Supplemental Material for "*National biology learning objectives and assessment questions often overlook science's connection to society*"

This supplemental document contains Tables S1-S9.

Table S1. Summary of the biology education resources included in the study.

Name	**Citation**	**Description**	**Total items (n)**	**LOs (n)**	**AQs (n)**
		College preparatory			
Next Generation Science Standards, grade 11 life sciences	*High School Life Sciences*. (n.d.). Next Generation Science Standards. https://www.nextgenscience.org/	An educational framework used widely in K-12 education in the US. It has three dimensions: science and engineering practices, disciplinary core ideas, and crosscutting concepts. Each grade has specific standards which teachers use to structure their courses and are used to inform the development of standardized tests.	**31**	31	0
Washington Comprehensive Assessment of Science	*Prepare for the WCAS*. (n.d.). https://wa.portal.cambiumast.com/prepare-for-wcas.html	A standardized exam to measure the level of proficiency that Washington grade 11 students have achieved. It is based on the Next Generation Science Standards.	**18**	0	18
AP Biology	*AP Biology Exam – AP Students | College Board. (n.d.). https://apstudents.collegeboard.org/courses/ap-biology/assessment*	An advanced placement (AP) course offered to high school students. After taking the course, students have the option to take the AP Biology exam which can give them college credit to transfer to their university based on performance.	**548**	416	132
		College level			
Genetics Learning Framework	*Genetics Learning Framework*. (n.d.). Genetics Society of America. https://genetics-gsa.org/education/genetics-learning-framework/	A list of core concepts and competencies representing the knowledge that an undergraduate should gain during an introductory genetics course. Designed to support instructors in designing their courses. Developed by the Genetics Society of America's Education Committee.	**99**	99	0
Four-Dimensional Ecology Education	*The Framework – Four-Dimensional*	A framework for teaching ecology at the	**77**	77	0

Framework	*Ecological Education*. (n.d.). https://www.esa.org/4dee/framework/	undergraduate level. Each of the four dimensions has elements nested within them. Iteratively developed by the Ecological Society of America.			
Learning Objectives for Introductory Biology	Hennessey & Freeman. (2024). Nationally endorsed learning objectives to improve course design in introductory biology. *PLOS ONE*, *19*(8), e0308545. https://doi.org/10.1371/journal.pone.0308545	A set of specific learning objectives for introductory biology courses (for majors). Developed by a team of education researchers with input from over 800 instructors across the US. Designed to cover 75% of the curriculum, with the remaining 25% up to the instructor's discretion. Aligned to the core concepts and competencies set forth in *Vision and Change.*	**163**	163	0
Biochemistry and Molecular Biology Core Concepts	*Core concept teaching strategies*. (n.d.). https://www.asbmb.org/education/core-concept-teaching-strategies	A resource for teaching core concepts and competencies in biochemistry and molecular biology, developed by the American Society for Biochemistry and Molecular Biology. Developed with input from biology faculty and undergraduate students by a group of biology educators and education researchers.	**201**	201	0
Understanding Evolution Framework	*Understanding Evolution*. (n.d.). Understanding Evolution. https://evolution.berkeley.edu/teach-evolution/conceptual-framework/	A conceptual framework for teaching evolution across grade levels (from K-2 to undergraduate). We focused on the Undergraduate-level items. Understanding Evolution is a non-commercial, education website managed by the University of California Museum of Paleontology.	**137**	137	0
International Society for Computational Biology Competencies	Brooksbank, Brazas, Mulder, et al. (2024). The ISCB competency framework v. 3: A	A core competency framework to support the development of bioinformatics courses, consisting of knowledge,	**245**	245	0

	revised and extended standard for bioinformatics education and training. *Bioinformatics Advances*, *4*(1), vbae166. https://doi.org/10.1093/bioadv/vbae166	skills, and attitudes necessary for bioinformatics. Development was led by the International Society for Computational Biology, with input from the broad bioinformatics training community.			
American Association of Immunologists Recommendations	Porter, Amiel, Bose, et al. (2021). American Association of Immunologists Recommendations for an Undergraduate Course in Immunology. *ImmunoHorizons*, *5*(6), 448–465. https://doi.org/10.4049/immunohorizons.2100030	A set of key topics, foundational concepts, subtopics, examples, and advanced subtopics to support curriculum development in higher education. Developed by the American Association of Immunologists Education Committee with input from faculty from undergraduate, graduate, and medical institutions.	**716**	716	0
ImmunoSkills Guide	Pandey, Elliott, Liepkalns, et al. (2024). The ImmunoSkills Guide: Competencies for undergraduate immunology curricula. *PLOS ONE*, *19*(11), e0313339. https://doi.org/10.1371/journal.pone.0313339	A hierarchical learning framework comprised of core competencies, illustrative skills, and example learning outcomes. Developed based on data from surveys, focus groups, and interviews with biology educators and faculty. Designed to be a resource for structuring immunology undergraduate courses and programs.	**61**	61	0
Core Concepts for Neuroscience	Chen, Phillips, Schaefer, Sonner. (2023). Community-Derived Core Concepts for Neuroscience Higher Education. *CBE—Life Sciences Education*, *22*(2), ar18. https://doi.org/10.1187/cbe.22-02-0018	Core concepts for neuroscience to provide a framework for organizing facts and structuring curricula in neuroscience. The core concepts were created via a nationwide (US) survey and working session of over 100 neuroscience educators.	**35**	35	0

Bioinformatics Core Competencies	Wilson Sayres, Hauser, Sierk, et al. (2018). Bioinformatics core competencies for undergraduate life sciences education. *PLoS ONE*, *13*(6), e0196878. https://doi.org/10.1371/journal.pone.0196878	A set of core competencies in bioinformatics for undergraduate life sciences students developed by a group of biologists and biology education researchers via a national (US) survey of biology faculty.	**36**	36	0
Core Concepts of Physiology	Michael, & McFarland. (2020). Another look at the core concepts of physiology: Revisions and resources. *Advances in Physiology Education, 44(4),* 752–762. https://doi.org/10.1152/advan.00114.2020	A revised version of the original core concepts of physiology published in 2011. Both iterations were created by a group of biology educators and education researchers. The core concepts of physiology are intended to provide instructors with recommendations for course structure and learning outcomes.	**14**	14	0
Curriculum Guidelines for Undergraduate Microbiology Education	ASM Curriculum Guidelines for Undergraduate Microbiology. (2024, March 5). *American Society for Microbiology.* https://asm.org:443/guideline/asm-curriculum-guidelines-for-undergraduate-microb	A set of concepts and skills for undergraduate general microbiology courses, designed to be curriculum recommendations. Created by a task force from the American Society for Microbiology.	**49**	49	0
MCAT	*Free Planning and Study Resources. (n.d.). Students & Residents. https://students-residents.aamc.org/prepare-mcat-exam/free-planning-and-study-resources*	Medical school entrance exam that undergraduate biology students often prepare for during their final 1-2 years of coursework.	**460**	0	460

Table S2. Descriptions of the coding response options for each variable in the coding rubric (**Table 2**).

Variable	Response option	Description
Explicitness of SOCIAL context (LOs)	Vague potential to incorporate SOCIAL context	An instructor could incorporate SOCIAL context when addressing this LO, but SOCIAL context was not necessary for achieving the LO.
	Clear potential/implicitly incorporates SOCIAL context	The LO was written in such a way that the SOCIAL context was implicit, or was clearly guiding the instructor to include SOCIAL context.
	Explicitly incorporates SOCIAL context	The language of the LO explicitly included SOCIAL context.
Subdiscipline	Anatomy	Study of the structure and arrangement of an organism's body parts
	Biochemistry	Study of the chemical reactions and chemical properties present in biological systems
	Biophysics	Study of the physics principles and theories that apply within biological systems
	Biotechnology	Study of new technologies or innovations regarding biological systems
	Botany	Study of plants
	Cell biology	Study of cellular structures and organisms
	Computational biology	Study of quantitative biology that requires computer-based tools, modeling, and programming
	Developmental biology	Study of the development of biological systems
	Ecology	Study of the relationships between living organisms and their physical environment
	Evolutionary biology	Study of the evolution of life on Earth from the molecular to organismal levels
	Genetics	Study of genes, genetic variation, and heredity, including the central dogma of biology and genomics
	Immunology	Study of the immune system and its component parts across levels of organization, including public health
	Marine biology	Study of the organisms that live in marine environments and their interactions with each other and the environment
	Microbiology	Study of microbes and microscopic organisms
	Neurobiology	Study of the nervous system

	Paleontology	Study of the history of life on Earth, primarily through rocks and fossils
	Pharmacology	Study of drugs and their mechanisms
	Physiology	Study of how the systems within an organism interact and function to sustain life
	Zoology	Study of animal behavior and physiology
	Agnostic	Not specific to a single subdiscipline of biology
Topic	Environment (including pollution)	Related to environmental phenomena, descriptions of ecology, pollution
	Public health	Related to pandemics, infectious disease, vaccination campaigns
	Human health/disease (individual)	Related to specific diseases that an individual faces (e.g., cancer, diabetes)
	Interdisciplinary nature of science	Science fields are interconnected with each other and also connected to non-science fields
	Ethics	Related to ethical considerations of research, such as IRB, IACUC, and lab safety procedures
	Climate change	Related to global climate change patterns and disruptions to global climate. May be explicitly anthropogenic or not
	Technology and innovation	Related to advances in technology (e.g., gene drive, AI, how vaccines work)
	Conservation and resource management	Related to human interventions to protect the environment or individual species
	Individual sustainable actions	Related to solutions to climate change and sustainability that are relevant at the individual level
	Collective sustainable actions (e.g., Kyoto Protocol)	Related to solutions to climate change and sustainability that are relevant at the societal level
	History and philosophy of science	Related to historical events relevant to science or the philosophical underpinnings of science
	Human economic systems (e.g., agriculture, genetic engineering, forestry)	Related to agriculture yields, species management for human populations to survive (e.g., eradicating malaria), and other economic and societal systems that are reliant upon ecosystems or species
	Other biology	Related to a biology topic not included above
	Other non-biology	Related to a non-biology topic not included above

Aspect of curriculum (LO)	Concept/content	A statement of content knowledge, topic, or biological concept that students are expected to gain
	Competency/skill	A skill that students are expected to demonstrate
Location (AQ)	Set-up/Passage	The initial framing of the question, which could be in the form of a passage, presentation of data, or brief description presented to students to provide context
	Task	The root of what the question is asking students to do
Learner-centered language (AQ)	Activity or object of daily living (i.e. "You drop a ball")	“You” are the individual completing the task using an everyday object described in the set-up of the question
	Science-specific task or item (i.e. "You are a pediatrician, you titrate")	“You” are the individual completing the science-related task described in the set-up of the question
Core concept (Brownell et al., 2014)	Evolution	Evolution is a change in allele frequencies caused by mutations, natural selection, gene flow, or genetic drift. Populations can diverge, leading to the formation of new species.
	Structure and function	Biological structures can be studied at all levels of organization, from molecules to ecosystems. A structure’s function is a product of its physical characteristics (e.g., size and chemical composition).
	Information flow, exchange, and storage	Organisms inherit genetic and epigenetic information that contribute to an individual’s phenotype. The timing and degree of gene expression is highly regulated, in a way that affects phenotype. Cells/organs/organisms constantly monitor their internal and external environment. Perception and transmission of this information allows organisms to respond to changing conditions.
	Pathways and transformations of energy and matter	Life takes work – it can only be sustained with inputs of energy. Natural selection has favored the evolution of regulatory systems that allow individuals to use limited resources efficiently.
	Systems	Biological molecules, cells, tissues, organs, and individuals do not exist in isolation— they interact in a highly regulated way. Organisms have evolved complex systems to integrate internal and external information and respond to their changing environments.
	None	The item is not related to one of the 5 core concepts described above (i.e., is only related to science and society, e.g., ethics)
Core competency (Clemmons et	Ability to apply the process of science	Competence in process of science outcomes will help students become not only proficient scientists, but also critical thinkers and scientifically literate citizens.

al., 2020)		Specific skills include scientific thinking, information literacy, critical thinking, understanding the nature of science, question formulation, study design, and data interpretation and evaluation.
	Ability to use quantitative reasoning	This competency is integral to work in all biological subdisciplines and an important component of several other core competencies. Specific skills include math, logic, data management and presentation, and an introduction to computation.
	Ability to use modeling and simulation	Models are tools that scientists use to develop new insights into complex and dynamic biological structures, mechanisms, and systems. Example model types include: mathematical (e.g., equations, charts), computational (e.g., simulations), visual (e.g., diagrams, concept maps), and physical (e.g., 3D models).
	Ability to tap into the interdisciplinary nature of science	Efforts to solve today's complex problems will require perspectives of those working at multiple biological scales (i.e., molecules to ecosystems), in multiple STEM fields (e.g., math, engineering), and in non-STEM fields (e.g., humanities, social sciences), and from input from those outside academia (e.g., city planners, medical practitioners, community leaders).
	Ability to communicate and collaborate with other disciplines	Communication and collaboration are essential components of the scientific process. Skills include communicating effectively with biologists, other non-biology experts, and the general public for a variety of purposes and practicing metacognition – the ability to accurately sense and regulate one's behavior both as an individual and as part of a team.
Time scale	Pre-1900	Related to a historical figure or event from before 1900
	1901-1950	Related to a historical figure or event between 1901 and 1950
	1951-2000	Related to a historical figure or event between 1951 and 2000
	2001-present	Related to a historical figure or event after 2001
	Future (2100-)	Related to a future projected event (after 2100)
	N/A (time scale irrelevant and/or not provided)	Not related to a specific historical figure or event
SSI (Sadler, 2009; Wang et al., 2017)	Yes	Directly related to a complex societal challenge with conceptual, procedural, and/or methodological connections to science
	No	Not directly related to a complex societal challenge with conceptual, procedural, and/or methodological

		connections to science
BioSkills science and society program- level learning outcome (Clemmons et al., 2020)	Ethics	Demonstrate the ability to critically analyze ethical issues in the conduct of science.
	Societal influences	Consider the potential impacts of outside influences (historical, cultural, political, technological) on how science is practiced.
	Science's impact on society	Apply scientific reasoning in daily life and recognize the impacts of science on a local and global scale.
BioSkills science and society course-level learning outcome (Clemmons et al., 2020)	1-1 Ethical considerations of research study	Identify and evaluate ethical considerations (e.g., use of animal or human subjects, conflicts of interest, confirmation bias) in a given research study.
	1-2 Ethical controversies	Critique how ethical controversies in biological research have been and can continue to be addressed by the scientific community.
	2-1 Bias and background	Describe examples of how scientists' backgrounds and biases can influence science and how science is enhanced through diversity.
	2-2 Systemic factors	Identify and describe how systemic factors (e.g., socioeconomic, political) affect how and by whom science is conducted.
	3-1 Evidence-based decisions	Apply evidence-based reasoning and biological knowledge in daily life (e.g., consuming popular media, deciding how to vote).
	3-2 Relevant examples	Use examples to describe the relevance of science in everyday experiences.
	3-3 Social impacts of research	Identify and describe the broader societal impacts of biological research on different stakeholders.
	3-4 Scientists as communicators	Describe the roles scientists have in facilitating public understanding of science.
Critical consciousness / Justice-orientation (Continuum) (Meuler et al., 2023)	None/scarce	A topic is alluded to or mentioned, no other detail provided
	Detail	A topic is expanded on, perhaps an example is provided that illustrates the topic
	Nuance	A topic is presented in a way that would allow reasonable people to disagree, two sides mentioned, pros and cons to a certain topic/issue, science is only one part of the picture/issue
	Inequity/Equity	A topic and/or issue is described as disproportionately impacting some individuals more than others, recognizing a lack of fairness in a situation, or recognizing that some people are impacted in a way

		that is different than others, etc.
	Justice	A certain inequity or injustice is described as being able to be addressed BY science and explains how science can be used to help strive toward social justice

Table S3. Source-specific frequencies for items coded (percentages out of the total number of items within each source) and where they fell on the continuum.

Name of source	Items coded; % (n)	Continuum: Scarce; n	Continuum: Detail; n	Continuum: Nuance; n	Continuum: Inequity/ Equity; n	Continuum: Justice; n
College preparatory						
Next Generation Science Standards, grade 11 life sciences	12.9 (4)	0	2	2	0	0
Washington Comprehensive Assessment of Science	5.6 (1)	0	1	0	0	0
AP Biology	2.4 (13)	4	8	1	0	0
College level						
Genetics Learning Framework	5.1 (5)	4	0	1	0	0
Four Dimensional Ecology Education Framework	23.4 (18)	9	5	3	0	1
Learning Objectives for Introductory Biology	6.7 (11)	5	5	1	0	0
Biochemistry and Molecular Biology Core Concepts	2.5 (5)	2	2	1	0	0
Understanding Evolution Framework	8.8 (12)	7	5	0	0	0
International Society for Computational Biology Competencies	19.6 (48)	20	22	5	1	0
American Association of Immunologists Recommendations	4.1 (29)	8	17	4	0	0
ImmunoSkills Guide	21.3 (13)	6	6	1	0	0

Core Concepts for Neuroscience	28.6 (10)	4	6	0	0	0
Bioinformatics Core Competencies	11.1 (4)	0	1	3	0	0
Core Concepts of Physiology	14.3 (2)	1	1	0	0	0
Curriculum Guidelines for Undergraduate Microbiology Education	14.3 (7)	4	2	1	0	0
MCAT	6.7 (31)	17	4	2	8	0

Table S4. Summary of the number of items that included SOCIAL context across subdisciplines of biology. Percentages out of the number of items coded (n=213).

Subdiscipline	Count	Percentage
Agnostic	72	33.8
Immunology	53	24.9
Ecology	42	19.7
Computational biology	18	8.5
Evolutionary biology	18	8.5
Genetics	11	5.2
Microbiology	9	4.2
Biotechnology	4	1.9
Physiology	4	1.9
Biochemistry	3	1.4
Neurobiology	2	0.9
Marine biology	1	0.5

Table S5. Summary of the number of items that included SOCIAL context across different topics. Percentages out of the number of items coded (n=213).

Topic	Count	Percentage
Ethics	53	24.9
Public health	52	24.4
History and philosophy of science	43	20.2
Environment	41	19.2
Other non-biology	38	17.8
Human health/disease	31	14.6
Technology and innovation	26	12.2
Science communication	25	11.7
Other biology	20	9.4
Evolution	13	6.1
Interdisciplinary nature of science	11	5.2
Conservation and resource management	10	4.7
Human economic systems	7	3.3
Climate change	6	2.8
Information literacy	6	2.8
Sociology	5	2.3
Genetics	3	1.4
Individual sustainable actions	2	0.9
Biodiversity	2	0.9
Psychology	2	0.9
Collective sustainable actions	1	0.5
Policy	1	0.5
Process of science	1	0.5
Homeostasis	1	0.5

Table S6. Summary of the number of items that included SOCIAL context and their alignment to the core concepts and competencies. Percentages out of the number of items coded (n=213).

Core concept or competency	**Count**	**Percentage**
Core concepts		
Systems	125	58.7
Evolution	16	7.5
Information flow, exchange, and storage	9	4.2
Pathways and transformations of energy and matter	7	3.3
Structure and function	0	0.0
None	19	8.9
Core competencies		
Process of science	58	27.2
Communicate and collaborate with other disciplines	28	13.1
Interdisciplinary nature of science	16	7.5
Quantitative reasoning	1	0.5
Modeling and simulation	1	0.5
None	5	2.3

Table S7. Summary of the number of items that included SOCIAL context across different time scales. Percentages out of the number of items coded (n=213).

Time scale	Count	Percentage
N/A	183	85.9
Pre-1900	8	3.8
1901-1950	4	1.9
1951-2000	20	9.4
2001-present	4	1.9

Table S8. Distribution of items across levels of the continuum, disaggregated by topic. Each cell represents the number of items that were coded as relating to a particular topic for each level of the continuum.

Topic	Scarce	Detail	Nuance	Inequity/Equity	Justice
Ethics	9	26	15	2	1
Public health	14	24	6	8	0
History and philosophy of science	24	14	5	0	0
Environment	12	23	5	0	1
Human health/disease	9	16	4	2	0
Technology and innovation	14	7	5	0	0
Science communication	20	3	2	0	0
Evolution	5	8	0	0	0
Interdisciplinary nature of science	5	2	4	0	0
Conservation and resource management	2	6	2	0	0
Human economic systems	3	4	0	0	0
Climate change	3	3	0	0	0
Information literacy	3	3	0	0	0
Sociology	3	1	0	1	0
Genetics	3	0	0	0	0
Individual sustainable actions	0	1	1	0	0
Biodiversity	1	1	0	0	0
Psychology	2	0	0	0	0
Collective sustainable actions	0	0	1	0	0
Policy	0	0	1	0	0
Process of science	1	0	0	0	0
Homeostasis	1	0	0	0	0

Table S9. Distribution of items across levels of the continuum, disaggregated by whether the source was college preparatory or college level.

Level	Scarce	Detail	Nuance	Inequity/Equity	Justice
College prep	4	11	3	0	0
College	87	76	22	9	1