concludes with cell culture, allowing students to apply their knowledge of cell biology and molecular techniques in a practical setting, providing hands-on experience with cell growth and maintenance.

Overall, this rearrangement ensures a logical progression from basic to more advanced techniques, with each lab building on the concepts and skills learned in previous labs. The integration of basic lab equipment and biostatistics ensures that students are well-prepared for data analysis and practical applications in biological research. This structure provides a comprehensive and cohesive learning experience, covering a wide range of fundamental and advanced topics in biology, thereby enhancing the educational outcomes for undergraduate biology students.

Learning objectives and outcomes of the biology laboratory curriculum

To further support the implementation of the proposed two-semester framework, learning objectives for each included laboratory exercise were developed (Supplemental Material) and broad learning outcomes are listed in Table 3. These objectives/outcomes, were designed using action verbs from Bloom's revised taxonomy, and aimed to foster comprehensive student development through alignment with frameworks such as the Bologna Process, the Tuning Educational Structures in Europe, and the Vision and Change initiative (7-10). This approach ensures the curriculum promotes both technical skill development and broader competencies required for success in modern biological sciences.

Both the learning objectives and outcomes focus on foundational skills (e.g., laboratory safety, pipetting, and microscopy), core biological techniques (e.g., PCR and gel electrophoresis), and interdisciplinary applications (e.g., biostatistics and cell culture). They are structured into three categories: Knowledge and Understanding, Practical Skills, and Transversal Skills, to ensure comprehensive development. For example, "Knowledge and Understanding" covers defining processes like osmosis and enzyme kinetics, while "Practical Skills" emphasize hands-on tasks such as performing qualitative biomolecule tests. "Transversal Skills" further cultivate critical thinking, collaboration, and ethical reasoning by integrating peer-review exercises and real-world problem-solving scenarios into lab work. This holistic approach ensures that students acquire versatile scientific competencies tailored for modern challenges in health sciences.

Some competencies span all laboratories and as such are not explicitly listed. To illustrate, the laboratory is a great environment to strengthen collaboration and teamworking skills. All laboratories may be carried out in groups of two or more students it should also be encouraged that students rotate roles to develop diverse skills. Following the work students could work together to produce a lab report, a digital portfolio, a poster or oral presentation or even an application. Peer review should also be integrated throughout.

Digital competencies are also becoming increasingly important so students should be encouraged to incorporate simulations and online labs in their learning. Digital lab notebooks for documenting observations and conclusions are a great place to start and virtual pre-lab exercises to practice experimental planning greatly support learning as well. These virtual labs may be used in a variety of ways to encourage learning in a safe environment prior to entering the lab, as a group exercise in class or outside the classroom. Artificial intelligence (AI) tools are growing in significance. As such, instructors should incorporate discussions about the limitations and reliability of AI tools (e.g., chat-based AI or analytical software) when applied to scientific contexts, ensuring that students approach these tools critically rather than relying on them blindly. In a recent publication Papaneophytou and Nicolaou (2025) propose a number of tools that may be used in laboratory teaching and beyond (11).

DISCUSSION

The globalization of health education is not merely a theoretical concept but a practical necessity. As health challenges become more global in nature, such as pandemics, antimicrobial resistance, and chronic diseases, there is a pressing need for health professionals who are trained to operate in diverse and international contexts. To address this, the current study aimed to develop a standardized biology laboratory curriculum that balances global competency with local adaptability. Most health-related undergraduate programs included biology as a taught component while the incorporation of a laboratory varied.

Standardized Biology Laboratory Curriculum Framework

Our data indicated that the following laboratories were the most frequently integrated in Biology laboratory curricula: (i) Microscopy, (ii) Isolation of DNA and PCR, (iii) Separation of DNA by size: Agarose gel electrophoresis (SDS-PAGE), (iv) Cell Division (Mitosis and Meiosis), (v) Cell Structure and Function - Osmosis (plant and animal), (vi) Lab Safety (Lab report / equipment) and (vii) Using basic lab equipment. This framework supports the development of essential competencies, providing a consistent foundation for advanced health education.

Based on the above, herein we propose the ‘Common Biology Laboratory Curriculum’ for a unified curriculum which is a reflection of the most frequently offered labs. A unified curriculum ensures that all health professionals are equipped with the same foundational knowledge and skills, enabling them to collaborate effectively on global health initiatives. This has been pursued in other disciplines such as pharmacology, nursing and medical curricula that have also identified gaps in curriculum alignment and proceeded with curriculum harmonization (12-14). Furthermore, this standardized biology curriculum provides students the foundational knowledge and competencies in key concepts in cellular and molecular biology, which underpin physiological mechanisms and preparing them for the integration of organ-system-level studies.

The proposed curriculum provides a coherent and progressive learning experience over two semesters. The first semester focuses on foundational laboratory skills and knowledge, including lab safety and basic equipment usage. The introduction of microscopy, cell structure and function, and biomolecule identification provides a solid base for understanding biological processes, which is further developed through the study of metabolism. The second semester builds upon this foundation, introducing cell division and biostatistics to enhance students' analytical capabilities, which are essential for scientific inquiry and research. The curriculum then delves into genetics, microbiology, and molecular biology, culminating in cell culture techniques. This progression not only reinforces theoretical knowledge but also hones practical skills, preparing students for the multifaceted nature of health-related careers.

To support the curriculum’s implementation, learning objectives were designed across three categories: Knowledge and Understanding, Practical Skills, and Transversal Skills. These objectives were informed by the Bologna Process, Tuning Educational Structures in Europe, and the Vision and Change initiative, ensuring alignment with international standards (7-10). The Bologna Process has established the foundation for European higher education harmonization, emphasizing transparency and comparability of qualifications across institutions (9), the Tuning Educational Structures in Europe project, has developed discipline-specific competencies, identifying essential skills including technical laboratory proficiency, experimental design capabilities, and scientific communication (10) and the Vision and Change initiative in undergraduate biology education emphasizes six core competencies that guide curriculum development in the United States, ranging from applying the process of science to understanding the relationship between science and society (7,8).

Integration with Health Sciences Education: Building and Physiological Foundations

The biology laboratory serves as a vital bridge between scientific knowledge and societal applications, preparing students to address real-world health challenges that affect communities globally. For instance, when students master PCR techniques in our DNA isolation lab, they're not merely learning a protocol, they're developing capabilities essential for COVID-19 testing, genetic disease screening, and forensic investigations that serve justice. Similarly, during the microbial culture laboratory, students learn to identify and quantify bacteria, directly connecting to public health initiatives addressing antibiotic resistance, a crisis the WHO identifies as one of the top global health threats. The biomolecules identification lab takes on profound societal meaning when students analyze nutritional content in foods, particularly when we discuss how these techniques help address malnutrition in resource-limited settings or inform public health policies on food labelling. The genetics laboratories, where students calculate disease probabilities for conditions like thalassemia, prepare future healthcare professionals to provide culturally sensitive genetic counselling to families in affected communities.

Even our emphasis on laboratory safety and waste management reflects broader societal responsibilities, as students learn to minimize environmental impact, a skill increasingly crucial as we face climate-related health challenges. Through collaborative projects and digital portfolios, students learn to communicate complex scientific concepts to diverse audiences, an essential skill for translating laboratory discoveries into public health interventions that benefit society at large.

The curriculum is designed to provide a robust foundational framework of biology skills, which directly support the understanding of physiological systems at the cellular, molecular, and systemic levels. Rather than operating as isolated technical exercises, these biology laboratories establish the experimental and conceptual foundations essential for advanced physiology education, aligning with the core competency approach emphasized by Schaefer & Michael (2024) (15). For example, osmosis laboratories provide students with hands-on experience of membrane transport and water potential, concepts that directly underpin renal function, fluid balance, and cardiovascular dynamics in physiology courses (Supplemental Material: Learning Objectives, Lab 4 Cell Structure and Function (Osmosis): A-LO1, A-LO3, B-LO2, C-LO6). Similarly, enzyme kinetics experiments demonstrate how environmental factors affect biochemical reaction rates, establishing the quantitative foundation students need to understand metabolic regulation, pharmacokinetics, and cellular energetics (Supplemental Material: Learning Objectives, Lab 6/7 Metabolism of the Cell Enzyme (pH and temperature): A-LO2, B-LO4, C-LO5, C-LO6). Cell culture techniques allow students to observe how cells respond to environmental changes and signaling molecules, providing the experimental basis for understanding tissue adaptation, immune responses, and therapeutic interventions in physiological systems (Supplemental Material: Learning Objectives, Lab 8 Cell Culture: A-LO1, B-LO7, C-LO4, C-LO5, C-LO6; Lab 3 Microscopy (light): B-LO2, B-LO3). By embedding these principles in experiential learning, students develop both the technical competencies and analytical thinking skills necessary to bridge molecular processes with integrative physiological mechanisms (for example, quantitative reasoning and data analysis outcomes in Supplemental Material: Learning Objectives, Osmosis: C-LO6; Enzyme kinetics: C-LO5, C-LO6; Cell culture: C-LO4). This approach aligns with modern physiology education's emphasis on core competencies and prepares students to understand complex physiological systems through the lens of their underlying biological foundations, ensuring they arrive in advanced courses with the skills needed to grasp systemic regulation and homeostatic mechanisms.

The biology laboratories also support the core competencies central to physiology education. Students gain proficiency in data analysis, experimental design, and hypothesis testing directly supports understanding of systemic mechanisms like nervous control, hormonal feedback loops, and cardiovascular dynamics. For example, enzyme kinetics introduces the quantitative principles underpinning metabolic processes, while microbial labs deepen understanding of host-pathogen interactions critical to immune physiology. By bridging disciplines, the curriculum ensures students are fully equipped to transition into complex physiology coursework.

Importantly, the current study revealed that the integration of laboratories varied widely in health-related disciplines. This finding underscores the disparity in laboratory education across institutions and highlights the importance of incorporating practical labs to foster understanding of biological sciences (5,16). Given the significant role that biology labs play in skill development, there is a compelling case for their further integration into health science curricula. By embedding comprehensive laboratory experiences within undergraduate programs, educators can ensure that students acquire the necessary skills to meet the demands of the healthcare industry. This integration not only enhances the quality of education but also prepares students to address complex global health challenges effectively. Biology laboratories serve as essential platforms for developing practical skills and competencies that are crucial for health science students. Through hands-on experiments, students gain proficiency in laboratory techniques, data analysis, and scientific inquiry, which are fundamental to their future roles as health professionals. The experiential learning environment of biology labs fosters critical thinking and problem-solving abilities, enabling students to apply theoretical knowledge in real-world contexts (5,17). In particular, these foundational skills empower students to interpret physiological data and experimental outcomes more effectively, bridging molecular processes with clinical concepts in subsequent coursework.

Implementation Considerations and Future Directions

It is also important to note that not all curricula may incorporate two Semesters of Biology laboratories and also a lot of programs actually offer integrated PBL-based curricula (18). The proposed curriculum is flexible and modular, allowing educators to implement labs within broader PBL cycles or condense them into a single semester where necessary (18). Where physical laboratories cannot be offered due to time or financial constraints, curriculum developers may consider incorporating virtual labs to either substitute or supplement face-to-face laboratory teaching. In the post Covid-19 era, advances in virtual simulations have revolutionized health education, making high-quality laboratory training accessible in cost-effective, logistically flexible formats (11,19,20). Virtual labs offer several advantages that make them a feasible and necessary component of modern health education. They provide students with the opportunity to engage in interactive and immersive learning experiences that can mimic real-world laboratory settings. This technology allows students to conduct experiments, manipulate variables, and observe outcomes in a controlled, risk-free environment. Additionally, virtual labs can be cost-effective, reducing the need for physical resources and space while still providing high-quality educational content. The integration of technology, such as virtual simulations and online learning platforms, has revolutionized health education, making it more accessible and flexible (20). This accessibility ensures that all students, regardless of their geographical or socio-economic status, have the opportunity to gain practical laboratory experience. As educational institutions continue to adapt to the evolving landscape of higher education, virtual labs represent a promising solution to the challenges of delivering comprehensive laboratory training. By embracing these innovative tools, educators can ensure that students are well-prepared to meet the demands of the healthcare industry, even in the face of logistical constraints.

Limitations of the study include the availability and level of detail in course outlines, as well as language barriers that may have affected the interpretation of syllabi. These limitations suggest that the actual integration of biology labs in health curricula may be underrepresented in this study. Further, laboratory learning outcomes were communicated differently in course outlines. Still, the issues with variability of learning outcomes have been previously discussed (21). Future research could aim to overcome these limitations by possibly collaborating with native speakers or experts in educational translation. Nonetheless, the current study sets the stage for a standardized curriculum that can help bridge the gaps in educational disparities, promote equity, and facilitate the mobility of health professionals across borders. This is particularly important in the field of health sciences, where the quality of education directly impacts patient care and public health outcomes. Future research should focus on optimizing the integration of biology labs into curricula and validating the proposed curriculum across diverse educational contents. By refining these educational strategies, institutions can provide a more robust and cohesive learning experience, ultimately contributing to the development of competent and skilled health professionals ready to tackle the challenges of an interconnected world (1).

Conclusion

In conclusion, a strong grounding in Biology is indispensable for students pursuing careers in health and medical sciences. Laboratories are important in the development of skills and a deeper understanding of complex concepts allowing students to acquire key competencies. In an increasingly interconnected world, the globalization of health education will play a crucial role in preparing health professionals to address global health challenges. By adopting standardized curricula, particularly in foundational subjects like biology and its associated laboratory work, universities can ensure that all students receive a high-quality education, promoting equity and excellence in health care worldwide. In doing so, the essential links between foundational biology lab skills and advanced physiological understanding become more explicit, enhancing our collective ability to train proficient, globally oriented health professionals.

SUPPLEMENTAL MATERIAL

Supplemental Table S1 [DOI Link: https://figshare.com/s/ad29498e2be91122d9ad]

Supplemental Table S2 [DOI Link: https://figshare.com/s/34a3225760005c62f3c9]

Supplemental Material - Learning Objectives [DOI Link: https://figshare.com/s/e4695a5fb6fb4c6919ba]

GRANTS

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DISCLOSURES

Nothing to declare.

AUTHOR CONTRIBUTIONS

SAN, Conceived and designed research, SAN, PN, ED, PDB, BP, GL: performed experiments, SAN and PN: analyzed data, SAN, PN, BP: interpreted results of experiments, SAN: prepared figures, SAN: drafted manuscript, SAN, PN, ED, PDB, BP, GL: edited and revised manuscript, SAN, PN, ED, PDB, BP, GL: approved final version of manuscript.

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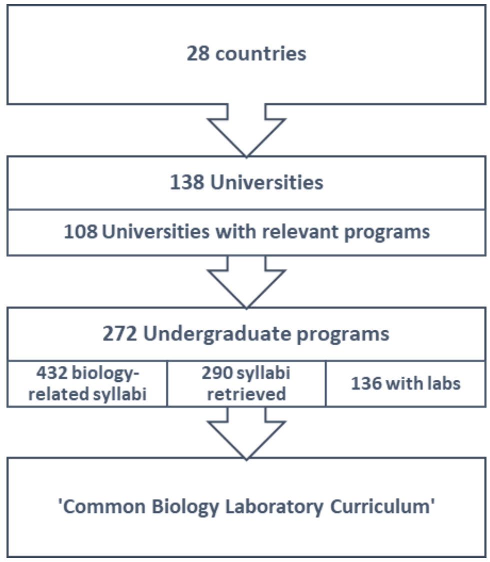
FIGURE LEGENDS

Figure 1: An overview of the search process and identification of Biology laboratory curricula.

Figure 2: A. Health-related undergraduate programs researched for Biology teaching. B. Percentage of programs that included Biology courses. C. Percentage of programs with Biology that also included a laboratory section.


28 countries
138 Universities
108 Universities with relevant programs
272 Undergraduate programs
432 biology-related syllabi
290 syllabi retrieved
136 with labs
'Common Biology Laboratory Curriculum'

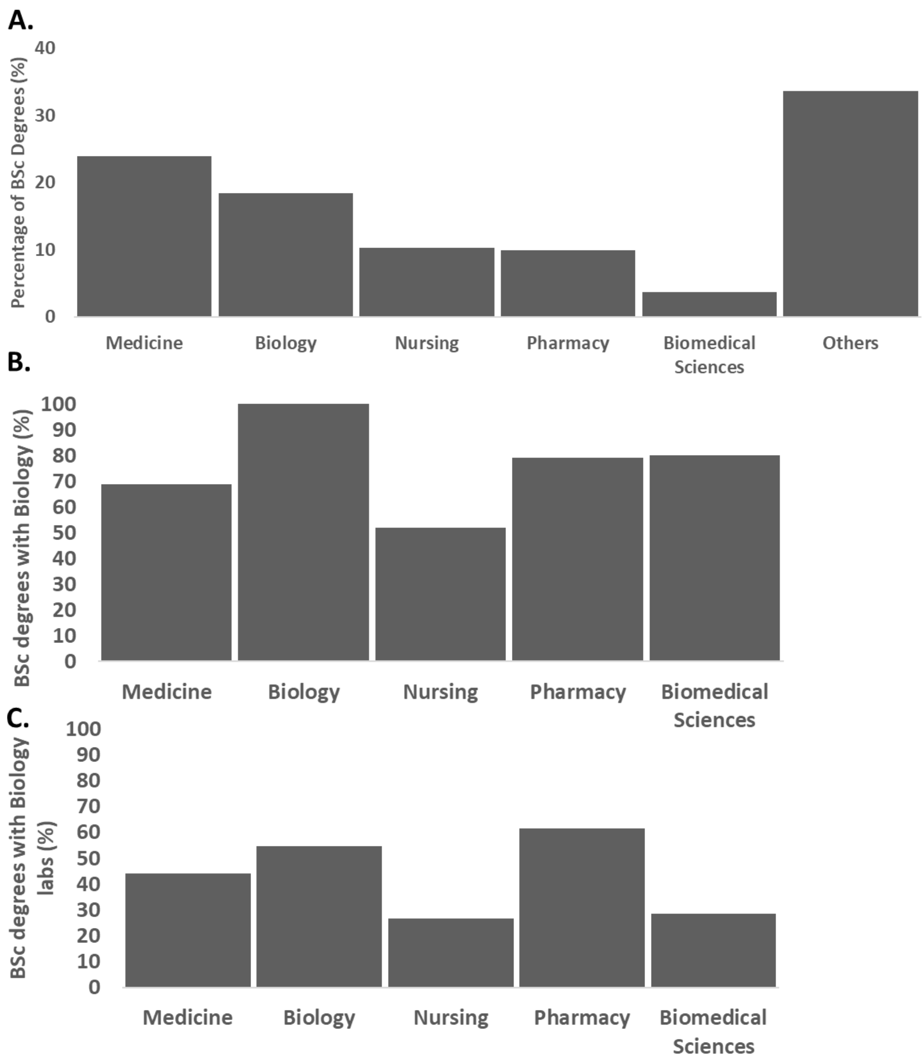

A.
Percentage of BSc Degrees (%)
40
30
20
10
0
Medicine
Biology
Nursing
Pharmacy
Biomedical Sciences
Others
B.
BSc degrees with Biology (%)
100
90
80
70
60
50
40
30
20
10
0
Medicine
Biology
Nursing
Pharmacy
Biomedical Sciences
C.
BSc degrees with Biology labs (%)
100
90
80
70
60
50
40
30
20
10
0
Medicine
Biology
Nursing
Pharmacy
Biomedical Sciences

Table 1: Course syllabi titles used for laboratory information extraction

Course Name	**% (n)**
Cell Biology / Biology of the Cell	25.7 (35)
Molecular Biology/Cellular and Molecular Biology	21.3 (29)
Biology / General Biology (I and II)/Introduction to Biology	20.6 (28)
Biochemistry	14.7 (20)
Microbiology	8.8 (12)
Biology and Genetics / Biology and Human Genetics / Human Biology and Genetics	4.4 (6)
Others	4.4 (6)
TOTAL	136

Table 2: The proposed Biology Laboratory curriculum outlines two Semesters

Semester I	Semester II
Lab Safety (Lab report / equipment)	Cell Division (Mitosis and Meiosis)
Using basic lab equipment (pipettes, scales, pH meter, centrifuge, spectrophotometer, stock solutions)	Biostatistics: Introduction to probabilities
Microscopy (light)	Mendelian Genetics and Genetic Problems
Cell Structure and Function - Osmosis (plant and animal)	Microbial culture and growth
Biomolecules (identification tests)	Isolation of DNA and PCR
Metabolism of the Cell Enzyme (pH)	Restriction endonuclease digestion of DNA
Metabolism of the Cell Enzyme (temperature)	Separation of DNA by size: Agarose gel electrophoresis (SDS-PAGE)
Electron microscopy	Cell culture

Table 3: Learning Outcomes for the Entire Two-Semester Course

A.	**Knowledge and Understanding**
1.	Explain core concepts spanning cell structure, function, metabolism (enzymology, osmosis), cell division (mitosis and meiosis), and genetics (Mendelian and molecular).
2.	Describe the theoretical basis and procedural steps for standard biological laboratory techniques, including microscopy, biomolecule testing, and enzyme kinetics analysis.
3.	Recognize and interpret laboratory safety standards, hazard symbols, and ethical considerations related to waste disposal and scientific practices.
4.	Compare and contrast the applications and limitations of different investigative tools, such as light versus electron microscopy, and qualitative versus quantitative testing methods.
B.	**Practical Skills**
1.	Safely and accurately operate basic laboratory equipment, including microscopes, pipettes, scales, centrifuges, and spectrophotometers.
2.	Consistently apply good laboratory practices, select appropriate personal protective equipment (PPE), and execute basic emergency response procedures.
3.	Conduct hands-on experiments, including preparing slides and wet mounts, performing dilutions and standard solutions, and interpreting results of qualitative tests (e.g., biomolecules, enzyme activity).
4.	Execute calibration and maintenance procedures for laboratory equipment and accurately collect and record experimental data.
C.	**Transversal Skills**
1.	Conduct risk assessments for new procedures, identify common errors in technique, troubleshoot experimental problems, and propose effective corrective actions.
2.	Collect, organize, construct, and interpret graphical or statistical data related to biological experiments (e.g., enzyme kinetics graphs, mitotic index calculations, pedigree analysis).
3.	Utilize mathematical principles (e.g., calculations of magnification, water potential, solute concentrations, genetic probabilities) to analyze and solve biological problems.
4.	Design controlled experimental protocols, apply scientific principles to real-world scenarios (e.g., disease inheritance, nutritional health, sustainable practices), and justify experimental choices in a scientific format (e.g., lab reports, research proposals).
5.	Communicate scientific methods and findings clearly in written, visual, and oral formats, using appropriate digital tools.