

1 RESEARCH ARTICLE

2 Standardizing Biology Labs in Health Education Curriculum

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

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15

16 **ABSTRACT**

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

37 NEW & NOTEWORTHY

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

43 **Keywords:** Biology laboratory; Curriculum standardization; Health education; Undergraduate education;
44

45 INTRODUCTION

46 In an increasingly interconnected world, the globalization of health education has become a critical
47 priority. The World Health Organization (WHO) has emphasized the need for harmonized health
48 education standards in their "Global strategy on human resources for health: Workforce 2030" report
49 (1). The current trend in internationalization and sharing of curricula in transnational collaborations lead
50 to the need for a unified curriculum across universities and countries to ensure that all students receive
51 a consistent and high-quality education, regardless of their geographical location (2). A transformative
52 approach to health education prepares professionals to meet the challenges of the 21st century
53 including improved quality assurance and the facilitation of international student and faculty exchanges
54 (2,3). This is a gradual and on-going process that requires careful planning and consideration for cultural
55 nuances (4).

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

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

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

85

86 **MATERIALS AND METHODS**

87 *Study Design*

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

93 *Selection of Relevant Programs*

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

102 *Data Extraction and Analysis*

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

111 All collected syllabi underwent a full review for laboratory content, focusing on the presence and
112 frequency of specific laboratory techniques. To ensure consistent categorization, labs with overlapping
113 or synonymous titles were grouped together, and their occurrences were tallied to produce an overall
114 frequency count. The laboratories were then ranked according to how often they appeared in the
115 syllabi. From these aggregated findings, a proposed two-semester curriculum (16 laboratory topics) was
116 developed to guide standardization, reflecting the most frequent and pedagogically relevant lab topics

117 across institutions. These topics represent fundamental principles and skills in the biological sciences
118 and were chosen to provide a structured foundation for students.

119 Development of Learning Objectives and Outcomes

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

129 RESULTS

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

136 272 relevant health-related undergraduate programs were identified. The most common were Medicine
137 (n = 65), Biology (n = 49), Nursing (n = 29), Pharmacy (n = 27) and Biomedical Sciences (n = 9). From
138 those and as expected, all undergraduate Biology program included basic Biology courses, so did most
139 Pharmacy, Medicine and Biomedical Sciences degrees while nursing incorporated basic Biology in about
140 half their curricula (Figure 2). Of the courses that incorporated Biology in Medicine less than half
141 incorporated a laboratory (Figure 2C). 50% of Biology and Pharmacy undergraduate degrees included
142 labs, while in Nursing and Biomedical Sciences about a quarter of the courses also included a laboratory
143 component (Figure 2C).

144 The biology laboratory curriculum

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

150 One important aspect of this endeavor was to make sure that the identified curriculum made practical
151 sense. In a Semester in an undergraduate program, one would expect to cover about 7-10 laboratories.
152 The 16 most frequently identified laboratories were selected and arranged in a pedagogically logical
153 sequence. These topics represent fundamental principles and skills in the biological sciences and were
154 chosen to provide a structured foundation for students. The chosen laboratories were then cross-
155 referenced with core competencies outlined in the European Tuning and Vision & Change frameworks
156 and are shown in Table 2 (7,8,10). The proposed rearrangement of the biology labs across two
157 semesters is designed to ensure a logical progression of skills and knowledge for undergraduate

158 students. In the first semester, the sequence begins with lab safety, which is crucial for establishing a
159 foundation of proper safety protocols and equipment handling. This is followed by an introduction to
160 basic lab equipment, ensuring students are proficient in essential techniques that will be used
161 throughout the semester. Light microscopy is introduced early to help students develop observational
162 skills and understand cell structure, which are fundamental for many biological studies. Building on
163 these skills, the lab on cell structure and function through osmosis provides a deeper understanding of
164 cell biology. The identification of biomolecules is then covered, providing essential biochemical
165 knowledge that is foundational for studying metabolism and other cellular processes. The labs on
166 enzyme activity, focusing on the effects of pH and temperature, introduce students to metabolic
167 processes and enzyme kinetics. The semester concludes with electron microscopy, allowing students to
168 compare and contrast it with light microscopy, thereby deepening their understanding of cellular
169 components.

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

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

190 Learning objectives and outcomes of the biology laboratory curriculum

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

198 Both the learning objectives and outcomes focus on foundational skills (e.g., laboratory safety, pipetting,
199 and microscopy), core biological techniques (e.g., PCR and gel electrophoresis), and interdisciplinary

200 applications (e.g., biostatistics and cell culture). They are structured into three categories: Knowledge
201 and Understanding, Practical Skills, and Transversal Skills, to ensure comprehensive development. For
202 example, "Knowledge and Understanding" covers defining processes like osmosis and enzyme kinetics,
203 while "Practical Skills" emphasize hands-on tasks such as performing qualitative biomolecule tests.
204 "Transversal Skills" further cultivate critical thinking, collaboration, and ethical reasoning by integrating
205 peer-review exercises and real-world problem-solving scenarios into lab work. This holistic approach
206 ensures that students acquire versatile scientific competencies tailored for modern challenges in health
207 sciences.

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

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

224

225 **DISCUSSION**

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

233 Standardized Biology Laboratory Curriculum Framework

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

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

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

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

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

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

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

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

318 Importantly, the current study revealed that the integration of laboratories varied widely in health-
319 related disciplines. This finding underscores the disparity in laboratory education across institutions and
320 highlights the importance of incorporating practical labs to foster understanding of biological sciences
321 (5,16). Given the significant role that biology labs play in skill development, there is a compelling case for
322 their further integration into health science curricula. By embedding comprehensive laboratory
323 experiences within undergraduate programs, educators can ensure that students acquire the necessary
324 skills to meet the demands of the healthcare industry. This integration not only enhances the quality of

325 education but also prepares students to address complex global health challenges effectively. Biology
326 laboratories serve as essential platforms for developing practical skills and competencies that are crucial
327 for health science students. Through hands-on experiments, students gain proficiency in laboratory
328 techniques, data analysis, and scientific inquiry, which are fundamental to their future roles as health
329 professionals. The experiential learning environment of biology labs fosters critical thinking and
330 problem-solving abilities, enabling students to apply theoretical knowledge in real-world contexts (5,17).
331 In particular, these foundational skills empower students to interpret physiological data and
332 experimental outcomes more effectively, bridging molecular processes with clinical concepts in
333 subsequent coursework.

334 Implementation Considerations and Future Directions

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

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

368 and cohesive learning experience, ultimately contributing to the development of competent and skilled
369 health professionals ready to tackle the challenges of an interconnected world (1).

370 Conclusion

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

381

382 SUPPLEMENTAL MATERIAL

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

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

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

386

387 GRANTS

388 Erasmus+ Programme under Grant number: 2023-1-CY01-KA220-HED-000166031 (to SAN).

389 DISCLOSURES

390 Nothing to declare.

391 AUTHOR CONTRIBUTIONS

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

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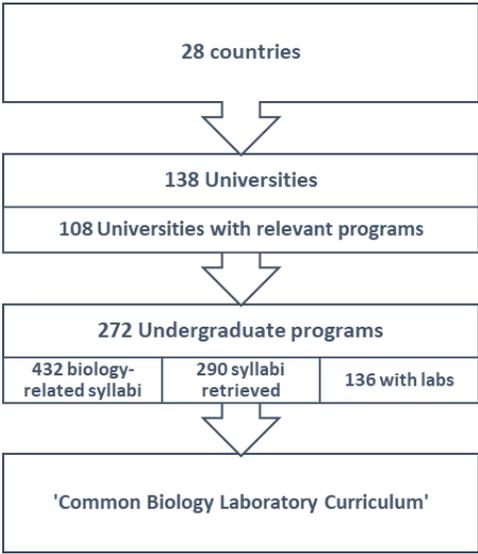
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441 **FIGURE LEGENDS**

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

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



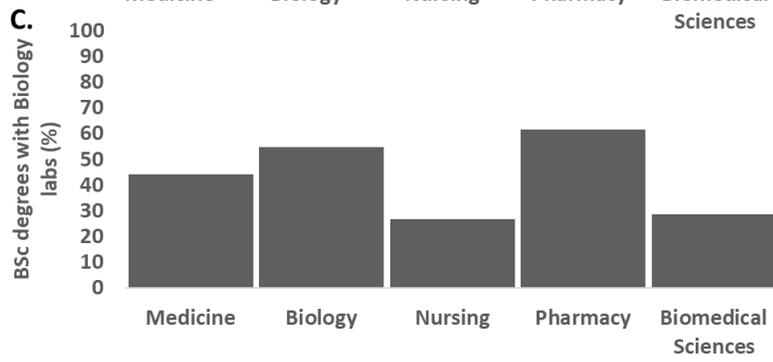
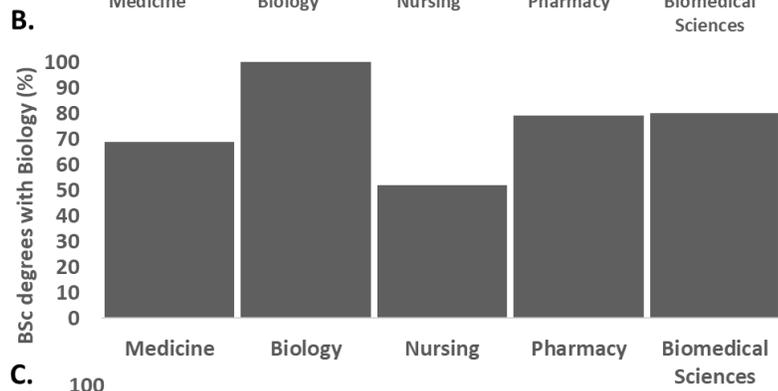
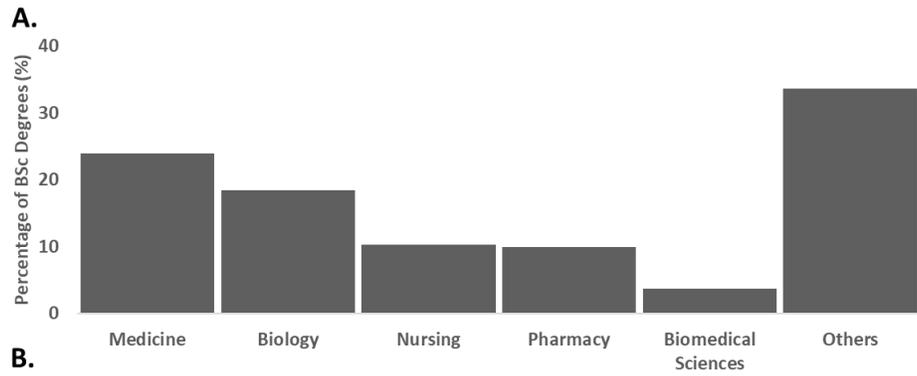


Table 1: Course syllabi titles used for laboratory information extraction

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
<ol style="list-style-type: none">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
<ol style="list-style-type: none">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
<ol style="list-style-type: none">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.