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BioSkills Guide: Development and National Validation of a Tool for Interpreting the Vision and Change Core Competencies

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BioSkills Guide: Development and National Validation of a Tool for Interpreting the *Vision and Change* Core Competencies

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ABSTRACT
To excel in modern science, technology, engineering, and mathematics careers, biology majors need a range of transferable skills, yet competency development is often a relatively underdeveloped facet of the undergraduate curriculum. We have elaborated the *Vision and Change* core competency framework into a resource called the BioSkills Guide, a set of measurable learning outcomes that can be more readily implemented by faculty. Following an iterative review process including more than 200 educators, we gathered evidence of the BioSkills Guide's content validity using a national survey of more than 400 educators. Rates of respondent support were high (74.3–99.6%) across the 77 outcomes in the final draft. Our national sample during the development and validation phases included college biology educators representing more than 250 institutions, including 73 community colleges, and a range of course levels and biology subdisciplines. Comparison of the BioSkills Guide with other science competency frameworks reveals significant overlap but some gaps and ambiguities. These differences may reflect areas where understandings of competencies are still evolving in the undergraduate biology community, warranting future research. We envision the BioSkills Guide supporting a variety of applications in undergraduate biology, including backward design of individual lessons and courses, competency assessment development, and curriculum mapping and planning.

INTRODUCTION
Undergraduate biology students pursue a wide variety of career paths. Approximately 46% of undergraduates majoring in life sciences–related fields go on to science, technology, engineering, and mathematics (STEM) or STEM-related occupations, including research, engineering, management, and healthcare (Landivar, 2013). The more than half of life science majors employed outside of STEM can be found in non–STEM related management, business, and K–12 education, among many other positions. Considering that the majority of college students and the general public indicate career success as the primary motivation for attending college (Pew Research Center, 2016; Twenge and Donnelly, 2016; Strada Education Network, 2018), it follows that undergraduate biology curricula should include competencies that will help students thrive in their postcollege pursuits, in or out of STEM.

Employers across fields routinely rank competencies such as collaboration, communication, and problem solving at the top of the list of desirable employee traits (Strauss, 2017; National Association of Colleges and Employers, 2018), and also report that new hires are not adequately trained in these areas (Bayer Corporation, 2014; Hart Research Associates, 2018). While "skills gap" rhetoric and the associated vocational framing of higher education has been criticized (Cappelli, 2015; Camilli and Hira, 2019), college courses are nonetheless a natural environment for competency development because of the opportunities to practice skills in the context of

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relevant knowledge and receive formative feedback from disciplinary experts (Hora, 2018).

Competencies and STEM Curriculum Reform

Many national reports have pushed educators to re-examine how competencies are integrated into undergraduate STEM course work (National Research Council [NRC], 2003, 2012b; National Academies of Sciences, Engineering, and Medicine [NASEM], 2016). In undergraduate biology, these recommendations are presented in the report *Vision and Change in Undergraduate Biology Education: A Call to Action* (American Association for the Advancement of Science [AAAS], 2011). The recommendations of *Vision and Change* emerged from discussions among more than 500 stakeholders in undergraduate biology education, including educators, administrators, students, scientists, and education researchers. To prepare students for modern careers, the report urges biology educators to frame discussions of curricula around five core concepts and six core competencies (listed in Table 1).

The publication of *Vision and Change* in 2011 coincided temporally with several similar efforts to guide STEM curriculum reform. The updated AP Biology Curriculum Framework emphasized science practices (College Board, 2015). Foundations for Future Physicians advised premedical and medical educators away from curriculum based on lists of courses and toward the measurement of scientific competencies (Association of American Medical Colleges & Howard Hughes Medical Institute, 2009). The NRC's *Framework for K–12 Science Education* advocated for the "three-dimensional" (3D) integration of disciplinary core ideas, crosscutting concepts, and scientific practices (NRC, 2012a). The *Framework for K–12 Science Education*'s approach to elementary and secondary science education aimed to improve science literacy in the population as a whole by better engaging students in authentic scientific experiences. Since its publication, the *Framework for K–12 Science Education* has emerged as the consensus framework for developing K–12 science curricula and has been enumerated into the Next Generation Science Standards (Next Generation Science Standards [NGSS] Lead States, 2013).

In comparing the *Vision and Change* core competencies with the *Framework for K–12 Science Education* scientific practices, we find a few notable differences (Table 1). Whereas *Vision and Change* explicitly includes the ability to collaborate and to understand the relationship between science and society, these practices are not directly called out in the *Framework for K–12 Science Education*. Similarly, while the *Framework for K–12 Science Education* specifically highlights the ability of students to construct explanations, this practice is only implicitly included in *Vision and Change* within the core competency of process of science. However, taken as a whole, the overlap between the core competencies and scientific practices is substantial (Table 1). The parallel evolution of K–12 and undergraduate curricular goals represents an opportunity to cohesively improve educational outcomes and is an area that deserves continued attention to ensure a smooth transition from high school to college.

The development of the *Vision and Change* curricular recommendations was an important milestone in undergraduate biology education. By bringing together biologists and biology education experts to reimagine the curriculum, the resulting recommendations were specifically tailored to undergraduate biology but with substantial overlap with related educational efforts. Furthermore, the resulting concepts and competencies provided a common goal, written in the language of biology educators, promoting buy-in. As such, the *Vision and Change* curricular framework has been widely embraced by the undergraduate biology community (AAAS, 2015, 2018, 2019; Brancaccio-Taras *et al.*, 2016; Dirks and Knight, 2016; *CourseSource*, n.d.). However, because the report's descriptions of the core concepts and competencies were left intentionally brief to encourage ongoing conversations among educators, they require elaboration in order to be implemented. Since then, two groups have unpacked the core concepts into more detailed frameworks (Brownell *et al.*, 2014a; Cary and Branchaw, 2017).

For competencies, biology education researchers have enumerated a variety of specific scientific practices, including science process skills (Coil *et al.*, 2010), experimentation (Pelaez *et al.*, 2017), scientific literacy (Gormally *et al.*, 2012),

TABLE 1. Comparison of *Vision and Change in Undergraduate Biology Education* core competencies (AAAS, 2011) and *Framework for K–12 Science Education* scientific practices (NRC, 2012a)

Vision and Change core competencies	Framework for K–12 Science Education scientific practices
• Ability to apply the process of science	• Asking questions • Analyzing and interpreting data • Planning and carrying out investigations • Engaging in argument from evidence • Obtaining, evaluating, and communicating information[a]
• Ability to use quantitative reasoning	• Using mathematics and computational thinking
• Ability to use modeling and simulation[b]	• Developing and using models
• Ability to tap into the interdisciplinary nature of science	• Crosscutting concepts[c]
• Ability to communicate and collaborate with other disciplines	• Obtaining, evaluating, and communicating information[a]
• Ability to understand the relationship between science and society	
	• Constructing explanations

[a]This scientific practice aligns with two of the core competencies.
[b]Conceptions of what models are and how they are used are not well defined in *Vision and Change* and thus may differ from the scientific practice presented in the *Framework for K–12 Science Education*.
[c]Crosscutting concepts is a separate dimension of the 3D *Framework for K–12 Science Education*, not a scientific practice.

responsible conduct of research (Diaz-Martinez *et al.*, 2019), quantitative reasoning (Durán and Marshall, 2018; Stanhope *et al.*, 2017), bioinformatics (Wilson Sayres *et al.*, 2018), data science (Kjelvik and Schultheis, 2019), data communication (Angra and Gardner, 2016), modeling (Quillin and Thomas, 2015; Diaz Eaton *et al.*, 2019), the interdisciplinary nature of science (Tripp and Shortlidge, 2019), and scientific writing (Timmerman *et al.*, 2011). Efforts to define general or STEM-wide educational goals for college graduates can also inform how we teach competencies in biology, such as the Association of American College and University VALUE rubrics (Rhodes, 2010) and more targeted work on information literacy (Association of College and Research Libraries, 2015), communication (Mercer-Mapstone and Kuchel, 2017), and process skills (Understanding Science, 2016; Cole *et al.*, 2018). However, no resource has yet been developed that *holistically* considers competencies across college biology programs or that is intentionally aligned with the recommendations of *Vision and Change*.

Project Goals and Context

With the overarching goal of improving biology undergraduates' achievement of competencies relevant to their careers and life as scientifically literate citizens, we set out to expand the six *Vision and Change* core competencies into measurable learning outcomes that describe what general biology majors should be able to *do* by the time they graduate. The intention of this work is to establish competency learning outcomes that:

1. define what each of the broadly stated competencies means for an undergraduate biology major, especially for less commonly discussed competencies such as modeling and interdisciplinary nature of science;
2. draw on instructor expertise to calibrate an appropriate level of competency that can be achieved over the course of a 4-year biology program;
3. serve as a starting point for backward design of individual courses or departmental programs; and
4. ease interpretation, and therefore adoption, of the *Vision and Change* core competencies in undergraduate college curricula.

The term "competency" describes a "blend of content knowledge and related skills" (NRC, 2012b) and is thus appropriate for describing complex tasks like modeling biological systems or understanding the interrelatedness of science and society. The term "scientific practice" is employed similarly in the *Framework for K–12 Science Education* (NRC, 2012a). However, throughout the development of this resource through workshops, roundtables, and informal conversations, we found that the term "skill" was more immediately recognizable (to biology educators not engaging in discipline-based education research [DBER]) and less frequently unintentionally confused with the term "concept" (especially when talking about "concepts and competencies"). While it should be noted that use of the term "skill" can connote a simplified behaviorist framing of science education (e.g., teacher-centered practice and rote memorization via repetitive drills; Agarkar and Brock, 2017), we did not find this implied definition to be held among our sample of biology educators. Instead, we found that the term "skills" was understood to refer to a broad set of competencies performed within a biological context. For the purpose of this study, we have therefore used the term "skills" interchangeably with "competencies" and have named the resource we developed the "BioSkills Guide."

We describe here the iterative, mixed-methods approach we used to develop and establish content validity of the BioSkills Guide. We interpreted evidence of content validity as expert judgment of the relationship between the parts of the framework (i.e., the learning outcomes in the BioSkills Guide) and the construct (i.e., core competencies for undergraduate biology course work; American Educational Research Association *et al.*, 2014). We collected evidence of content validity via a survey of college biology educators across a range of institution types and geographic locations within the United States, a population we selected based on their combined expertise in biology and undergraduate biology teaching. Many educators in our sample were discipline-based education researchers, and thus brought that expertise as well. We also chose to focus on this population because they are the intended users of the guide. Institutional change has been shown to be most effective when the work is envisioned and led by those directly impacted by the change (Henderson *et al.*, 2010). A similar grassroots approach was used to develop *Vision and Change* itself, as well as related frameworks elaborating the core concepts (Brownell *et al.*, 2014a; Cary and Branchaw, 2017), which have been widely utilized in our field (Smith *et al.*, 2019; Branchaw *et al.*, 2020). We believe this approach is another reason why *Vision and Change* has been so impactful in biology education.

Specifically, we asked the following research questions (RQs):

RQ1a: Can we identify an essential set of learning outcomes aligned with the *Vision and Change* core competencies?
RQ1b: How much do biology educators agree on this essential set of competency learning outcomes?
RQ2a: Does biology educators' support of learning outcomes differ across competencies?
RQ2b: Do biology educators with different professional backgrounds differ in their support of learning outcomes across competencies?

The final draft of the BioSkills Guide contains 77 measurable learning outcomes (20 program-level and 57 course-level outcomes) that elaborate the six *Vision and Change* core competencies. Both the BioSkills Guide and an "expanded BioSkills Guide," which contains illustrative examples of activities intended to support student mastery of the learning outcomes, are available in the Supplemental Material. The BioSkills Guide is also available at https://qubeshub.org/qubesresources/publications/1305.

METHODS

This work can be divided into two phases: a constructive development phase (RQ1a) and an evaluative validation phase (RQ1b; the phases are summarized in Figure 1). During the development phase, we used a range of methods to gather biology education community feedback on sequential drafts of the BioSkills Guide: Web surveys, unstructured and semi-structured interviews, workshops, and roundtables (Table 2). During the validation phase, we used a Web survey to measure support for the final draft among the broader biology

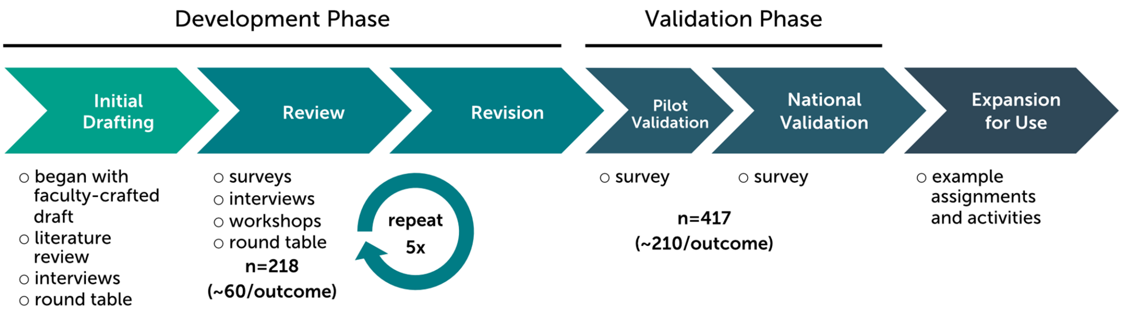

FIGURE 1. **BioSkills Guide methods overview. Initial drafting included all work to generate BioSkills Guide version I. Five rounds of review and revision were carried out on versions I–V (RQ1a). Pilot validation evaluated version VI (RQ1b). National validation evaluated final version of BioSkills Guide (RQ1b).**

education community. We then applied the validation phase survey data to answer RQ2a and 2b. This study was approved by the University of Washington, Human Subjects Division as exempt (STUDY00001746).

Development Phase

To address RQ1a, we developed the initial draft of the BioSkills Guide by building on a set of programmatic learning outcomes crafted by biology faculty at a large, public research university in the Northwest as part of routine departmental curricular review. We supplemented the initial draft by cross-checking its content with the literature, leading unstructured interviews with competency experts, and gathering feedback on a portion of the draft at a roundtable at a national biology education conference (additional details in Supplemental Methods).

We next began the first of five rounds of review and revision of iterative drafts of the learning outcomes (Table 2). First, we collected feedback on version I of the outcomes in writing and via a virtual meeting with our advisory board (three biology faculty with expertise in institutional change, programmatic assessment, and/or curricular framework development). To review version II of the guide, we collected written feedback on

TABLE 2. **Unique participants and institutions during BioSkills Guide development and validation**

Phase	Round	Mode of review	Number of unique participants	Number of unique institutions
Development	Initial drafting	Faculty working groups + department roundtables	20	1
		Literature review		
		Interviews with competency experts	11	4
		Roundtable	24[a]	6[b]
	Version I review	Written feedback from advisory board	3	3
	Version II review	Workshop 1	24[a]	4[b]
	Version III review	Survey 1	21	18[b]
		Workshop 2	6	3
	Version IV review	Survey 2	45	19[b]
		Interviews with community college faculty	3	3
		Interviews with survey respondents	5	5
		Interviews with competency experts	6	5
		Roundtable	21	17
		Workshop 3	32	22
	Version V review	Survey 3	27	21[b]
		Workshop 4	21	1
		Workshop 5	8	1
	Review, combined		**218**[c,d]	**87**[c,d]
Validation	Pilot	Survey 4	20	11[b]
	National	Survey 5	397	220[b]
	Validation, combined		**417**[d]	**225**[c,d]
All, combined			**634**[c,d]	**271**[c,d]

[a]Number of participants is an underestimation, because not all participants completed sign-in sheet.
[b]Number of institutions is an underestimation, because institution is unknown for some participants.
[c]Number of total participants is a conservative estimation due to missing information as described in notes a and b. Number is lower than the sum of above rows because a small percent of people participated at multiple stages, which has been accounted for where possible (e.g., known participants were only counted once; anonymous survey respondents indicating they had previously reviewed the BioSkills Guide were deducted from the total).
[d]Bolding indicates total number of unique participants or institutions for a given phase.

outcome importance, ease of understanding, and completeness at a workshop of biology faculty, postdocs, and graduate students. The final three rounds were larger in scale, and each included a survey to gather feedback on outcome importance, ease of understanding, completeness, and categorization from at least 21 college biology educators (five to 19 per learning outcome per round; Table 2 and Supplemental Table 4). We recruited respondents at regional and national biology education meetings and through regional biology education networks. To participate in any of the surveys, respondents must have served as instructor of record of a college-level biology course. We chose this inclusion criterion because college biology instructors have expertise in both biology and undergraduate biology teaching. Many respondents also had DBER experience (48.4% during the development phase). We gathered additional input on versions III–V drafts using four workshops, one roundtable, and 14 one-on-one interviews. Additional details on BioSkills Guide development are in Supplemental Methods.

At the end of each round of review, we compiled and summarized all relevant data (i.e., data from workshops, interviews, roundtables, or surveys) from that round into a single document to inform revisions. This document was then reviewed by committee (two authors, A.W.C. and A.J.C., for versions I–III revisions; three authors, A.W.C., A.J.C., and J.C.H., for versions IV and V revisions) and used to collectively decide on revisions. The committee discussed all revisions and their justifications over the course of several meetings per round, revisiting relevant feedback from previous rounds as necessary.

During revisions, we reworded outcomes based on feedback to ensure they were easy to understand, calibrated to the right level of challenge for an undergraduate program, and widely relevant to a variety of biology subdisciplines, institution types, and course levels (Supplemental Table 1). New outcomes were considered for addition if they were suggested by more than one participant. We removed outcomes only after multiple rounds of negative feedback despite revisions to improve ease of understanding or possible concerns about challenge level or relevance. We did not have an *a priori* quantitative threshold for survey ratings to determine whether to retain outcomes; however, we critically evaluated any outcomes that had lower than 90% ratings of "important" or "very important" by reviewing qualitative feedback from survey comments, interviews, and workshops. This process resulted in the removal of 21 outcomes total (ranging from 50% to 88% survey ratings of "important" or "very important," with an average of 73.5%) over the course of five rounds of review (Supplemental Table 1). Occasionally, outcomes were removed despite having higher quantitative support than other outcomes that were retained, due to qualitative feedback, such as the outcome had substantial overlap with other outcomes, was too specialized or at too high of a challenge level for an undergraduate general biology major, or could not be readily assessed. In general, we identified problems in the drafts by looking at outcomes that had low ratings or low consensus (e.g., a mixture of low and high ratings). We then used qualitative feedback from survey comments, workshops, roundtables, and interviews to inform revisions.

Validation Phase

To address RQ1b, we next sought to gather evidence of content validity of the final draft via a survey of college biology educators. Before proceeding with a national survey, however, we first conducted a pilot validation on a smaller pool of educators ($n = 20$). After reviewing the results, we revised one outcome: "Identify methodological problems and suggest alternative approaches or solutions." The previous revision of this outcome had reworded it to use language that was appropriate for a wide range of study types (not just experiments) and happened to remove the term "troubleshooting." We speculated that this term had resounded with respondents and thus led to previously observed greater levels of support, so we revised the outcome to reintroduce it. This was the only revision to the guide before moving on to the large-scale national validation (Supplemental Table 1). Additional details on the pilot validation can be found in Supplemental Methods.

For national validation, we invited participation through direct emails and Listservs: Society for Advancement of Biology Education Research (SABER), Partnership for Undergraduate Life Sciences Education regional networks, HHMI Summer Institutes, authors of *CourseSource* articles tagged with "science process skills," Community College BioInsites, Northwest Biology Instructors Organization, the Science Education Partnership and Assessment Laboratory network, Human Anatomy and Physiology Society, SABER Physiology Special Interest Group, several other regional biology education–related networks, and 38 participants suggested by previous survey participants. We additionally encouraged advisory board members, other collaborators, and survey respondents to share the survey invitation widely. Because of the snowball sampling approach and the expected overlap of many of the email lists, it is not possible to estimate the total number of people who were invited to participate. To participate in the survey, respondents had to meet the same survey inclusion criterion (i.e., having taught a college biology course) as during the development phase.

For RQ1b analysis, we combined data from the pilot validation and national validation surveys. Of the 572 people who initiated the validation phase surveys (21 for pilot validation, 551 for national validation), 22 people did not meet our survey inclusion criterion and 133 people did not respond to any questions after the initial screening question (i.e., did not rate any learning outcomes) and so could not be included in our analysis. It is possible that some of these 133 individuals started the survey on one device (e.g., home computer, mobile phone) and later restarted and completed the survey using a different device (e.g., work computer), thus some of these 133 instances may include individuals who ultimately responded to the survey. We do not have demographic data (e.g., institution type, familiarity with *Vision and Change*) for these 133 instances and therefore cannot assess whether these individuals differed on demographic characteristics compared with those who did rate at least one learning outcome. Ultimately, responses from 417 people were retained for the analysis for RQ1b (572 – 22 – 133 = 417; total responses per outcome ranged from 211 to 237).

One minor modification was made in the BioSkills Guide after national validation. The modeling learning outcome "Build and revise conceptual models (e.g., diagrams, concept maps, flow charts) to propose how a biological system or process works" was revised to remove the parenthetical list of examples. We made this revision based on postvalidation feedback from modeling experts, among whom there was disagreement as to whether visual representations such as diagrams and concept maps constitute conceptual models. To avoid confusion, we removed the examples. No other revisions were made to the learning outcomes after the national validation survey (Supplemental Table 1).

Survey Design

As mentioned earlier, we employed five surveys over the course of this project (three in the development phase and two in the validation phase; Table 2). Surveys were designed and administered following best practices in survey design and the principles of social exchange theory (Dillman *et al.*, 2014). For development phase surveys, respondents rated each learning outcome on bipolar five-point Likert scales for: (1) how important or unimportant it is for a graduating general biology major to achieve ("very important," "important," "neither important nor unimportant," "unimportant," and "very unimportant"), and (2) how easy or difficult it is for them to understand ("very easy," "easy," "neither easy nor difficult," "difficult," "very difficult"). We also asked respondents to comment on their responses, suggest missing outcomes, and evaluate (yes/no) whether each learning outcome was accurately categorized within its program-level outcome (when evaluating course-level outcomes) or competency (when evaluating program-level outcomes). For validation phase surveys, we shortened the questionnaire by removing the items on ease of understanding and categorization and by reducing the frequency of questions that asked respondents to comment on their responses. To minimize time commitments and thus maximize survey responses, we asked respondents to review outcomes associated with only two (during development phase) or three (during validation phase) randomly assigned competencies, with the option to review up to all six competencies. We collected respondent demographic information for all surveys. See Supplemental Tables 2 and 6 for a summary of demographic information collected. The complete questionnaires for version V review and national validation can be found in Supplemental Material.

Descriptive Analysis of Survey Responses

To address RQ1a and 1b, we calculated and visualized descriptive statistics of survey responses and respondent demographics in R v. 3.5.1 (R Core Team, 2018) using the tidyverse, ggmap, maps, ggthemes, ggpubr, and wesanderson packages (Kahle and Wickham, 2013; Wickham, 2016; Ram and Wickham, 2018; Kassambara, 2018; Arnold, 2019). For importance and ease of understanding responses, we calculated the mean, minimum, and maximum ratings (where 5 = "very important" or "very easy" and 1 = "very unimportant" or "very difficult"). We binned responses of "very important" or "important" as "support," and calculated "percent support" as the percent of respondents who "supported" the outcome out of all respondents who reviewed that outcome. We calculated the percent of respondents who selected "very easy" or "easy" out of all respondents who reviewed that outcome (development phase only). We calculated the percent of respondents who indicated that the outcome was accurately categorized within its competency or program-level learning outcome (development phase only, unpublished data). We read and summarized the open-ended comments to inform revisions (development phase) or to summarize suggestions of missing outcomes (validation phase). We summarized responses to demographic questions by calculating the frequency and percent of respondents who selected different responses for each question. We determined the Carnegie Classification of their institution types, minority-serving institution (MSI) status, and geographic locations by matching their institutions' names with the Carnegie data set (Indiana University Center for Postsecondary Research, 2016). We then mapped participant locations using their institutions' city and state GPS coordinates, obtained via the Google API (Kahle and Wickham, 2013).

Treatment of Missing Data for Statistical Modeling

To address RQ2a and RQ2b, we fit models of respondents' support of learning outcomes using the competency of each outcome and respondents' answers to end-of-survey demographic questions as predictors. Of our 417 initial respondents (i.e., respondents that rated at least one outcome) included in the RQ1b analysis, 71 did not provide all five demographic characteristics investigated in RQ2, and therefore were not included in these analyses. After removing these 71 individuals, our analytic data set for RQ2 contained responses from 346 respondents, comprising 15,321 importance ratings across 77 learning outcomes. To ensure that these omissions did not bias our inference, we compared rates of outcome support (i.e., the dependent variable in our models) from the 71 individuals who were removed from the RQ2 analyses with rates of outcome support from the 346 individuals that were retained and found that rates of outcome support did not differ overall or by competency across the two groups (Supplemental Methods and Supplemental Table 9). As we did not have all demographic data on the 71 individuals removed from our RQ2 analyses, we cannot assess whether demographic characteristics of the individuals we removed differed from those for the individuals we retained.

As we randomly assigned respondents to rate outcomes for particular subset of competencies, all respondents did not rate all outcomes. Thus, the number of ratings per outcome in the RQ2 analytic data set ranged from 183 to 206. When respondents were not assigned to rate outcomes from a particular competency, these data are missing completely at random. The multilevel models we use in this study (described later) allow for an unequal number of measurements across respondents in such cases (West *et al.*, 2014). There were a few instances in which respondents saw an outcome within an assigned competency but did not rate it (i.e., item nonresponse), but this behavior was rare (an average of 0.4% for each outcome). Our analyses do not include ratings on these missing outcomes, and this small amount of missing data is unlikely to bias our results (Graham, 2009).

Statistical Models of Learning Outcome Ratings

In estimating models for RQ2a and 2b, we accounted for three key aspects of our data structure. First, each respondent rated multiple competencies, and each competency contained multiple outcomes (refer to Supplemental Figure 1). We accounted for the nonindependence in respondents and learning outcomes by fitting multilevel models with respondent and learning outcome as random effects (random intercepts) (Theobald, 2018). Second, by design, each respondent rated learning outcomes corresponding to a random subset of competencies, so not all learning outcomes were evaluated by all respondents. To account for the imperfect nesting of responses within respondents and learning outcomes in our analyses, we used cross-classified multilevel models (Yan and Tourangeau, 2008; Olson and Smyth, 2015). Third, respondents rated importance on a five-point Likert scale (from "very important" to "very unimportant"), but the ratings for learning outcomes were generally very high (i.e., not normally distributed. We accounted for this skewed distribution by using the binary variable "support" (i.e., support = 1 if the learning outcome was rated "important" or "very important," otherwise support = 0) as our dependent variable. Thus, we fit cross-classified multilevel binary logistic regression models (Raudenbush and Bryk, 2002) to address RQ2a and 2b. We estimated these models using the meqrlogit command in Stata (v. 14.2).

We investigated six categorical independent variables as fixed effects: 1) the competency associated with the learning outcome (see six core competencies in Table 1) and five respondent demographics. The demographic variables were: 2) institution type (associate's, bachelor's, master's, or doctoral granting) and whether or not the respondent 3) has experience in DBER, 4) is currently engaged in disciplinary biology research, 5) has experience in ecology/evolutionary biology research, or 6) has familiarity with *Vision and Change*. These respondent characteristics were coded using answers to the survey's demographic questions (e.g., DBER experience and ecology/evolution experience variables were inferred from jointly considering responses to field of current research and graduate training questions).

We used backward model selection to test our hypotheses that the competency of learning outcomes (RQ2a) and the demographics of respondents (RQ2b) affect respondents' rating of learning outcomes.

For each research question, we began with a complex model and removed fixed effects one by one that did not improve model fit in order to find the best-fitting and most parsimonious models. Specifically, for RQ2a, the initial complex model used "support" as the dependent variable and included a random effect for learning outcome, a random effect for respondent, and a fixed effect for learning outcome competency. For RQ2b, the initial complex model used "support" as the dependent variable and included a random effect for learning outcome, a random effect for respondent, and five interactions as fixed effects: competency X institution type, competency X experience in DBER, competency X engagement in disciplinary biology research, competency X experience in ecology/evolution, and competency X *Vision and Change* familiarity.

During model selection, we determined model fit by comparing the Akaike information criterion (AIC) value of each model to the previous model. We interpreted two models with $\Delta AIC \leq 2$ to have equivalent fit, and in those cases chose the more parsimonious model. Otherwise, the model with the lower AIC value was interpreted to have a better fit. We used likelihood ratio tests to investigate the fit of random effects. Inclusion of random effects for learning outcome and respondent was supported for all models.

As there are many problems with interpreting individual coefficients from logistic regression models (Long and Freese, 2014; Mustillo *et al.*, 2018), we used predicted probabilities to interpret the best-fitting models. For RQ2a, we used the estimated regression equation from the best-fitting model to calculate the predicted probability that a respondent would support an outcome within each of the six competencies. For RQ2b, we used the estimated regression equation from the best-fitting model to calculate the predicted probability of outcome support for each combination of competency and respondent demographics of interest, holding all other variables at their means (Long and Freese, 2014). When comparing two predicted probabilities, we considered nonoverlapping 95% confidence intervals as statistically significant differences.

Additional details on data processing, analysis of missing data, and descriptive statistics of our six independent variables can be found in Supplemental Methods and Supplemental Tables 10 and 11.

Aligning Examples with Learning Outcomes

During initial drafting, several faculty included a list of examples of in-class activities and assignments associated with each learning outcome. After national validation, we updated this list by revising, adding, or realigning examples in keeping with outcome revisions. Example additions drew from conversations with biology educators throughout the development phase. Two authors (A.W.C. and A.J.C.) who have experience teaching undergraduate biology courses and expertise in molecular and cell biology carried out the drafting and revising portion of this work. To confirm alignment of the examples with corresponding course-level learning outcomes, three additional college biology instructors (including author J.C.H.) independently reviewed the examples and assessed alignment (yes/no). We selected these additional example reviewers based on their complementary expertise in ecology, evolutionary biology, and physiology. We removed or revised examples until unanimous agreement on alignment was reached.

RESULTS

Development of the BioSkills Guide

RQ1a: Can We Identify an Essential Set of Learning Outcomes Aligned with the Vision and Change Core Competencies? Soliciting and incorporating feedback from participants with diverse professional expertise in undergraduate biology education was essential to ensure we identified core competency learning outcomes that were useful on a broad scale. The initial draft of the BioSkills Guide was crafted by faculty and expanded to include input from 51 unique participants from at least eight institutions. We then carried out five increasingly larger rounds of review and revision, engaging approximately 218 unique participants from at least 87 institutions (Table 2). Throughout the development phase, we monitored demographics of participant pools and took steps to gather feedback from traditionally undersampled groups (Figure 2, B and C and Supplemental Tables 2 and 3).

To triangulate faculty perceptions of competency outcomes, we collected and applied quantitative and qualitative feedback on drafts of the BioSkills Guide (Figure 1). In general, we observed that interview, workshop, and roundtable data corroborated many of the trends observed from the surveys, with the same outcomes being least supported (e.g., rated "unimportant") or arousing confusion (e.g., rated "difficult" to understand). This provided evidence that the survey was as effective as the other qualitative methods at gauging faculty perceptions of competencies. The survey therefore enabled us to quantitatively assess areas of strength and weakness within drafts more quickly and across a broader population. Using both quantitative and qualitative feedback, every outcome was revised for

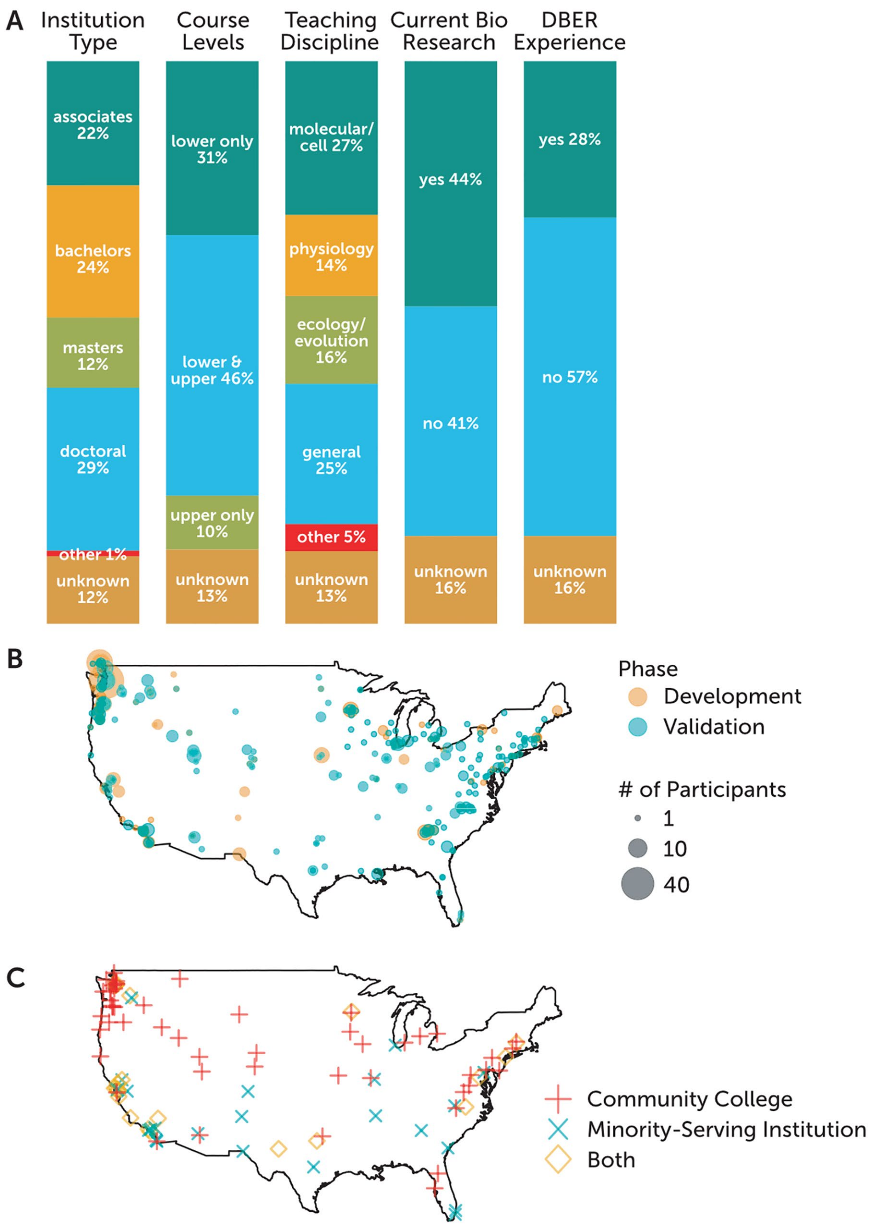

FIGURE 2. BioSkills Guide development and validation participants spanned a range of institution types, expertise, and geographic locations. (A) Self-reported demographics of validation phase survey respondents ($n = 417$). Current engagement in disciplinary biology research was inferred from field of current research. Experience in DBER was inferred from fields of current research and graduate training. (B) Geographic distribution of participants from 263 unique institutions, representing 556 participants with known institutions. Size is proportional to the number of participants from that institution. Only institutions in the continental United States and British Columbia are shown. Additional participants came from Alaska, Alberta, Hawaii, India, Puerto Rico, and Scotland (eight institutions). (C) Geographic distribution of participants from community colleges and MSIs: 73 unique community colleges and 49 unique MSIs (46 shown; not shown are MSIs in Alaska and Puerto Rico); 23 institutions were classified as both community colleges and MSIs.

substance and/or style at least once over the course of the development phase, with most outcomes being revised several times (Supplemental Table 1).

There are four key structural features of the BioSkills Guide that were introduced by faculty early in the development phase. First, the initial draft was written as *learning outcomes* (i.e., descriptions of what students will be able to know and do) rather than statements (i.e., descriptions of the competency itself). We kept this structure to better support backward design (Wiggins and McTighe, 1998). Second, the guide has a two-tiered structure: each core competency contains two to six *program-level* learning outcomes, and each program-level learning outcome contains two to six *course-level* learning outcomes (illustrated in Supplemental Figure 1). Faculty who participated in the initial drafting spontaneously generated this nested organization, likely reflecting their intended use(s) of the guide for a range of curricular tasks at the program and course levels. Third, the initial draft was written at the level of *a graduating general biology major* (4-year program). We decided to keep this focus to align with the goals of *Vision and Change*, which presented the core concepts and competencies as an overarching framework for the entire undergraduate biology curriculum (AAAS, 2011). A similar approach was taken during development of the BioCore Guide for the core concepts, based on their alignment with *Vision and Change* and the finding that the vast majority of colleges offer a general biology degree (Brownell *et al.*, 2014a). Finally, we decided, via conversations with our advisory board, to include only *measurable* learning outcomes so as to directly support assessment use and development. This led us to reframe outcomes related to student attitudes and affect (e.g., an outcome on appreciating the role of science in everyday life was revised to "use examples to describe the relevance of science in everyday experiences").

National Validation of the BioSkills Guide

RQ1b: How Much Do Biology Educators Agree on This Essential Set of Competency Learning Outcomes? We gathered evidence of content validity of the final draft of the BioSkills Guide using a national survey. We decided to move to validation based on the results of the fifth round of review (version V). Specifically, the lowest-rated outcome from the version V survey had 72.7% support (Figure 3 and Supplemental Table 4). The previous minimums were 16.7% and 50% for versions III and IV surveys, respectively. Furthermore, all outcomes were

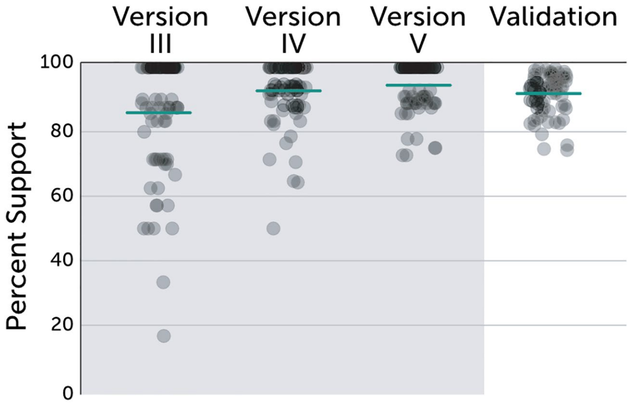

FIGURE 3. Learning outcome ratings show increasing consensus over iterative rounds of revision. Survey ratings were summarized by calculating the percent of respondents who selected "important" or "very important" for each outcome (i.e., percent support). Ratings from pilot and national validation surveys were combined as "validation" (RQ1b). Each circle represents a single learning outcome. Horizontal lines indicate means across all outcomes from that survey. Points are jittered to reveal distribution. These data are represented in tabular form in Table 3.

rated "easy" or "very easy" to understand by the majority of respondents (Supplemental Figure 2 and Supplemental Table 5), and no new substantial suggestions for changes were raised in survey comments or workshop feedback on version V.

The validation survey included 417 college biology educators, from at least 225 institutions, who evaluated the learning outcomes for their importance for a graduating general biology major (Table 2). Respondents had representation from a range of geographic regions, biology subdisciplines taught, course levels taught, research focuses, and institution types (Figure 2 and Supplemental Table 6), including respondents representing a range of community colleges and MSIs (Figure 2C and Supplemental Table 3).

Each respondent was asked to review a subset of outcomes, resulting in each outcome being reviewed by 211–237 college biology educators. The lowest mean importance rating for any outcome was 4 (equivalent to a rating of "important"), and the average mean importance rating across all outcomes was 4.5 (Supplemental Tables 4 and 7). We additionally inferred "percent support" for each outcome by calculating the percent of respondents who reviewed it who rated it as "important" or "very important." Percent support ranged from 74.3% to 99.6%, with a mean of 91.9% (Figure 3 and Supplemental Table 4). Nearly two-thirds (or 51) of the 77 outcomes had greater than 90% support (Table 3). Four outcomes had less than 80% support, with the lowest-rated outcome being supported by 74% of respondents who reviewed it (Table 4). In addition to having respondents rate the outcomes, we asked them to describe any essential learning outcomes that were missing from the guide (summarized in Supplemental Table 8).

Interpreting Statistical Models of Learning Outcome Support

RQ2a: Does Biology Educators' Support of Learning Outcomes Differ across Competencies? For RQ2a, we hypothesized that differences in learning outcome ratings (as observed in RQ1b) could, in part, be explained by the learning outcome's competency, with certain competencies being more supported than others. Indeed, a model that included competency had a better fit than one that did not ($\Delta AIC = -22.21$; Supplemental Table 12). It is worth noting that, despite the fact that inclusion of competency improved model fit, predicted probabilities of support were high across all six competencies (ranging from 94.2% to 99.1% support; Figure 4A).

RQ2b: Do Biology Educators with Different Professional Backgrounds Differ in Their Support of Learning Outcomes across Competencies? For RQ2b, we hypothesized that differences in respondent demographics like expertise (i.e., experience in DBER, experience with ecology/evolutionary biology research, familiarity with *Vision and Change*) or professional culture (i.e., institution type, current engagement in disciplinary biology research) would affect respondents' support of learning outcomes in different competencies, likely through differences in perceptions of their usefulness or feasibility. For example, respondents who have spent time conducting ecology and/or evolutionary biology research might rate modeling and quantitative reasoning learning outcomes more highly because of the important role quantitative modeling has historically played in these fields. We tested this hypothesis using backward model selection, fitting models that included the interaction of competency and our five respondent demographics. We found that the best-fitting model was one that included three competency by demographic interactions and one respondent

TABLE 3. Learning outcome ratings show increasing support over iterative rounds of revision

		Learning outcome support levels[a]				
Phase	Round	>90%	80–90%	70–80%	<70%	*Total*[b]
Development	Version III	38	20	8	14	80[c]
	Version IV	57	14	4	3	78
	Version V	56	18	6	0	80
Validation	Pilot	66	8	3	0	77
	National	52	21	4	0	77
	Combined[d]	51	22	4	0	77

[a]Survey ratings were summarized by calculating the percent of respondents who selected "important" or "very important" for each outcome (i.e., percent support). Outcomes were then binned into the indicated ranges. These data are visually represented in Figure 3.
[b]Total number of learning outcomes in indicated round of review.
[c]One outcome (out of 81 total) was mistakenly omitted from the version III survey.
[d]Number of learning outcomes in indicated support level range after combining survey responses from pilot and national validation rounds and recalculating percent support for each learning outcome.

TABLE 4. Top five and bottom five supported learning outcomes from validation phase

Competency	Outcome[a]	Percent support[b]	Mean[c]	Maximum[c]	Minimum[c]
Quantitative reasoning	Perform basic calculations (e.g., percentages, frequencies, rates, means).	99.6	4.9	5	3
Quantitative reasoning	Create and interpret informative graphs and other data visualizations.	99.6	4.9	5	3
Process of science	Analyze data, summarize resulting patterns, and draw appropriate conclusions.	99.1	4.8	5	1
Quantitative reasoning	Interpret the biological meaning of quantitative results.	99.1	4.7	5	3
Quantitative reasoning	Record, organize, and annotate simple data sets.	98.7	4.8	5	3
Process of science	Evaluate and suggest best practices for responsible research conduct (e.g., lab safety, record keeping, proper citation of sources).	82	4.2	5	2
Science and society	Identify and describe how systemic factors (e.g., socioeconomic, political) affect how and by whom science is conducted.	78.9	4.1	5	1
Modeling	Modeling: build and evaluate models of biological systems.[a]	75.5	4	5	1
Interdisciplinary nature of science	Suggest how collaborators in STEM and non-STEM disciplines could contribute to solutions of real-world problems.	74.3	4	5	1
Interdisciplinary nature of science	Describe examples of real-world problems that are too complex to be solved by applying biological approaches alone.	74	4	5	1

[a]All outcomes shown except "modeling: build and evaluate models of biological systems" are course-level learning outcomes.
[b]Percent support was calculated as the percent of respondents who rated the outcome as "important" or "very important." Five highest- and lowest-rated outcomes by percent support are shown.
[c]Mean, maximum, and minimum of survey respondents' importance ratings, where 5 = "very important" and 1 = "very unimportant."

demographic main effect. Specifically, respondents' support of outcomes within each competency differed based on their institution types, experience in DBER, and current engagement in biology research (Supplemental Table 12). Respondents' support of outcomes within each competency did not differ based on their familiarity with *Vision and Change* nor their experience with ecology/evolutionary biology research; however, experience with ecology/evolutionary research was retained in the best-fitting model as a main effect (Supplemental Figure 3).

The magnitudes of the observed differences were again small (Figure 4B). For example, respondents who have experience with DBER exhibited similarly high support for modeling (97.5%), quantitative reasoning (99.0%), process of science (98.4%), and communication and collaboration (98.0%) outcomes. In contrast, respondents who do not have experience with DBER were statistically significantly less likely to support modeling outcomes (92.9%) than quantitative reasoning (99.2%), process of science (98.8%), or communication and collaboration (98.8%) outcomes (i.e., the confidence intervals did not overlap; Figure 4B). However, predicted probabilities for learning outcome support were uniformly above 90% for all respondent groups and competencies, and the greatest difference observed was 6.3%.

Summary of the Core Competencies

Below we provide descriptions of the core competencies that summarize our understandings of college biology educator priorities, as represented by the learning outcomes in the final draft of the BioSkills Guide (Supplemental Material).

Process of Science. The process of science outcomes are presented in a particular order; however, in practice, they are applied in a nonlinear manner. For example, scientific thinking and information literacy include foundational scientific competencies such as critical thinking and understanding the nature of science, and thus are integral to all parts of the process of science. Question formulation, study design, and data interpretation and evaluation are iteratively applied when carrying out a scientific study, and also must be mastered to achieve competence in evaluating scientific information. The final program-level outcome, "doing research," emerged from conversations with biology educators who emphasized that the experience of applying and integrating the other process of science outcomes while engaging in research leads to outcomes that are likely greater than the sum of their parts. Course-based or independent research experiences in the lab or field are generally thought to be particularly well suited for teaching process of science; however, many of these outcomes can also be practiced by engaging with scientific literature and existing data sets. Competence in process of science outcomes will help students become not only proficient scientists, but also critical thinkers and scientifically literate citizens.

Quantitative Reasoning. This comprehensive interpretation of quantitative reasoning includes math, logic, data management and presentation, and an introduction to computation. Beyond being essential for many data analysis tasks, this competency is integral to work in all biological subdisciplines and an important component of several other core competencies. Indeed, the universality of math and logic provide a "common language" that can facilitate interdisciplinary conversations. Furthermore, the outcomes emphasize the application of quantitative reasoning *in the context of* understanding and studying biology, mirroring national recommendations to rethink how math is integrated into undergraduate biology course work. In summary, the outcomes presented here can be included in nearly any biology course to support the development of strong quantitative competency.

Modeling. Models are tools that scientists use to develop new insights into complex and dynamic biological structures,

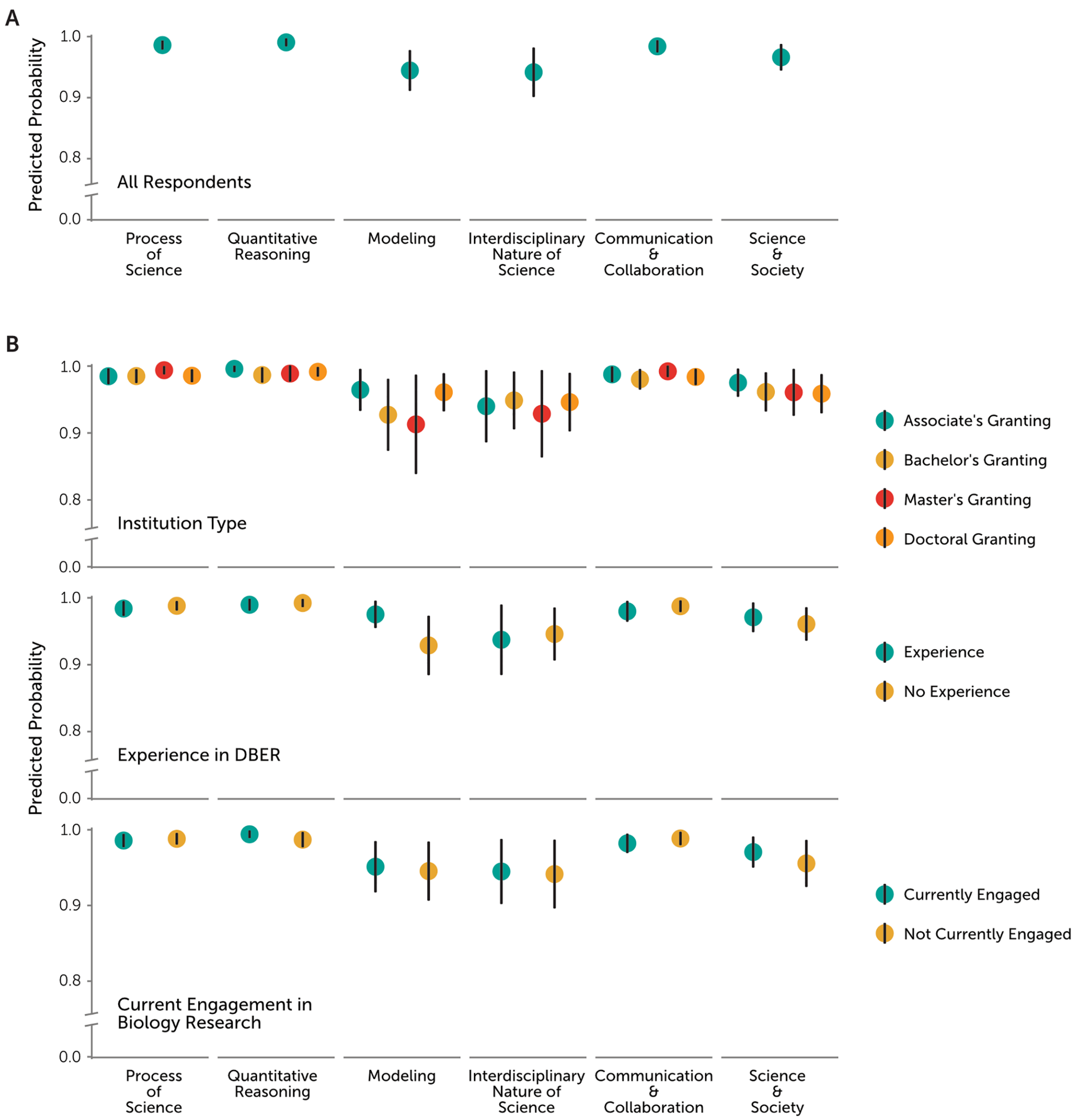

FIGURE 4. Competency and respondent demographics have significant but small effects on learning outcome support. Predicted probabilities of a respondent supporting (i.e., rating "important" or "very important") a learning outcome in the indicated competency for (A) all respondents (RQ2a) or (B) respondents in various demographic groups (RQ2b). Predicted probabilities were calculated using best-fitting models for each research question. Vertical lines represent 95% confidence intervals. Note that *y*-axis has been truncated.

mechanisms, and systems. Biologists routinely use models informally to develop their ideas and communicate them with others. Models can also be built and manipulated to refine hypotheses, predict future outcomes, and investigate relationships among parts of a system. It is important to note that there are many different types of models, each with its own applications, strengths, and limitations that must be evaluated by the user. The modeling outcomes can be practiced using an array of different model types: mathematical (e.g., equations, charts), computational (e.g., simulations), visual (e.g., diagrams, concept maps), and physical (e.g., 3D models).

Interdisciplinary Nature of Science. Scientific phenomena are not constrained by traditional disciplinary silos. To have a full understanding of biological systems, students need practice integrating scientific concepts across disciplines, including multiple fields of biology and disciplines of STEM. Furthermore, today's most pressing societal problems are ill-defined and multifaceted and therefore require interdisciplinary solutions. Efforts to solve these complex problems benefit from considering 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). Productive interdisciplinary biologists therefore recognize the value in collaborating with experts across disciplines and have the competency needed to communicate with diverse groups.

Communication and Collaboration. Communication and collaboration are essential components of the scientific process. These outcomes include competencies for interacting with biologists, other non-biology experts, and the general public for a variety of purposes. In the context of undergraduate biology, metacognition involves the ability to accurately sense and regulate one's behavior both as an individual and as part of a team.

Regardless of their specific career trajectories, all biology students require this competency to thoughtfully and effectively work and communicate with others.

Science and Society. Science does not exist in a vacuum. Scientific knowledge is constructed by the people engaged in science. It builds on past findings and changes in light of new interpretations, new data, and changing societal influences. Furthermore, advances in science affect lives and environments worldwide. For these reasons, students should learn to reflexively question not only how scientific findings were made, but by whom and for what purpose. A more integrated view of science as a socially situated way of understanding the world will help students be better scientists, advocates for science, and scientifically literate citizens.

Examples of Activities That Support Competency Development

The faculty who wrote the initial draft of the BioSkills Guide included classroom examples in addition to learning outcomes. A number of early development phase participants expressed that they appreciated having these examples for use in brainstorming ways competencies might be adapted for different courses. Based on this positive feedback, we decided to retain and supplement the examples so that they could be used by others (Supplemental Material). These examples are *not* exhaustive and have not undergone the same rigorous process of review as the learning outcomes, but we have confirmed alignment of the examples with five college biology educators with complementary subdisciplinary teaching expertise. We envision the examples aiding with interpretation of the learning outcomes in a variety of class settings (i.e., course levels, subdisciplines of biology, class sizes).

DISCUSSION

The BioSkills Guide Is a Nationally Validated Resource for the Core Competencies

Employing feedback from more than 600 college biology educators, we have developed and gathered evidence of content validity for a set of 77 essential learning outcomes for the six *Vision and Change* core competencies. During national validation, all learning outcomes had support from ≥74% of survey respondents, with an average of 92% support. This high level of support suggests that we successfully recruited and applied input from a range of educators during the development phase. As the broadest competency-focused learning outcome framework for undergraduate biology education to date, the BioSkills Guide provides insight on the array of competencies that biology educators consider essential for all biology majors to master during college. We propose that this guide be used to support a variety of curricular tasks, including course design, assessment development, and curriculum mapping (Figure 5).

Examining Variation in Educator Survey Responses

We used statistical modeling to investigate whether respondents' professional backgrounds could explain their likelihood of supporting outcomes in different competencies. We detected several respondent demographics that were associated with differences in support of learning outcomes within different competencies; however, observed differences may not have been large enough to be meaningful on a practical level. In other words, it is unclear whether differences in the perceived importance of particular outcomes by less than 10% of individuals among various educator populations is sufficient to sway curricular decisions.

The results of our RQ2 analyses suggest that 1) there was not sufficient variation in our data set to detect substantial differences, 2) educators from different backgrounds (at least those investigated in this study) think similarly about competencies, or 3) a combination of these two. In support of 1), 51 out of 77 outcomes had greater than 90% support, likely due to our intentional study design of iteratively revising outcomes to reach consensus during the development phase. In support of 2), it is reasonable that college biology educators in the United States are more culturally alike than different, given broad similarities in their graduate education experiences (Grunspan *et al.*, 2018). Thus, we believe the most likely explanation for the small size of the observed differences is a combination of study design and similarities in educator training.

We could not help but note that, in instances in which demographic by competency interactions existed, trends, albeit small, consistently pointed toward differences in support for the modeling competency (Figure 4B). Further work is needed to determine whether this trend is supported, but we offer a hypothesis based on observations made over the course of this project:

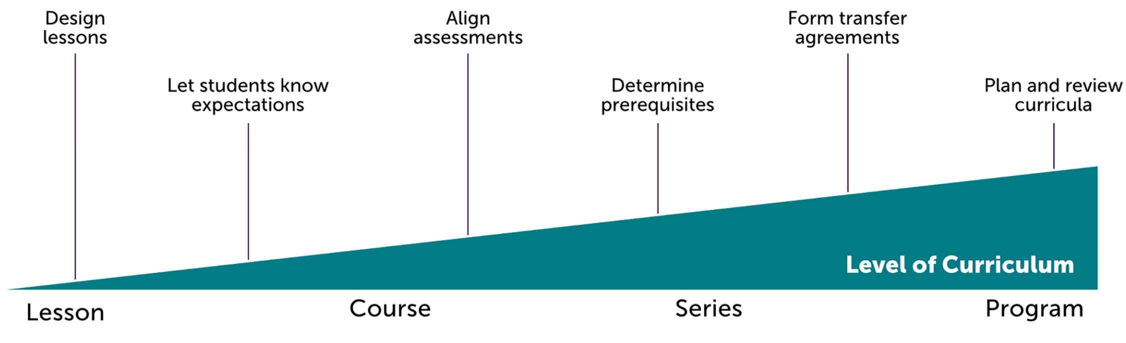

FIGURE 5. The BioSkills Guide can support a range of curricular scales.

Although we strove to write learning outcomes that are clear and concrete, it is possible that respondents interpreted the difficulty level or focus of modeling-related learning outcomes differently depending on their interpretation of the term "model." Varying definitions of models were a common theme in survey comments and interviews. Recently, a group of mathematicians and biologists (National Institute for Mathematical and Biological Synthesis [NIMBioS]) joined forces to address this issue (Diaz Eaton *et al.*, 2019). They argue that differences in conceptions of modeling among scientists within and across fields have stood in the way of progress in integrating modeling into undergraduate courses. In an effort to improve biology modeling education, they propose a framework, including a definition of model ("a simplified, abstract or concrete representation of relationships and/or processes in the real world, constructed for some purpose"; Diaz Eaton *et al.*, 2019, p. 5). It is important to note that this definition is not fully consistent with other work on models in science education in its relative emphasis of the role of models for generating new insights versus the role of models as representations (Gouvea and Passmore, 2017). Furthermore, whether a particular representation is considered to be a model depends on how a given user interacts with that representation. For example, an undergraduate student's drawing illustrating how genes are up-regulated by changes in the environment would not bring new insights for a molecular biologist but would be considered a conceptual model for the student, because the student is using the drawing to develop a more sophisticated understanding of how gene expression phenotypes are impacted by environmental conditions (Dauer *et al.*, 2019). While additional work is needed to build a shared understanding of modeling in the undergraduate STEM education community, we believe the NIMBioS definition of model is a valuable starting point for future discussions around the value, relevance, and possible implementations of modeling in college biology. Because the BioSkills Guide elaborates learning outcomes for undergraduate biology majors, we chose a similarly broad definition of models as representations of biological phenomena that can be used for a variety of purposes, as elaborated in the *Expanding Modeling* section.

Limitations of the BioSkills Guide

When developing the guide, we made two early design choices that constrained its content. First, we chose to align the outcomes with the *Vision and Change* core competency framework. We chose this approach in order to build on the momentum *Vision and Change* has already gained in the undergraduate biology community (Brownell *et al.*, 2014a; AAAS, 2015, 2018, 2019; Brancaccio-Taras *et al.*, 2016; Dirks and Knight, 2016; Cary and Branchaw, 2017; *CourseSource*, n.d.) and thus maximize the chances that we would build a resource that undergraduate biology educators would find useful and adopt. However, due to this choice, there are areas in which the guide does not align with other science curriculum frameworks. For example, while *Vision and Change* core competencies and the *Framework for K–12 Science Education* scientific practices overlap substantially (Table 1), the latter includes the practice of constructing explanations, where explanations are defined as "accounts that link scientific theory with specific observations and phenomena" (NRC, 2012a, p. 67)." Constructing explanations is not explicitly represented in either *Vision and Change* or the BioSkills Guide.

The second design choice was that we sought evidence of content validity via a survey of undergraduate biology educators and researchers in biology education, rather than science education researchers who focus on science practices, nature of science, science communication, scientific modeling, and so on. We chose this population for our sample because they are trained biologists and experienced biology instructors and are therefore well positioned to weigh in on learning outcomes that are most important in the context of undergraduate biology courses.

In addition, we chose undergraduate biology educators because they are the intended users of the guide. To achieve transformation in undergraduate science education, those undergoing the change must be a part of the change process (Henderson *et al.*, 2010). Furthermore, by developing the guide hand-in-hand with a broad sample of educators, we aimed to create a tool written in the language used and understood by those who would be implementing these practices in their classrooms. In many cases throughout the development phase, we found that small changes in wording affected reviewers' ratings of the learning outcomes, and thus precise use of language was essential. Indeed, developing a common language around scientific practices (e.g., the distinction between argumentation and explanation) has been shown to be a key step in adoption of NGSS by K–12 teachers (Friedrichsen and Barnett, 2018).

While sampling from this population has advantages, there are also limitations. Although a substantial share of our survey respondents indicated experience in DBER as well (48.4% during the development phase, 27.8% during the validation phase), the BioSkills Guide outcomes primarily represent biology educators' and discipline-based education researchers' understandings of competencies. Thus, some outcomes represent beliefs held by undergraduate biology educators and researchers that do not fully reflect current understandings in the science education research community. One example relates to the definition of "model," as described earlier. Another example is the learning outcome "design controlled experiments, including plans for analyzing the data," which could be interpreted to overlook the fact that many scientific studies are not experimental (McComas, 1998). In this case, this interpretation would only partially be true. Feedback we received during the development phase indicated that reviewers of the BioSkills Guide in fact recognized the importance of including nonexperimental studies when teaching the process of science. In response to this feedback, we replaced the word "experiment" in the initial draft with the word "study" in several outcomes to be inclusive of experimental and nonexperimental studies. However, workshop and interview data indicated that, on the whole, biology educators also supported explicitly teaching experimental design as a way to introduce students to the rigors of scientific thinking. This led to our retaining the term "experiment" in this particular learning outcome, which received 91.5% support during the validation phase.

Limitations such as these should be kept in mind when interpreting the guide, and we encourage educators to consult multiple frameworks when designing and revising curricula. We suggest that the *Framework for K–12 Science Education* (NRC, 2012a), as well as the associated standards (NGSS Lead States, 2013), is an especially important resource for undergraduate biology educators to be familiar with, given its impact in K–12 science education and the importance of scaffolding the transition from secondary to postsecondary science courses. The *Framework for K–12 Science Education* has transformed the K–12 education community's conversations about curriculum by providing a common language with a strong theoretical grounding. Since the framework's introduction in 2012, understandings of it have naturally deepened through the work of applying it in curricula and research (Brown and Sadler, 2018). Ongoing implementation work with the scientific practices, especially as they integrate with the framework's other dimensions (i.e., crosscutting concepts and disciplinary core ideas) has yielded many productive insights, including the importance of phenomena as an anchor for 3D curricula (Reiser *et al.*, 2017). In a similar vein, we hope that efforts to implement the BioSkills Guide will help facilitate growth in undergraduate biology education.

Points of discrepancy between the BioSkills Guide and other science education frameworks may reflect areas where understandings of science competencies or practices are still evolving. Future work should consider where and why biology educators' priorities and conceptions of competencies differ from experts in other fields, including the cognitive and learning sciences and other DBER fields. Such research will undoubtedly be made stronger by working cross-disciplinarily with those experts (Dolan, 2017).

Defining the Scope of Core Competencies

During the development phase, input from participants led us to expand or revise the focus of certain core competencies relative to their original descriptions in the *Vision and Change* report (AAAS, 2011). We believe that these evolutions in understanding are in keeping with the spirit of *Vision and Change*, which encouraged educators to engage in ongoing conversations about elaboration and implementation.

Defining the Role of Research in Process of Science. *Vision and Change* and other leaders in STEM education have emphasized the importance of incorporating research experiences into the undergraduate curriculum (AAAS, 2011; Auchincloss *et al.*, 2014; NASEM, 2017). We therefore drafted a program-level learning outcome related to "doing research" for process of science. However, it was initially unclear how this outcome should be worded and what course-level learning outcomes, if any, should be embedded within it. This outcome generally had strong support (>80% rating "important" or "very important") throughout the development phase, but a survey question asking for suggestions of appropriate course-level outcomes yielded only outcomes found elsewhere in the guide (e.g., collaboration, data analysis, information literacy) or affect-related outcomes (e.g., persistence, belonging), which we had previously decided were beyond the scope of this resource. We gained additional insight into this question through qualitative approaches. Roundtable and interview participants reiterated that the learning outcomes associated with research experiences, whether in a course-based or independent setting, were distinct from and "greater than the sum of the parts" of those gained during other activities aimed at practicing individual, related outcomes. Furthermore, many participants indicated the outcome was important for supporting continued efforts to systematically include research in undergraduate curricula (also see Cooper *et al.*, 2017). This feedback prompted us to retain this program-level outcome, even though it lacks accompanying course-level learning outcomes.

Expanding Modeling. The *Vision and Change* description of the "ability to use modeling and simulation" provides examples that emphasize the use of computational and mathematical models, such as "computational modeling of dynamic systems" and "incorporating stochasticity into biological models" (AAAS, 2011). From interviews and survey comments, we found that many participants likewise valued these skill sets, likely because they help prepare students for jobs (also see Durán and Marshall, 2018). However, many participants felt the definition of "modeling" should be expanded to include the use of conceptual models. This sentiment is supported by the K–12 STEM education literature, which establishes conceptual modeling as a foundational scientific practice (Passmore *et al.*, 2009; NRC, 2012a; Svoboda and Passmore, 2013). Such literature defines models and promotes their use based on their ability to help students (and scientists) develop new insights (Gouvea and Passmore, 2017). Indeed, building and interpreting conceptual models supports learning of other competencies and concepts, including data interpretation (Zagallo *et al.*, 2016), study design (Hester *et al.*, 2018), systems thinking (Dauer *et al.*, 2013, 2019; Bergan-Roller *et al.*, 2018), and evolution (Speth *et al.*, 2014). Proponents of incorporating drawing into the undergraduate biology curriculum have made similar arguments to increase the scope of modeling as a competency (Quillin and Thomas, 2015). Given this expansion of the competency, we decided to revise the competency "title" accordingly. Throughout the project, we found that the phrase "modeling and simulation" triggered thoughts of computational and mathematical models and their applications, to the exclusion of conceptual modeling. We have therefore revised the shorthand title of this competency to the simpler "modeling" to emphasize the range of models (e.g., conceptual, physical, mathematical, computational; also see Diaz Eaton *et al.*, 2019) that students may create and work with in college biology courses.

Defining the Interdisciplinary Nature of Science. Like modeling, the "ability to tap into the interdisciplinary nature of science" is a forward-looking competency. It represents the forefront of biological research, but not necessarily current practices in the majority of undergraduate biology classrooms. Elaborating it into learning outcomes therefore required additional work, including interviews with interdisciplinary biologists, examination of the literature (e.g., Project Kaleidoscope, 2011; Gouvea *et al.*, 2013; National Academy of Engineering and National Research Council, 2014), and discussions at two roundtables at national biology education research conferences. Since initiating this work, a framework has been presented for implementing this competency in undergraduate biology education, including a working definition: "Interdisciplinary science is the collaborative process of integrating knowledge/expertise from trained individuals of two or more disciplines—leveraging various perspectives, approaches, and research methods/methodologies—to provide advancement beyond the scope of one discipline's ability" (Tripp and Shortlidge, 2019, p. 5). We believe this definition aligns well with the content of the interdisciplinary nature of science learning outcomes in the final draft of the BioSkills Guide, especially in its emphasis on collaboration.

Expanding Communication and Collaboration. The faculty team who composed the initial draft of the BioSkills Guide expanded the communication and collaboration competency significantly. First, they loosened the constraints implied by the title assigned by *Vision and Change* ("ability to communicate and collaborate *with other disciplines*") to encompass communication and collaboration with many types of people: other biologists, scientists in other disciplines, and non-scientists. This expansion was unanimously supported by participant feedback throughout the development phase and has been promoted in the literature (Brownell *et al.*, 2013; Mercer-Mapstone and Kuchel, 2017). Second, the drafting faculty included a program-level outcome relating to metacognition. Metacognition and other self-regulated learning skills were not included in the *Vision and Change* core competencies, but the majority of survey respondents nonetheless supported these outcomes. Some respondents raised concerns about the appropriateness of categorizing metacognition in this competency. However, because its inclusion was well-supported by qualitative and quantitative feedback and it was most directly connected with this competency, we have retained it here.

Next Steps for the Core Competencies

The BioSkills Guide defines course- and program-level learning outcomes for the core competencies, but there is more work to be done to support backward design of competency teaching. Instructors will need to create lesson-level learning objectives that describe how competencies will be taught and assessed in the context of day-to-day class sessions. It is likely that a similar national-level effort to define lesson-level objectives would be particularly challenging because of the number of possible combinations. First of all, most authentic scientific tasks (e.g., presenting data for peer review, using models and interdisciplinary understandings to make hypotheses about observed phenomena, proposing solutions to real-world problems) require simultaneous use of multiple competencies. Second, instructors will need to define how core competencies interface with biology content and concepts. To this end, existing tools for interpreting the *Vision and Change* core concepts (Brownell *et al.*, 2014a; Cary and Branchaw, 2017) will be valuable companions to the BioSkills Guide, together providing a holistic view of national recommendations for the undergraduate biology curriculum.

We view the complexities of combining concepts and competencies in daily learning objectives as a feature of the course-planning process, allowing instructors to retain flexibility and creative freedom. Furthermore, one well-designed lesson can provide the opportunity to practice multiple concepts and competencies. For example, to model the process of cell respiration, students apply not only the competency of modeling but also conceptual understandings of systems and the transformation of matter and energy (Dauer *et al.*, 2013; Bergan-Roller *et al.*, 2018). The 3D Learning Assessment Protocol (Laverty *et al.*, 2016), informed by the multidimensional design of the *Framework for K–12 Science Education* (NRC, 2012a), may be a valuable resource for considering these sorts of combinations. Several groups have already begun proposing solutions to this work in the context of *Vision and Change* (Dirks and Knight, 2016; Cary and Branchaw, 2017).

Another complexity to consider when planning core competency teaching is *at what point in the curriculum* competencies should be taught and *in what order*. Scaffolding competencies across course series or whole programs will require thoughtful reflection on the component parts of each learning outcome and how students develop these outcomes over time. To assist in this work, there are a number of resources focusing on particular competencies (e.g., see Quillin and Thomas, 2015; Angra and Gardner, 2016; Pelaez *et al.*, 2017; Wilson Sayres *et al.*, 2018; Diaz Eaton *et al.*, 2019; Diaz-Martinez *et al.*, 2019; Tripp and Shortlidge, 2019), all of which describe specific competencies in further detail than is contained in the BioSkills Guide. Additionally, work developing learning progressions in K–12 education, and more recently higher education, could guide future investigations of competency scaffolding (Schwarz *et al.*, 2009; Scott *et al.*, 2019). We encourage educators to be thoughtful not only about how individual competencies can build over the course of a college education, but how all of the competencies will work together to form complex, authentic expertise that is greater than the sum of its parts.

Given that more than 50% of STEM majors attend a community college during their undergraduate careers (National Science Foundation, National Center for Science and Engineering Statistics, 2010), yet less than 5% of biology education research studies include community college participation (Schinske *et al.*, 2017), we were intentional about including community college faculty throughout the development and validation of the BioSkills Guide (Figure 2C and Supplemental Table 3). So, while the learning outcomes are calibrated to what a general biology major should be able to do by the end of a *4-year* degree, we were able to develop widely relevant outcomes by identifying connections between each competency and current teaching practices of 2-year faculty. Nonetheless, it remains an open question whether certain competencies should be emphasized at the introductory level, either because they are necessary prerequisites to upper-level work or because introductory biology may be a key opportunity to develop biological literacy for the many people who begin but do not end up completing a life sciences major. Discussions of how and when to teach competencies in introductory biology are ongoing (Kruchten *et al.*, 2018). It will be essential that priorities, needs, and barriers for faculty from a range of institutional contexts, particularly community colleges, are considered in those discussions (e.g., Corwin *et al.*, 2019).

Applications of the BioSkills Guide

The BioSkills Guide is intended to be a resource, not a prescription. We encourage educators to adapt the outcomes to align with their students' interests, needs, and current abilities. Reviewing the suggestions for additional learning outcomes made by national validation survey respondents (Supplemental Table 8) provides some preliminary insight into how educators may choose to revise the guide. For example, some respondents wished to increase the challenge level of particular outcomes (e.g., "use computational tools to analyze large data sets" rather than "describe how biologists answer research questions using … large data sets") or to create more focused outcomes (e.g., "describe the ways scientific research has mistreated people from minority groups" rather than "describe the broader societal impacts of biological research on different stakeholders"). Moreover, the content of the guide as a whole should be revisited and updated over time, as college educator perceptions will evolve in response to the changing nature of biology, the scientific job market, and increased adoption of NGSS at the K–12 level.

We envision many applications of the BioSkills Guide across curricular scales (Figure 5). The guide intentionally contains a two-tiered structure, with program-level learning outcomes that are intended to be completed by the end of a 4-year degree and course-level learning outcomes that are smaller in scale and more closely resemble outcomes listed on a course syllabus. The program-level learning outcomes could serve as a framework for curriculum mapping, allowing departments to document which courses teach which competencies and subsequently identify program strengths, redundancies, and gaps. These data can then inform a variety of departmental tasks, including allocating funds for development of new courses, re-evaluating degree requirements, assembling evidence for accreditation, and selecting and implementing programmatic assessments. Course-level learning outcomes can spark more informed discussions about particular program-level outcomes and will likely be valuable in discussions of articulation and transfer across course levels.

Course-level learning outcomes can additionally be used for backward design of individual courses. It can be immensely clarifying to move from broader learning goals such as "Students will be able to communicate science effectively" to concrete learning outcomes such as "Students will be able to use a variety of modes to communicate science (e.g., oral, written, visual)." Furthermore, the outcomes and their aligned example activities included in the expanded BioSkills Guide (Supplemental Material) can be used for planning new lessons and for recognizing competencies that are already included in a particular class. Examples such as "write blogs, essays, papers, or pamphlets to communicate findings," "present data as infographics," and "give mini-lectures in the classroom" help emphasize the range of ways communication may occur in the classroom. Once clear learning outcomes have been defined, they can be shared with students to explain the purpose of various activities and assignments and increase transparency in instructor expectations. This may help students develop expert-like values for competency development (Marbach-Ad *et al.*, 2019) and encourage them to align their time and effort with faculty's intended curricular goals.

The BioSkills learning outcomes may be especially relevant for the design of high-impact practices, such as course-based undergraduate research experiences (CUREs), service learning, and internships (Kuh, 2008; Auchincloss *et al.*, 2014; Brownell and Kloser, 2015), which already emphasize competencies, but often are not developed using backward design (Cooper *et al.*, 2017). In these cases, there is a risk of misalignment between instructor intentions, in-class activities, and assessments (Wiggins and McTighe, 1998). One possible reason for the lack of backward design in these cases is that writing clear, measurable learning outcomes can be challenging and time-consuming. We hope the BioSkills Guide will allow instructors to more quickly formulate learning outcomes, freeing up time for the subsequent steps of backward design (i.e., designing summative and formative assessments and planning instruction).

Assessment is an essential part of evidence-based curricular review. For some competencies, such as process of science, a number of high-quality assessments have been developed (e.g., Sirum and Humburg, 2011; Timmerman *et al.*, 2011; Gormally *et al.*, 2012; Brownell *et al.*, 2014b; Dasgupta *et al.*, 2014; Deane *et al.*, 2016; for a general discussion of CURE assessment, see Shortlidge and Brownell, 2016). However, substantial gaps remain in the availability of assessments for most other competencies. The BioSkills Guide could be used as a framework for assessment development, similar to how the BioCore Guide was used to develop a suite of programmatic conceptual assessments intentionally aligned with *Vision and Change* core concepts (Smith *et al.*, 2019). Given the difficulty of assessing particular competencies (e.g., collaboration) with fixed-choice or even written-response questions, it is unlikely that a single assessment could be designed to cover all six competencies. However, by aligning currently available competency assessments with the BioSkills Guide, outcomes lacking aligned assessments will become apparent and point to areas in need of future work.

While motivations and paths for implementing the BioSkills Guide will vary by department and instructor, the end goal remains the same: better integration of competency teaching in undergraduate biology education. With more intentional and effective competency teaching, biology graduates will be more fully prepared for their next steps, whether those steps are in biology, STEM more generally, or outside STEM completely. The six core competencies encompass essential skills, embedded in scientific knowledge, needed in competitive careers and also in the daily life of a scientifically literate citizen. We have developed and gathered content validity evidence for the BioSkills Guide with input from a diverse group of biology educators to ensure value for courses in a variety of subdisciplines and levels and biology departments at a variety of institution types. Thus, we hope the BioSkills Guide will help facilitate progress in meeting the recommendations of *Vision and Change* with the long-term goal of preparing students for modern careers.

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Supplemental Material

CBE—Life Sciences Education

Clemmons *et al*.

SUPPLEMENTAL MATERIALS

Supplemental Material 1. BioSkills Guide.

Nationally validated program- and course-level learning outcomes for the Vision and Change core competencies.

Supplemental Material 2. Expanded BioSkills Guide with aligned examples.

Educator-aligned (n=5) examples for each BioSkills Guide course-level learning outcome.

Supplemental Material 3. Supplemental Figures.

Supplemental Material 4. Supplemental Tables.

Supplemental Material 5. Supplemental Methods.

Additional details on the methods used in this project.

Supplemental Material 6. BioSkills development phase questionnaire.

Questionnaire used during development phase survey for review of Version V. Questionnaires for versions III and IV were very similar, except for revision of learning outcomes.

Supplemental Material 7. BioSkills validation phase questionnaire.

Questionnaire used during national validation survey. Questionnaire for pilot validation was identical, except for wording of one learning outcome.

Supplemental Material 1. BioSkills Guide.

Nationally validated program- and course-level learning outcomes for the Vision and Change core competencies.

PROCESS OF SCIENCE

Program-Level Learning Outcomes	Course-Level Learning Outcomes
SCIENTIFIC THINKING Explain how science generates knowledge of the natural world.	Explain how scientists use inference and evidence-based reasoning to generate knowledge.
	Describe the iterative nature of science and how new evidence can lead to the revision of scientific knowledge.
INFORMATION LITERACY Locate, interpret, and evaluate scientific information.	Find and evaluate the credibility of a variety of sources of scientific information, including popular science media and scientific journals.
	Interpret, summarize, and evaluate evidence in primary literature.
	Evaluate claims in scientific papers, popular science media, and other sources using evidence-based reasoning.
QUESTION FORMULATION Pose testable questions and hypotheses to address gaps in knowledge.	Recognize gaps in our current understanding of a biological system or process and identify what specific information is missing.
	Develop research questions based on your own or others' observations.
	Formulate testable hypotheses and state their predictions.
STUDY DESIGN Plan, evaluate, and implement scientific investigations.	Compare the strengths and limitations of various study designs.
	Design controlled experiments, including plans for analyzing the data.
	Execute protocols and accurately record measurements and observations.
	Identify methodological problems and suggest how to troubleshoot them.
	Evaluate and suggest best practices for responsible research conduct (e.g., lab safety, record keeping, proper citation of sources).
DATA INTERPRETATION & EVALUATION Interpret, evaluate, and draw conclusions from data in order to make evidence-based arguments about the natural world.	Analyze data, summarize resulting patterns, and draw appropriate conclusions.
	Describe sources of error and uncertainty in data.
	Make evidence-based arguments using your own and others' findings.
	Relate conclusions to original hypothesis, consider alternative hypotheses, and suggest future research directions based on findings.
DOING RESEARCH Apply science process skills to address a research question in a course-based or independent research experience.	

QUANTITATIVE REASONING

Program-Level Learning Outcomes	Course-Level Learning Outcomes
NUMERACY Use basic mathematics (e.g., algebra, probability, unit conversion) in biological contexts.	Perform basic calculations (e.g., percentages, frequencies, rates, means).
	Select and apply appropriate equations (e.g., Hardy-Weinberg, Nernst, Gibbs free energy) to solve problems.
	Interpret and manipulate mathematical relationships (e.g., scale, ratios, units) to make quantitative comparisons.
	Use probability and understanding of biological variability to reason about biological processes and statistical analyses.
	Use rough estimates informed by biological knowledge to check quantitative work.
	Describe how quantitative reasoning helps biologists understand the natural world.
QUANTITATIVE & COMPUTATIONAL DATA ANALYSIS Apply the tools of graphing, statistics, and data science to analyze biological data.	Record, organize, and annotate simple data sets.
	Create and interpret informative graphs and other data visualizations.
	Select, carry out, and interpret statistical analyses.
	Describe how biologists answer research questions using databases, large data sets, and data science tools.
	Interpret the biological meaning of quantitative results.

MODELING

Program-Level Learning Outcomes	Course-Level Learning Outcomes
PURPOSE OF MODELS Recognize the important roles that scientific models, of many different types (conceptual, mathematical, physical, etc.), play in predicting and communicating biological phenomena.	Describe why biologists use simplified representations (models) when solving problems and communicating ideas.
	Given two models of the same biological process or system, compare their strengths, limitations, and assumptions.
MODEL APPLICATION Make inferences and solve problems using models and simulations.	Summarize relationships and trends that can be inferred from a given model or simulation.
	Use models and simulations to make predictions and refine hypotheses.
MODELING Build and evaluate models of biological systems.	Build and revise conceptual models to propose how a biological system or process works.
	Identify important components of a system and describe how they influence each other (e.g., positively or negatively).
	Evaluate conceptual, mathematical, or computational models by comparing their predictions with empirical data.

INTERDISCIPLINARY NATURE OF SCIENCE

Program-Level Learning Outcomes	Course-Level Learning Outcomes
CONNECTING SCIENTIFIC KNOWLEDGE Integrate concepts across other STEM disciplines (e.g., chemistry, physics) and multiple fields of biology (e.g., cell biology, ecology).	Given a biological problem, identify relevant concepts from other STEM disciplines or fields of biology.
	Build models or explanations of simple biological processes that include concepts from other STEM disciplines or multiple fields of biology.
INTERDISCIPLINARY PROBLEM SOLVING Consider interdisciplinary solutions to real-world problems.	Describe examples of real-world problems that are too complex to be solved by applying biological approaches alone.
	Suggest how collaborators in STEM & non-STEM disciplines could contribute to solutions of real-world problems.
	Be able to explain biological concepts, data, and methods, including their limitations, using language understandable by collaborators in other disciplines.

COMMUNICATION & COLLABORATION

Program-Level Learning Outcomes	Course-Level Learning Outcomes
COMMUNICATION Share ideas, data, and findings with others clearly and accurately.	Use appropriate language and style to communicate science effectively to targeted audiences (e.g., general public, biology experts, collaborators in other disciplines).
	Use a variety of modes to communicate science (e.g., oral, written, visual).
COLLABORATION Work productively in teams with people who have diverse backgrounds, skill sets, and perspectives.	Work with teammates to establish and periodically update group plans and expectations (e.g., team goals, project timeline, rules for group interactions, individual and collaborative tasks).
	Elicit, listen to, and incorporate ideas from teammates with different perspectives and backgrounds.
	Work effectively with teammates to complete projects.
COLLEGIAL REVIEW Provide and respond to constructive feedback in order to improve individual and team work.	Evaluate feedback from others and revise work or behavior appropriately.
	Critique others' work and ideas constructively and respectfully.
METACOGNITION Reflect on your own learning, performance, and achievements.	Evaluate your own understanding and skill level.
	Assess personal progress and contributions to your team and generate a plan to change your behavior as needed.

SCIENCE & SOCIETY

Program-Level Learning Outcomes	Course-Level Learning Outcomes
ETHICS Demonstrate the ability to critically analyze ethical issues in the conduct of science.	Identify and evaluate ethical considerations (e.g., use of animal or human subjects, conflicts of interest, confirmation bias) in a given research study.
	Critique how ethical controversies in biological research have been and can continue to be addressed by the scientific community.
SOCIETAL INFLUENCES Consider the potential impacts of outside influences (historical, cultural, political, technological) on how science is practiced.	Describe examples of how scientists' backgrounds and biases can influence science and how science is enhanced through diversity.
	Identify and describe how systemic factors (e.g., socioeconomic, political) affect how and by whom science is conducted.
SCIENCE'S IMPACT ON SOCIETY Apply scientific reasoning in daily life and recognize the impacts of science on a local and global scale.	Apply evidence-based reasoning and biological knowledge in daily life (e.g., consuming popular media, deciding how to vote).
	Use examples to describe the relevance of science in everyday experiences.
	Identify and describe the broader societal impacts of biological research on different stakeholders.
	Describe the roles scientists have in facilitating public understanding of science.

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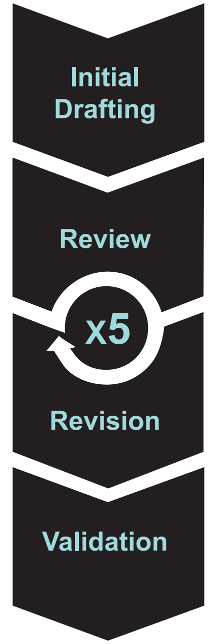
To download or share the BioSkills Guide:
https://qubeshub.org/qubesresources/publications/1305

HOW WAS THE BIOSKILLS GUIDE DEVELOPED?



Initial Drafting
- Began with faculty-crafted draft
- Literature review
- Interviews
- Workshop

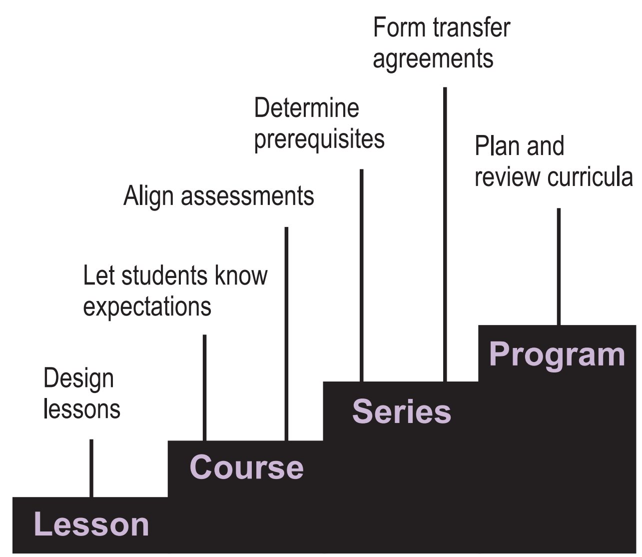
Review / Revision (x5)
- Surveys
- Interviews
- Workshops

n=218 (~60/outcome)

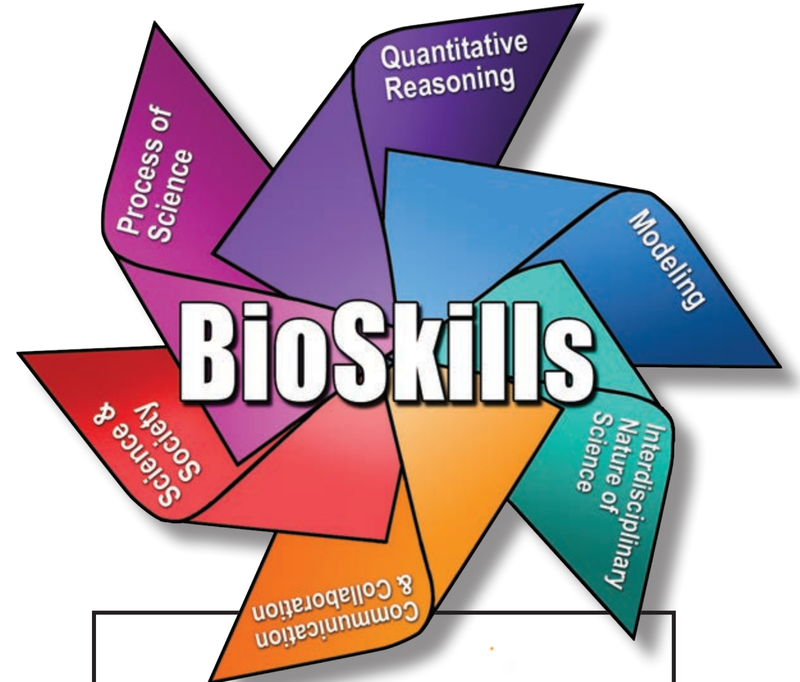
Validation
- Survey

n=417 (~210/outcome)

HOW CAN THE BIOSKILLS GUIDE HELP YOU?



A Tool for Interpreting the Vision and Change CORE COMPETENCIES



The BioSkills Guide comprises program- and course-level learning outcomes that elaborate what general biology majors should be able to do by the time they graduate. Building on the six core competencies of Vision and Change, the learning outcomes were developed and then nationally validated using input from over 600 college biology educators from a range of biology subdisciplines and institution types.

Supplemental Material 2. Expanded BioSkills Guide with aligned examples.

Educator-aligned (n=5) examples for each BioSkills Guide course-level learning outcome.

Expanded BioSkills Guide: Process of Science

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
SCIENTIFIC THINKING **Explain how science generates knowledge of the natural world.**	Explain how scientists use inference and evidence-based reasoning to generate knowledge.	Differentiate between evidence and claims in various types of scientific media.
		Explain to a non-scientist what scientists mean when they say “the data suggest…”
		Describe ways that some conclusions could be more certain than others.
		Evaluate popular arguments against vaccines and climate change.
	Describe the iterative nature of science and how new evidence can lead to the revision of scientific knowledge.	Provide an example illustrating how a new finding led to the revision of scientific understanding.
		Explain the merits of repeating a study in different contexts (e.g., different model systems, ecological systems, or experimental parameters) for generating increasingly refined hypotheses.
INFORMATION LITERACY **Locate, interpret, and evaluate scientific information.**	Find and evaluate the credibility of a variety of sources of scientific information, including popular science media and scientific journals.	Carry out literature searches using databases, Google Scholar, and library resources.
		Identify authors and potential conflicts of interest in web sources.
		Identify reliable online and print sources for use when making decisions.
	Interpret, summarize, and evaluate evidence in primary literature.	Summarize conclusions from data figures or Results section of a journal article before reading Discussion section.
		Interpret and teach data figures to peers in jigsaw or small group settings.
		Lead or participate in journal clubs.
	Evaluate claims in scientific papers, popular science media, and other sources using evidence-based reasoning.	Differentiate between objective evidence and subjective opinions in popular media or discussion sections of primary literature.
		Critique scientific information in daily life (e.g., nutritional and medical guidelines) by reviewing primary literature.
		Critique the evidence supporting two conflicting hypotheses.
		Compare treatments of similar science topics in primary literature, popular science media, and online discussions.

Expanded BioSkills Guide: Process of Science

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
QUESTION FORMULATION Pose testable questions and hypotheses to address gaps in knowledge.	Recognize gaps in our current understanding of a biological system or process and identify what specific information is missing.	When explaining or diagramming a biological process, recognize areas of uncertainty or missing steps.
		Read the introduction section of a journal article and identify what was known at the time the study began and what unanswered question the study was designed to address.
		Read multiple sources (e.g. primary literature, review articles, popular science articles) and summarize what is known and not known about a particular scientific topic.
	Develop research questions based on your own or others' observations.	Review and interpret existing lab notebooks and preliminary data from other lab members in order to identify unanswered questions.
		Suggest follow-up questions based on patterns in data.
		Make note of day-to-day observations that you don't understand and reframe into scientific questions.
	Formulate testable hypotheses and state their predictions.	Identify hypotheses and predictions in a scientific publication.
		Evaluate peers' hypotheses for testability.
		Sketch graphs or schematics of predicted study results based on hypotheses.
		Elaborate the proposed model underlying a hypothesis using a cartoon or flow chart.
		Write the "hypothesis & specific aims" portion of a mock grant proposal.
STUDY DESIGN Plan, evaluate, and implement scientific investigations.	Compare the strengths and limitations of various study designs.	Evaluate peers' study designs' alignment with hypotheses.
		Identify and describe important study design elements of published studies (e.g., predictor and response variables, sample selection, replicates).
		Distinguish between experimental and observational study designs, deductive and inductive approaches.
		Describe the advantages and limitations of different types of studies (e.g., randomized controlled trials, retrospective studies, natural experiments, comparative studies).
	Design controlled experiments, including plans for analyzing the data.	Design experiment using simulations.
		Draw a flow diagram or cartoon of proposed or published experimental design.
		Identify and design necessary controls, both biological and methodological.
		Explain how experimental design will account for or detect technical or biological variability.
		Select appropriate measurement and statistical methods for a given research design.

Expanded BioSkills Guide: Process of Science

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
STUDY DESIGN Plan, evaluate, and implement scientific investigations. *(continued)*	Execute protocols and accurately record measurements and observations.	Read and follow protocols, making note of where practices may have differed from protocol descriptions (i.e. mistakes, ambiguity).
		Keep detailed notes on observations about samples/subjects made before, during, and after protocols.
		Generate organized tables or spreadsheets to record measurements.
		Maintain a laboratory notebook and carefully save and index digital data files.
		Become proficient with common experimental techniques in a given subdiscipline.
	Identify methodological problems and suggest how to troubleshoot them.	Interpret positive and negative controls to evaluate success of an experiment.
		Use notes and observations taken during study to pinpoint most likely source of problems.
		Read about methods to propose possible sources of technical errors and appropriate corrections.
	Evaluate and suggest best practices for responsible research conduct (e.g., lab safety, record keeping, proper citation of sources).	Complete lab safety training, and maintain recommended practices (e.g., personal protective equipment, proper use and storage of chemicals).
		Use consistent file names and metadata (e.g., collection date, variable naming) formats to save digital files so that they may be used by others in the future.
		Process and store samples using appropriate techniques to preserve data quality (or make note of any improper handling of samples).

Expanded BioSkills Guide: Process of Science

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
DATA INTERPRETATION & EVALUATION **Interpret, evaluate, and draw conclusions from data in order to make evidence-based arguments about the natural world.**	Analyze data, summarize resulting patterns, and draw appropriate conclusions.	Transform and display data for exploration and analysis.
		Identify trends and distributions in data.
		Relate data to conceptual models.
		Present data and conclusions clearly, noting limitations.
	Describe sources of error and uncertainty in data.	Select and use appropriate statistical methods to calculate the degree of certainty in results.
		Differentiate between sources and effects of technical and biological variability and make appropriate conclusions with such variability in mind.
		Describe any mistakes or unexpected conditions during data collection and explain how they could impact conclusions.
	Make evidence-based arguments using your own and others' findings.	Debate the pros and cons of various scientific practices based on evidence (e.g., the use of monocultures by agribusiness).
		Write an editorial outlining an argument for or against various scientific applications (e.g., the safety of using CRISPR technology in human embryos).
	Relate conclusions to original hypothesis, consider alternative hypotheses, and suggest future research directions based on findings.	Determine whether hypothesis was supported or refuted by data.
		Revise or refine hypothesis or model based on conclusions.
		Identify experiments that could be used to resolve ambiguity in results.
DOING RESEARCH **Apply science process skills to address a research question in a course-based or independent research experience.**		Identify a novel research question and propose an appropriate study design to test it.
		Given a research question, formulate a hypothesis, identify a relevant online data set, and run appropriate analyses to test hypothesis.
		Follow protocols to gather data in the field or lab, summarize and find patterns, and identify follow-up questions to address uncertainty in results.
		After attempting an experiment or study, reflect on its success and failures and repeat with adjustments.

Expanded BioSkills Guide: Quantitative Reasoning

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
NUMERACY Use basic mathematics (e.g., algebra, probability, unit conversions) in biological contexts.	Perform basic calculations (e.g., percentages, frequencies, rates, means).	Perform calculations as part of experimental planning (e.g., plan serial dilutions, use dimensional analysis to convert units).
		Use data to calculate rates of change (e.g., mutation rate, growth rate).
		Summarize data sets using common descriptive statistics (e.g., mean, median, standard deviation).
	Select and apply appropriate equations (e.g., Hardy-Weinberg, Nernst, Gibbs free energy) to solve problems.	Use Punnett Squares and related equations to calculate predicted phenotype and genotype frequencies from crosses.
		Plan how to prepare solutions and reaction mixes using $C_1*V_1=C_2*V_2$.
		Identify appropriate equations to interpret a given data set or scenario (e.g., population growth equations, Nernst and Goldman equations for equilibrium and membrane potentials).
		Translate words and concepts (e.g., descriptions of systems, hypotheses) into equations and terms (e.g., coefficients, rate of change).
	Interpret and manipulate mathematical relationships (e.g., scale, ratios, units) to make quantitative comparisons.	Convert between related units (e.g., given concentration, convert volume to mass).
		Calculate and interpret fold-change in a variable over time.
		Interpret units reported on graphs (e.g., differentiate between linear and log scales, interpret slope based on units of X and Y-axes).
		Relate surface area to volume in various biological structures (e.g., plasma membranes, alveoli, leaves).
	Use probability and understanding of biological variability to reason about biological processes and statistical analyses.	Apply 'either-or' and 'both-and' rules to calculate combined probabilities.
		Explain the strengths and limitations of using a p-value criterion (e.g., <0.05) to determine significance.
		Explain the difference between different measures of error and variation (e.g., standard error the mean vs. standard deviation).

Expanded BioSkills Guide: Quantitative Reasoning

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
NUMERACY Use basic mathematics (e.g., algebra, probability, unit conversions) in biological contexts. *(continued)*	Use rough estimates informed by biological knowledge to check quantitative work.	Make order-of-magnitude estimates.
		Extrapolate from data in order to make predictions.
	Describe how quantitative reasoning helps biologists understand the natural world.	Identify quantitative approaches that could be used when solving biological problems.
		Discuss examples of how 'big data' has allowed biologists to answer new research questions (e.g., the identification of quantitative trait loci, the use of satellite data to inform ecological models).
QUANTITATIVE & COMPUTATIONAL DATA ANALYSIS Apply the tools of graphing, statistics, and data science to analyze biological data.	Record, organize, and annotate simple data sets.	Save and organize data with future users in mind (e.g., include units, clearly label columns and rows, use intuitive file names).
		Identify and include relevant metadata in data tables (e.g., collection dates, origin of data).
		Add appropriately annotated data to large public databases and discuss the importance of data annotation in the maintenance of these resources.
		Use Excel, R, Python, Mathematica, or other programs to perform basic tasks in data management.
	Create and interpret informative graphs and other data visualizations.	Interpret tables and data visualizations (e.g., scatter plots, bar graphs, boxplots, histograms) in primary literature.
		Choose and create best form of chart for data type (e.g., logarithmic scale for growth rates, bar graphs for categorical data, histograms for counts).
		Modify visualization to emphasize important relationships between variables (e.g., add trend lines, color code subsets of data).
		Make predictions and construct explanations based on your own or others' data visualizations.
	Select, carry out, and interpret statistical analyses.	Calculate and explain the uses of different types of descriptive statistics (e.g., mean vs median, standard deviation vs. standard error of the mean).
		Use software (e.g., Excel, R) to calculate inferential statistics.
		Interpret statistics in primary literature (e.g., error bars and *p*-values).
		Select appropriate inferential statistical methods for research question (e.g., t-test for comparing mean of two groups, linear regression for modeling relationship between multiple variables, Chi-square for comparing distributions).

Expanded BioSkills Guide: Quantitative Reasoning

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
QUANTITATIVE & COMPUTATIONAL DATA ANALYSIS **Apply the tools of graphing, statistics, and data science to analyze biological data.** ***(continued)***	Describe how biologists answer research questions using databases, large data sets, and data science tools.	Give examples of research tasks that can be aided by common bioinformatic tools (e.g., BLAST to find homologs, Clustal to identify differences between sequences, Primer3 to reduce likelihood of unintended PCR products).
		Browse and describe the types of data available in various public databases (e.g., GenBank, UCSC genome browser, 1001 Genomes, NEON).
		Discuss examples where data science has contributed to our understanding of biology (e.g., genomics and genetics, metabolomics and human health, satellite data and the impacts of climate change).
	Interpret the biological meaning of quantitative results.	Describe equations and coefficients in terms of their biological meaning (e.g., k as "carrying capacity", N_e as "effective population size", C_t values as "gene expression levels").
		Interpret what graph curves (e.g., linear, exponential, saturation, sigmoidal) mean in different biological contexts (e.g., population growth, enzyme kinetics).
		Summarize data and relate back to hypotheses and other knowledge.
		Write the discussion section of a lab report, including alternative interpretations of data.

Expanded BioSkills Guide: Modeling

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
PURPOSE OF MODELS Recognize the important roles that scientific models, of many different types (conceptual, mathematical, physical, etc.), play in predicting and communicating biological phenomena.	Describe why biologists use simplified representations (models) when solving problems and communicating ideas.	Provide examples of models used by biologists (e.g., animal models of human disease, mathematical models of population genetics, 3D models of anatomical structures) and explain their advantages and disadvantages over "the real thing".
		Describe ways you use models in your own studying and research (e.g., textbook schematics or simulations for learning about abstract ideas, conceptual models when formulating hypotheses, 3D models in lab).
		Identify aspects of biological systems that would likely be simplified in a model and explain why (e.g., system dynamics are often omitted from 2D models because of difficulty in representing time).
	Given two models of the same biological process or system, compare their strengths, limitations, and assumptions.	Describe the purposes of different types of models (e.g., physical models for understanding 3D structure, mathematical models for predicting future events).
		Discuss the tradeoffs between model accuracy and simplicity.
		Identify and describe assumptions made in a given model or simulation (i.e. simplified conditions and unknown relationships).
		Choose and justify which model would be better for a given research question based on which parameters are included in the model and which are simplified.
MODEL APPLICATION Make inferences and solve problems using models and simulations.	Summarize relationships and trends that can be inferred from a given model or simulation.	Determine how two variables relate by manipulating a model and interpreting its output (e.g., the influence of Keq on ΔG in enzymatic reaction coupling, the interplay of resistance and concentration gradient in flux).
		Sketch a flow chart or cartoon of a biological process based on the output of a model or simulation.
		Infer biological trends based on the shape of the model output curve (e.g., linear, exponential, saturation, sigmoidal).
	Use models and simulations to make predictions and refine hypotheses.	Predict the impact of changing parameters on various outputs (e.g., the effect of selection coefficients on allele frequencies, the effect of environmental resources on fitness over time).
		Identify key components of a system based on their relative importance in a model's ability to explain data (e.g., master regulator transcription factors, keystone species).
		Propose environmental or public health policy solutions based on models and simulations (e.g., priorities for habitat restoration).

Expanded BioSkills Guide: Modeling

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
MODELING Build and evaluate models of biological systems.	Build and revise conceptual models to propose how a biological system or process works.	Sketch flow charts, diagrams, or concept maps while problem solving to organize thinking.
		Draw a cartoon or diagram of a biological process or system consistent with a given set of data.
		Generate a concept map using index cards or online programs to identify and visualize connections between concepts (e.g., transcription, translation, and signaling; ventilation, heart rate, and O_2 levels).
		Create diagrams or 3D models that emphasize important aspects of biological structures (e.g., ability to separate DNA base pairs for replication, amino acid R-group structure for protein function, tissue organization for organ function).
	Identify important components of a system and describe how they influence each other (e.g., positively or negatively).	Given a biological system (e.g., gut microbiome, carbon cycle, cellular respiration), list relevant components and categorize them as inputs, outputs, or mediators.
		Simplify models by identifying and removing components that are not necessary to recreate patterns of interest.
		Add quantitative signifiers to a concept map (i.e. "-" indicates two components covary indirectly).
	Evaluate conceptual, mathematical, or computational models by comparing their predictions with empirical data.	Conduct quality control tests by defining expected outcomes for a model or simulation, including conditions under which expected behaviors should occur (e.g., lac operon expression in presence of lactose and/or glucose).
		Use statistics (e.g., Chi-square tests, t-tests) to compare model outputs to observed distributions.
		When model predictions and empirical data don't match, propose variables that may be missing from model that could explain difference.
		Iteratively modify a model or simulation until quality control is passed.

Expanded BioSkills Guide: Interdisciplinary Nature of Science

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
CONNECTING SCIENTIFIC KNOWLEDGE **Integrate concepts across other STEM disciplines (e.g., chemistry, physics) and multiple fields of biology (e.g., cell biology, ecology).**	Given a biological problem, identify relevant concepts from other STEM disciplines or fields of biology.	Identify and use relevant knowledge from chemistry and physics when learning biology concepts (e.g., apply physics concepts when learning about microscopy or mass spectrometry, apply chemistry knowledge when describing molecular affinity).
		Describe influences of physical forces or chemical interactions in biological systems (e.g., flux in electrophysiology, bulk flow in respiration, hydrogen bonding in enzyme/substrate binding, chemosensation or biomechanics in plant-pollinator interactions).
		Use math to model biological systems.
	Build models or explanations of simple biological processes that include concepts from other STEM disciplines or multiple fields of biology.	Build a concept map connecting ideas from multiple disciplines in the context of a biological system (e.g., the kinetics, biochemistry, and functions of catalysis; the chemistry and physics of membrane potentials; the effects of abiotic factors and symbiotes on plant productivity).
		Sketch models or write explanations of biological systems that incorporate concepts from multiple disciplines, including how components interact across scales (i.e. atoms, molecules, cellular structures, organs, organisms, ecosystems).
INTERDISCIPLINARY PROBLEM SOLVING **Consider interdisciplinary solutions to real-world problems.**	Describe examples of real-world problems that are too complex to be solved by applying biological approaches alone.	Reflect on and propose solutions to case studies of complex problems with important societal consequences (e.g., ocean acidification, malaria epidemic, ecological impacts of urbanization).
		Identify stories in the news or other popular media that include the contributions of experts from multiple disciplines.
		Attend and summarize seminars from local faculty engaged in interdisciplinary research.
	Suggest how collaborators in STEM and non-STEM disciplines could contribute to solutions of real-world problems.	Discuss and describe the contributions of different stakeholders in actual policy proposals (e.g., clean water initiatives, carbon taxes, vaccination requirements).
		Identify gaps in own knowledge (e.g., as part of a case on diabetes, write questions for a chemist to improve understanding of symptoms and drug treatments).

Expanded BioSkills Guide: Interdisciplinary Nature of Science

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
INTERDISCIPLINARY PROBLEM SOLVING Consider interdisciplinary solutions to real-world problems. ***(continued)***	Be able to explain biological concepts, data, and methods, including their limitations, using language understandable by collaborators in other disciplines.	Identify and define terms that can have different meanings in different contexts (e.g., regression, acid/base, energy).
		Share data collection and analysis tasks with students from multiple disciplines (e.g., chemistry and biology students work together on a drug discovery project).
		Define constraints and parameters of a system to be used by colleagues in other disciplines (e.g., biology and computer science students collaborate to write computer scripts to analyze genomics data).
		Teach a student in another major about your research topic.

Expanded BioSkills Guide: Communication & Collaboration

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
COMMUNICATION Share ideas, data, and findings with others clearly and accurately.	Use appropriate language and style to communicate science effectively to targeted audiences (e.g., general public, biology experts, collaborators in other disciplines).	Adjust level of detail in data presentations depending on scientific audience (e.g., lab meeting for experts vs. class presentations for general biology audience).
		Build educational blogs, pamphlets, Wikipedia pages or magazine articles for audiences outside of the classroom.
		Write evidence-based policy recommendations for private or government agencies (e.g., Nature Conservancy, State Fish & Wildlife, Food & Drug Administration).
		Create tailored presentations or documents to inform the general public (e.g., bird-watching groups, museum visitors) about important new biological findings, avoiding overly sensational language.
	Use a variety of modes to communicate science (e.g., oral, written, visual).	Present data orally with supporting poster, slides, or chalkboard sketches.
		Write blogs, essays, papers, or pamphlets to communicate findings.
		Give mini-lectures in the classroom.
		Write a scientific abstract, research paper, senior thesis, or grant proposal.
		Present data as infographics.
COLLABORATION Work productively in teams with people who have diverse backgrounds, skill sets, and perspectives.	Work with teammates to establish and periodically update group plans and expectations (e.g., team goals, project timeline, rules for group interactions, individual and collaborative tasks).	Delegate tasks to accomplish larger projects (e.g., team-based learning, many-hands data collection, collaborative presentations).
		Prepare a group contract establishing norms and expectations (e.g., modes of communication, frequency of meetings, paths for feedback).
		Set aside team time to discuss progress and reorganize work distribution and decision-making processes as needed.
	Elicit, listen to, and incorporate ideas from teammates with different perspectives and backgrounds.	Learn from teammates in small groups (e.g., jigsaw reading of journal articles, think-pair-share).
		Ask clarifying questions from partner.
		Monitor group conversations for equitable participation.
		Take the role of different stakeholders and have a discussion about a policy issue using scientific evidence.

Expanded BioSkills Guide: Communication & Collaboration

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
COLLABORATION Work productively in teams with people who have diverse backgrounds, skill sets, and perspectives. *(continued)*	Work effectively with teammates to complete projects.	Establish mode of communication and resource sharing that works for all group members (e.g., emails, online file sharing applications, in person meetings).
		Seek outside help from instructor or TA when group reaches an impasse.
		Meet before presentations or deadlines to integrate individual products into a cohesive whole.
		Plan multiple opportunities to exchange drafts and share progress updates for whole-group feedback.
COLLEGIAL REVIEW Provide and respond to constructive feedback in order to improve individual and team work.	Evaluate feedback from others and revise work or behavior appropriately.	Modify posters, presentations, or papers based on comments by peers and instructors.
		Listen to and weigh alternative points of view.
		Ask others for specific types of feedback based on self-assessed weaknesses of work.
	Critique others' work and ideas constructively and respectfully.	Peer review papers and presentations, providing feedback on both content and style.
		Where appropriate, use existing methods to formalize feedback and maximize likelihood of use (e.g., 'compliment sandwich' or 'keep-quit-start').
		Evaluate performance of other team members and make constructive suggestions.
METACOGNITION Reflect on your own learning, performance, and achievements.	Evaluate your own understanding and skill level.	Compare your responses on an exam or assignment to a key and identify areas for improvement.
		Write down the "muddiest point" from a class or study session.
		Score your work as part of a team project.
	Assess personal progress and contributions to your team and generate a plan to change your behavior as needed.	Use practice test or midterm outcomes to determine how to modify study strategies.
		Develop time management strategies to meet competing deadlines.
		Set and revisit goals to reflect on personal growth (How have you improved? How can you ensure you reach your goal?).
		Monitor and adjust behavior based on informal and formal feedback from group members.

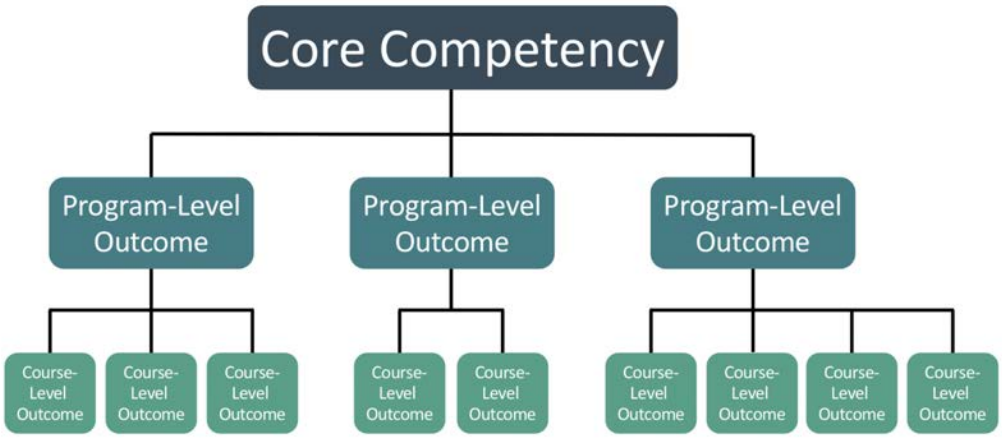
Expanded BioSkills Guide: Science & Society

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
ETHICS **Demonstrate the ability to critically analyze ethical issues in the conduct of science.**	Identify and evaluate ethical considerations (e.g., use of animal or human subjects, conflicts of interest, confirmation bias) in a given research study.	Discuss animal welfare and rights in biomedical research and agriculture.
		Outline relevant ethical considerations for a published study.
		Complete appropriate ethics training before conducting research.
		Identify relevant ethical considerations for experimental design before beginning an independent or course-based research study, and discuss appropriate accommodations.
	Critique how ethical controversies in biological research have been and can continue to be addressed by the scientific community.	Discuss historical cases of scientific misconduct or controversy (e.g., Rosalind Franklin and the history of women in science, Henrietta Lacks and informed consent).
		Debate current status and proposed solutions to modern scientific controversies (e.g., call for moratorium on human gene editing, the sharing of pathogenic virus sequences).
		Evaluate strengths and weaknesses of existing paths for ethics review (e.g., IRB and IACUC review processes).
		Compare research policies and guidelines (e.g., stem cell research, embryonic gene editing) in the US with other countries.
SOCIETAL INFLUENCES **Consider the potential impacts of outside influences (historical, cultural, political, technological) on how science is practiced.**	Describe examples of how scientists' backgrounds and biases can influence science and how science is enhanced through diversity.	Research and summarize the contributions of scientists from diverse backgrounds.
		Discuss cases where diversity in science led to innovation (e.g., maternal effect, sexual selection).
		Reflect on how scientists' worldviews affect their interpretations (e.g., "ladder of life" model of evolution, Earth as the center of the universe).
		Discuss the connections between social justice and science (e.g., the history of research on the genetic basis of race, funding for neglected tropical diseases).
	Identify and describe how systemic factors (e.g., socioeconomic, political) affect how and by whom science is conducted.	Critique the strengths and weaknesses of peer review for publication.
		Describe cases where a new technology changed the types of data that can be collected and therefore the scientific questions that can be answered (e.g., DNA sequencing, imaging technologies, large public databases).
		Listen to stories from the MeToo STEM movement and reflect on how scientific culture can affect who pursues and remains in science.
		Discuss ways that education and hiring practices might be changed to lessen or eliminate opportunity gaps for underrepresented groups in science.
		Discuss how funding determines what research is prioritized (e.g., neglected tropical diseases, climate change).

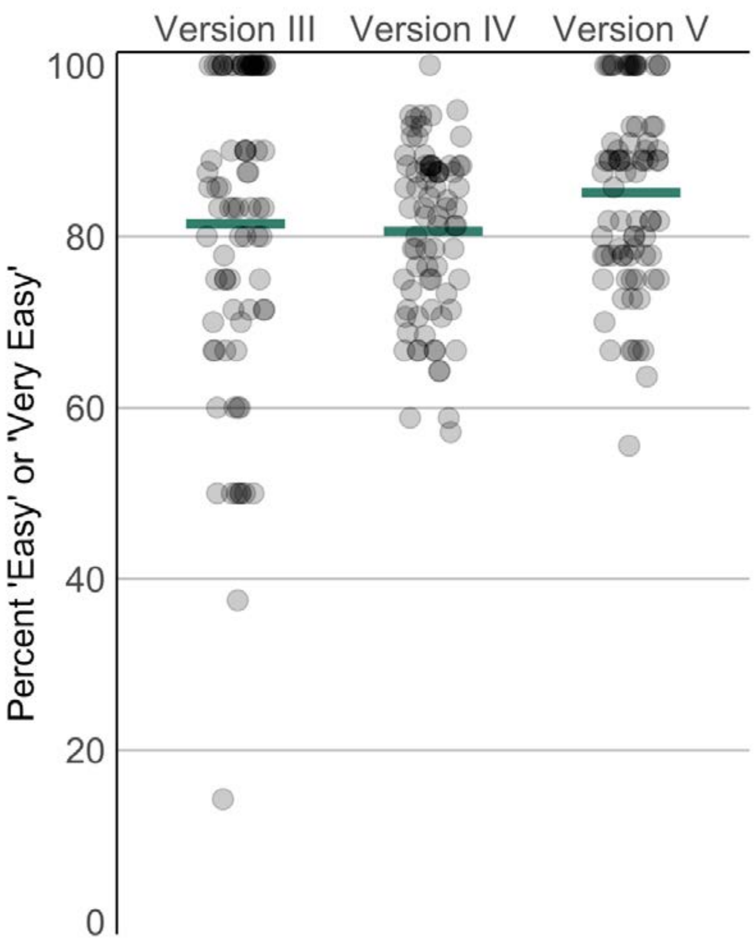
Expanded BioSkills Guide: Science & Society

Program-Level Learning Outcomes	Course-Level Learning Outcomes	Examples
SCIENCE'S IMPACT ON SOCIETY **Apply scientific reasoning in daily life and recognize the impacts of science on a local and global scale.**	Apply evidence-based reasoning and biological knowledge in daily life (e.g., consuming popular media, deciding how to vote).	Practice skepticism when consuming popular media about scientific or non-scientific topics.
		Reflect on how science is applied in personal decisions about health, use of technology, and interactions with the environment.
		Share relevant biology knowledge with friends and relatives during conversations about current events or health decisions.
	Use examples to describe the relevance of science in everyday experiences.	Notice and describe local plant ecology, the biology of food and nutrition, representations and reports of science in popular culture.
		Evaluate how evidence is used in government policy decisions (e.g., subsidies in agriculture, public health policy, funding of renewable energy).
	Identify and describe the broader societal impacts of biological research on different stakeholders.	Discuss past cases of biased research designs having negative repercussions (e.g., pharmacological trials on white male patients used to inform dosage in all populations).
		Reflect on unanticipated impacts of scientific advances (e.g., environmental policy, genetic engineering, personal genomics).
		Consider the perspectives of multiple stakeholders as part of lessons about current societal issues (e.g., comparing DNA found at crime scenes to genealogical records, impacts of human disturbance on wildlife health, climate-related habitat change).
	Describe the roles scientists have in facilitating public understanding of science.	Read and describe the purpose of various modes of presenting science for a general audience (e.g., Science section of the New York Times, museum exhibits, scientist interviews on news shows or podcasts).
		Write summaries of new biological findings for a general audience, including a discussion of why they should care.
		Discuss the importance of political advocacy as part of the role of professional scientists (e.g., voice of scientists in debates on vaccines, climate change, or misconceptions about race and genetics).
		Share biology knowledge while volunteering for non-profit organizations or participating in local community meetings.

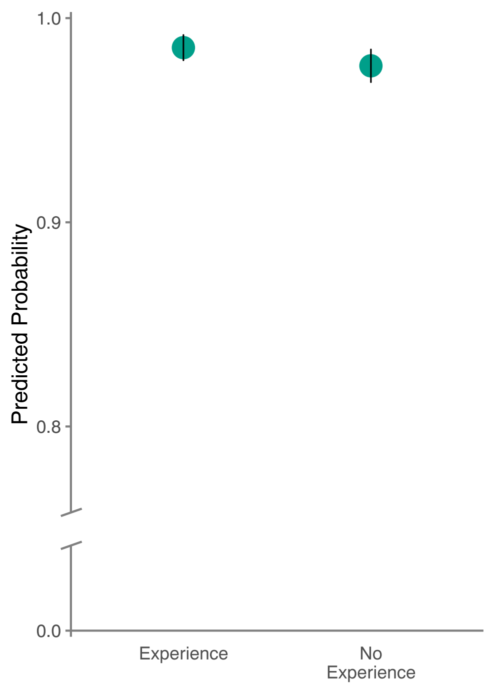
Supplemental Material 3. Supplemental Figures.



Supplemental Figure 1. Nested BioSkills Guide structure.
The BioSkills Guide has a two-tiered structure. Each of the six core competencies contains 2-6 program-level learning outcomes (20 total), and each program-level outcome contains 2-6 course-level outcomes (57 total).



Supplemental Figure 2. Change in 'ease of understanding' ratings over time.
For each learning outcome, ratings were summarized by calculating the percent of respondents who selected 'Easy' or 'Very Easy'. Horizontal lines indicate means. Points are jittered to reveal distribution. 'Ease of understanding' questions were not included in validation phase surveys.



Supplemental Figure 3. Effect of experience with ecology or evolutionary biology research on support for learning outcomes.

Experience in ecology or evolutionary biology research was retained as a main effect in the best fitting model for RQ2b. Predicted probabilities are shown. Vertical lines indicate 95% confidence intervals. Note that y-axis is truncated.

Supplemental Material 4. Supplemental Tables.

Supplemental Table 1. Summary of revisions.

[a] The number of learning outcomes that were removed, added, or reworded is shown for each round of revision. Rewordings included substantial rewrites and single word changes. The total number of outcomes (both program- and course-level) in the starting draft is also shown (i.e. there were 78 outcomes in Version IV).

[b] One outcome underwent minor revision after the national validation survey. Details of editing are in Methods.

	Number of Outcomes [a]			
Round	**Before Revision**	**Removed**	**Added**	**Reworded**
Version I -> Version II	86	1	1	30
Version II -> Version III	86	7	2	57
Version III -> Version IV	81	6	3	57
Version IV -> Version V	78	4	6	64
Version V -> Version VI	80	3	0	29
Version VI -> Final	77	0	0	1
Final Version [b]	77	0	0	1

Supplemental Table 2. Summary of self-reported demographics of survey respondents during development phase.

[a] Count and percent of total (out of 93, unless otherwise noted) of respondents who selected indicated response, aggregated across all three surveys from the development phase. Unknown indicates that respondent did not answer that question.

[b] Mean importance rating (1 = 'Very Unimportant', 5 = 'Very Important') was calculated across all outcomes reviewed by respondents who selected that response.

[c] Demographic questions were revised slightly between review of Version III and review of Version IV. These demographic characteristics can only be determined from respondents who reviewed Version IV or V (n=72).

[d] Because of survey revision, this demographic characteristic can only be determined from respondents who reviewed Version III (n=21).

[e] These questions allowed respondents to select all that apply, so percentages do not sum to 100.

[f] These characteristics were inferred from responses to questions about Graduate Training Subdiscipline and Current Research Subdiscipline.

Demographic	Response	n (%) [a]	Mean Importance [b]
Institution Type	Associate's Granting	10 (10.8%)	4.6
	Bachelor's Granting	9 (9.7%)	4.4
	Master's Granting	18 (19.4%)	4.6
	Doctoral Granting	42 (45.2%)	4.4
	Other	1 (1.1%)	4.3
	Unknown	13 (14%)	4.3
Current Position	Graduate Student	3 (3.2%)	4.7
	Postdoc	9 (9.7%)	4.5
	Lecturer/Instructor	17 (18.3%)	4.5
	Assistant/Associate/Full Professor	44 (47.3%)	4.5
	Staff	2 (2.2%)	4.4
	Other	4 (4.3%)	4.7
	Unknown	14 (15.1%)	4.3
Job Responsibility [c]	Teaching	25 (34.7%)	4.6
	Research	10 (13.9%)	4.5
	Teaching & Research Equally	14 (19.4%)	4.5
	Other	5 (6.9%)	4.3
	Unknown	18 (25%)	4.5
Course Levels Taught [e]	Non-Majors Lower (100-200)[2]	27 (17.2%)	4.5
	Majors Lower (100-200)	51 (32.5%)	4.5
	Upper (300-400)	41 (26.1%)	4.6
	Graduate (500+)	16 (10.2%)	4.5
	Unknown	22 (14%)	4.4
Teaching Subdiscipline [c]	Molecular/Cell/Development (MCD)	12 (16.7%)	4.5
	Physiology	6 (8.3%)	4.6
	Ecology/Evolution	12 (16.7%)	4.7
	General	11 (15.3%)	4.3
	Other	13 (18.1%)	4.4
	Unknown	18 (25%)	4.5

Expertise Subdiscipline [d]	MCD	8 (28.6%)	4.6
	Physiology	3 (10.7%)	4.4
	Ecology/Evolution	6 (21.4%)	4.3
	Discipline-Based Education Research (DBER)	5 (17.9%)	4.5
	Other	2 (7.1%)	4.5
	Unknown	4 (14.3%)	4.1
Current Research Subdiscipline [ce]	No Current Research	8 (10.1%)	4.5
	MCD	6 (7.6%)	4.4
	Physiology	2 (2.5%)	4.7
	Ecology/Evolution	5 (6.3%)	4.8
	DBER	37 (46.8%)	4.5
	Other	3 (3.8%)	4.5
	Unknown	18 (22.8%)	4.5
Graduate Training Subdiscipline [ce]	MCD	12 (14.6%)	4.5
	Physiology	8 (9.8%)	4.4
	Ecology/Evolution	19 (23.2%)	4.6
	DBER	10 (12.2%)	4.5
	Other	15 (18.3%)	4.4
	Unknown	18 (22%)	4.5
Currently Engaged in Biology Research [cf]	Not Currently Engaged in Biology Research	39 (54.2%)	4.5
	Current Research in Biology	15 (20.8%)	4.6
	Unknown	18 (25%)	4.5
DBER Experience [f]	No DBER Experience	26 (28%)	4.5
	DBER Experience	45 (48.4%)	4.5
	Unknown	22 (23.7%)	4.4
Familiarity with Vision and Change	Extremely Familiar	28 (30.1%)	4.6
	Very Familiar	24 (25.8%)	4.4
	Somewhat Familiar	13 (14%)	4.5
	Slightly Familiar	2 (2.2%)	4.4
	Not at all Familiar	3 (3.2%)	4.1
	Unknown	23 (24.7%)	4.4
Previous Involvement [c]	Previously Involved	10 (13.9%)	4.5
	New	44 (61.1%)	4.5
	Unknown	18 (25%)	4.5

Supplemental Table 3. Counts of unique participants and institutions, by institution type.

[a] Institution classification of all participants was determined by matching institution name with Carnegie classification dataset (Indiana University Center for Postsecondary Research, 2016).

[b] Total n and distribution for development phase is distinct from Supplemental Table 2 because these data also include workshop, round table, and interview participants.

Phase	Institution Type [a]	Participants, n (% of unique)	Institutions, n (% of unique)
Development [b]	Associate's	37 (14.4%)	24 (27.6%)
	Bachelor's	13 (5.1%)	10 (11.5%)
	Master's	31 (12.1%)	16 (18.4%)
	Doctoral	95 (37%)	29 (33.3%)
	International	37 (14.4%)	4 (4.6%)
	Other	4 (1.6%)	4 (4.6%)
	Unknown	40 (15.6%)	NA
Validation	Associate's	86 (20.6%)	59 (26.2%)
	Bachelor's	50 (12%)	36 (16%)
	Master's	67 (16.1%)	43 (19.1%)
	Doctoral	116 (27.8%)	77 (34.2%)
	International	7 (1.7%)	6 (2.7%)
	Other	5 (1.2%)	4 (1.8%)
	Unknown	86 (20.6%)	NA

Supplemental Table 4. Summary of learning outcome importance ratings across development and validation phases.

[a] Importance ratings (1 = 'Very Unimportant', 5 = 'Very Important') were individually summarized for each learning outcome by calculating percent support and the mean rating. Then, minimum, maximum, and mean were calculated across all learning outcomes for both summary measures.

[b] 'n total' is the number of unique survey respondents who participated in that survey. 'n outcome' is the number of respondents who reviewed each individual outcome (respondents were randomly assigned a subset of outcomes). 'n observations' is the number of rating data points collected across all outcomes and respondents.

		Percent support [a]			Mean rating [a]			n [b]		
Phase	Round	min	max	mean	min	max	mean	total	outcome	observations
Develop-ment	Version III	16.7	100	85.9	2.7	5	4.4	21	5-10	618
	Version IV	50	100	92.8	3.4	4.9	4.5	45	12-19	1197
	Version V	72.7	100	94.4	3.8	5	4.5	27	8-14	786
Validation	Pilot	72.7	100	94.9	3.9	4.9	4.5	20	11-12	905
	National	73.5	99.5	91.7	4	4.9	4.5	397	200-225	16667
	Combined	**74.3**	**99.6**	**91.9**	**4**	**4.9**	**4.5**	**417**	**211-237**	**17572**

Supplemental Table 5. Summary of descriptive statistics of learning outcome 'ease of understanding' ratings across development phase.

[a] 'Ease of understanding' ratings (1 = 'Very Difficult', 5 = 'Very Easy') were individually summarized for each learning outcome by calculating the percent of respondents who selected 'Easy' or 'Very Easy' and the mean rating. Then, minimum, maximum, and mean were calculated across all outcomes for both summary measures. Participant counts can be seen in Supplemental Table 4.

[b] 'Ease of understanding' questions were not included in validation phase surveys.

	Percent 'Easy' or 'Very Easy' [a]			Mean rating [a]		
Round [b]	min	max	mean	min	max	mean
Version III	14.3	100	81.5	2.6	5	4.3
Version IV	57.1	100	80.6	3.4	4.8	4.2
Version V	55.6	100	85.1	3.6	4.8	4.4

Supplemental Table 6. Self-reported demographics of survey respondents during validation phase.

[a] Number and percent (out of 417) of unique respondents who selected indicated response, aggregated across both surveys from the validation phase. Unknown indicates that respondent did not answer that question.

[b] Mean importance rating (1 = 'Very Unimportant', 5 = 'Very Important') was calculated across all outcomes reviewed by respondents who selected that response.

[c] These questions allowed respondents to select all that apply, so percentages do not sum to 100.

[d] These characteristics were inferred from responses to questions about Graduate Training Subdiscipline and Current Research Subdiscipline.

Demographic	Response	n (%) [a]	Mean Importance [b]
Institution Type	Associate's Granting	92 (22.1%)	4.5
	Bachelor's Granting	96 (23%)	4.5
	Master's Granting	51 (12.2%)	4.5
	Doctoral Granting	121 (29%)	4.5
	Other	7 (1.7%)	4.4
	Unknown	50 (12%)	4.4
Current Position	Graduate Student	5 (1.2%)	4.5
	Postdoc	5 (1.2%)	4.5
	Lecturer/Instructor	83 (19.9%)	4.5
	Assistant/Associate/Full Professor	253 (60.7%)	4.5
	Staff	5 (1.2%)	4.6
	Other	16 (3.8%)	4.6
	Unknown	50 (12%)	4.4
Job Responsibility	Teaching	258 (61.9%)	4.5
	Research	10 (2.4%)	4.5
	Teaching & Research Equally	79 (18.9%)	4.4
	Other	20 (4.8%)	4.6
	Unknown	50 (12%)	4.4
Teaching Subdiscipline	Molecular/Cell/Development	108 (25.9%)	4.4
	Physiology	49 (11.8%)	4.4
	Ecology/Evolution	65 (15.6%)	4.5
	General	103 (24.7%)	4.5
	Other	38 (9.1%)	4.4
	Unknown	54 (12.9%)	4.4
Course Levels [c]	Non-Majors Lower (100-200)	196 (47%)	4.5
	Majors Lower (100-200)	265 (63.5%)	4.5
	Upper (300-400)	221 (53%)	4.5
	Graduate (500+)	56 (13.4%)	4.4
	Unknown	55 (13.2%)	4.4
Course Levels, Aggregated	Lower-Level Only (100-200)	129 (30.9%)	4.5
	Advanced Only (300-500+)	40 (9.6%)	4.5
	Lower & Advanced	193 (46.3%)	4.5
	Unknown	55 (13.2%)	4.4

Current Research Subdiscipline [c]	No Current Research	86 (20.6%)	4.5
	Molecular/Cell/Development (MCD)	84 (20.1%)	4.4
	Physiology	17 (4.1%)	4.5
	Ecology/Evolution	68 (16.3%)	4.5
	Discipline-Based Education Research (DBER)	112 (26.9%)	4.5
	Unknown	65 (15.6%)	4.4
Current Research Subdiscipline, Aggregated	No Current Research	84 (20.1%)	4.5
	MCD Only	61 (14.6%)	4.4
	Physiology Only	11 (2.6%)	4.5
	Ecology/Evolution Only	53 (12.7%)	4.5
	DBER Only	90 (21.6%)	4.5
	Other Only	21 (5%)	4.5
	More than 2 Subdisciplines	6 (1.4%)	4.5
	MCD & Physiology	1 (0.2%)	4.8
	MCD & Ecology/Evolution	5 (1.2%)	4.3
	MCD & DBER	12 (2.9%)	4.4
	Physiology & Ecology/Evolution	2 (0.5%)	4.6
	Physiology & DBER	1 (0.2%)	4.7
	Ecology/Evolution & DBER	5 (1.2%)	4.6
	Unknown	65 (15.6%)	4.4
Graduate Training Subdiscipline [c]	MCD	182 (43.6%)	4.5
	Physiology	40 (9.6%)	4.5
	Ecology/Evolution	126 (30.2%)	4.5
	DBER	17 (4.1%)	4.6
	Other	40 (9.6%)	4.4
	Unknown	52 (12.5%)	4.4
Graduate Training Subdiscipline, Aggregated	MCD Only	165 (39.6%)	4.4
	Physiology Only	26 (6.2%)	4.5
	Ecology/Evolution Only	115 (27.6%)	4.5
	DBER Only	11 (2.6%)	4.5
	Other Only	24 (5.8%)	4.3
	More than 2 Subdisciplines	2 (0.5%)	4.8
	MCD & Physiology	8 (1.9%)	4.7
	MCD & Ecology/Evolution	5 (1.2%)	4.6
	MCD & DBER	3 (0.7%)	4.6
	Physiology & Ecology/Evolution	3 (0.7%)	4.5
	Physiology & DBER	1 (0.2%)	4.5
	Ecology/Evolution & DBER	2 (0.5%)	4.8
	Unknown	52 (12.5%)	4.4
DBER Experience [d]	No DBER Experience	236 (56.6%)	4.5
	DBER Experience	116 (27.8%)	4.5

	Unknown	65 (15.6%)	4.4
Currently Engaged in Biology Research [d]	Not Currently Engaged in Biology Research	170 (40.8%)	4.5
	Current Research in Biology	182 (43.6%)	4.5
	Unknown	65 (15.6%)	4.4
Familiarity with Vision and Change	Extremely Familiar	110 (26.4%)	4.5
	Very Familiar	146 (35%)	4.4
	Somewhat Familiar	68 (16.3%)	4.5
	Slightly Familiar	16 (3.8%)	4.2
	Not at all Familiar	26 (6.2%)	4.4
	Unknown	51 (12.2%)	4.4
Gender	Female	241 (57.8%)	4.5
	Male	120 (28.8%)	4.4
	Other	2 (0.5%)	4.7
	Unknown	54 (12.9%)	4.4
Previous Involvement	Previously Involved	29 (7%)	4.5
	New	334 (80.1%)	4.5
	Unknown	54 (12.9%)	4.4

Supplemental Table 7. Descriptive statistics of importance ratings for all outcomes during validation.

[a] Importance ratings (1 = 'Very Unimportant', 5 = 'Very Important') for each learning outcome were summarized by calculating percent support (percent 'Important' or 'Very Important' out of all ratings), mean, maximum, and minimum ratings. n=211-237 per outcome.

[b] This is the only outcome that was revised after the national validation survey. Details of editing are in Methods.

Process of Science					
Outcome #	**Outcome**	**% Support [a]**	**Mean**	**Max**	**Min**
1	SCIENTIFIC THINKING Explain how science generates knowledge of the natural world.	97	4.8	5	1
1.1	Explain how scientists use inference and evidence-based reasoning to generate knowledge.	97.4	4.6	5	1
1.2	Describe the iterative nature of science and how new evidence can lead to the revision of scientific knowledge.	97.9	4.7	5	1
2	INFORMATION LITERACY Locate, interpret, and evaluate scientific information.	98.3	4.8	5	1
2.1	Find and evaluate the credibility of a variety of sources of scientific information, including popular science media and scientific journals.	97	4.7	5	1
2.2	Interpret, summarize, and evaluate evidence in primary literature.	94.8	4.6	5	1
2.3	Evaluate claims in scientific papers, popular science media, and other sources using evidence-based reasoning.	97	4.7	5	1
3	QUESTION FORMULATION Pose testable questions and hypotheses to address gaps in knowledge.	95.7	4.6	5	1
3.1	Recognize gaps in our current understanding of a biological system or process and identify what specific information is missing.	83	4.1	5	1
3.2	Develop research questions based on your own or others' observations.	89.8	4.3	5	1
3.3	Formulate testable hypotheses and state their predictions.	95.3	4.6	5	1
4	STUDY DESIGN Plan, evaluate, and implement scientific investigations.	93.6	4.5	5	2
4.1	Compare the strengths and limitations of various study designs.	87.2	4.2	5	2
4.2	Design controlled experiments, including plans for analyzing the data.	91.5	4.5	5	2
4.3	Execute protocols and accurately record measurements and observations.	93.6	4.5	5	1
4.4	Identify methodological problems and suggest solutions or alternative approaches.	83.8	4.1	5	1
4.5	Evaluate and suggest best practices for responsible research conduct (e.g., lab safety, record keeping, proper citation of sources).	82	4.2	5	2
5	DATA INTERPRETATION & EVALUATION Interpret, evaluate, and draw conclusions from data in order to make evidence-based arguments about the natural world.	98.3	4.8	5	1
5.1	Analyze data, summarize resulting patterns, and draw appropriate conclusions.	99.1	4.8	5	1
5.2	Describe sources of error and uncertainty in data.	93.6	4.4	5	1
5.3	Make evidence-based arguments using your own and others' findings.	97.8	4.7	5	1
5.4	Relate conclusions to original hypothesis, consider alternative hypotheses, and suggest future research directions based on findings.	95.7	4.6	5	1
6	DOING RESEARCH Apply science process skills to address a research question in a course-based or independent research experience.	93.2	4.4	5	1

Quantitative Reasoning					
Outcome #	**Outcome**	**% Support**	**Mean**	**Max**	**Min**
1	NUMERACY Use basic mathematics (e.g., algebra, probability, unit conversions) in biological contexts.	98.6	4.8	5	2
1.1	Perform basic calculations (e.g., percentages, frequencies, rates, means).	99.6	4.9	5	3
1.2	Select and apply appropriate equations (e.g., Hardy-Weinberg, Nernst, Gibbs free energy) to solve problems.	86.5	4.3	5	2
1.3	Interpret and manipulate mathematical relationships (e.g., scale, ratios, units) to make quantitative comparisons.	98.2	4.7	5	3
1.4	Use probability and understanding of biological variability to reason about biological processes and statistical analyses.	96	4.6	5	2
1.5	Use rough estimates informed by biological knowledge to check quantitative work.	92.8	4.5	5	1

1.6	Describe how quantitative reasoning helps biologists understand the natural world.	91.9	4.5	5	2
2	QUANTITATIVE & COMPUTATIONAL DATA ANALYSIS Apply the tools of graphing, statistics, and data science to analyze biological data.	98.2	4.8	5	3
2.1	Record, organize, and annotate simple data sets.	98.7	4.8	5	3
2.2	Create and interpret informative graphs and other data visualizations.	99.6	4.9	5	3
2.3	Select, carry out, and interpret statistical analyses.	95.9	4.5	5	2
2.4	Describe how biologists answer research questions using databases, large data sets, and data science tools.	87.9	4.3	5	2
2.5	Interpret the biological meaning of quantitative results.	99.1	4.7	5	3

Modeling

Outcome #	Outcome	% Support	Mean	Max	Min
1	PURPOSE OF MODELS Recognize the important roles that scientific models, of many different types (conceptual, mathematical, physical, etc.), play in predicting and communicating biological phenomena.	93.9	4.5	5	2
1.1	Describe why biologists use simplified representations (models) when solving problems and communicating ideas.	88.3	4.3	5	2
1.2	Given two models of the same biological process or system, compare their strengths, limitations, and assumptions.	84.1	4.3	5	2
2	MODEL APPLICATION Make inferences and solve problems using models and simulations.	88.8	4.3	5	2
2.1	Summarize relationships and trends that can be inferred from a given model or simulation.	93.5	4.3	5	1
2.2	Use models and simulations to make predictions and refine hypotheses.	89.8	4.3	5	1
3	MODELING Build and evaluate models of biological systems.	75.5	4	5	1
3.1	Build and revise conceptual models to propose how a biological system or process works. [b]	86.4	4.2	5	1
3.2	Identify important components of a system and describe how they influence each other (e.g., positively or negatively).	93.9	4.5	5	1
3.3	Evaluate conceptual, mathematical, or computational models by comparing their predictions with empirical data.	82.6	4.2	5	1

Interdisciplinary Nature of Science

Outcome #	Outcome	% Support	Mean	Max	Min
1	CONNECTING SCIENTIFIC KNOWLEDGE Integrate concepts across other STEM disciplines (e.g., chemistry, physics) and multiple fields of biology (e.g., cell biology, ecology).	95.1	4.5	5	1
1.1	Given a biological problem, identify relevant concepts from other STEM disciplines or fields of biology.	89.4	4.2	5	1
1.2	Build models or explanations of simple biological processes that include concepts from other STEM disciplines or multiple fields of biology.	82.4	4.1	5	1
2	INTERDISCIPLINARY PROBLEM SOLVING Consider interdisciplinary solutions to real-world problems.	88.4	4.3	5	1
2.1	Describe examples of real-world problems that are too complex to be solved by applying biological approaches alone.	74	4	5	1
2.2	Suggest how collaborators in STEM and non-STEM disciplines could contribute to solutions of real-world problems.	74.3	4	5	1
2.3	Be able to explain biological concepts, data, and methods, including their limitations, using language understandable by collaborators in other disciplines.	91.6	4.5	5	1

Communication & Collaboration

Outcome #	Outcome	% Support	Mean	Max	Min
1	COMMUNICATION Share ideas, data, and findings with others clearly and accurately.	97.8	4.8	5	1
1.1	Use appropriate language and style to communicate science effectively to targeted audiences (e.g., general public, biology experts, collaborators in other disciplines).	96.1	4.5	5	3
1.2	Use a variety of modes to communicate science (e.g., oral, written, visual).	97	4.6	5	3
2	COLLABORATION Work productively in teams with people who have diverse backgrounds, skill sets, and perspectives.	97	4.6	5	1

2.1	Work with teammates to establish and periodically update group plans and expectations (e.g., team goals, project timeline, rules for group interactions, individual and collaborative tasks).	84.8	4.2	5	1
2.2	Elicit, listen to, and incorporate ideas from teammates with different perspectives and backgrounds.	94.4	4.5	5	1
2.3	Work effectively with teammates to complete projects.	97.8	4.6	5	1
3	COLLEGIAL REVIEW Provide and respond to constructive feedback in order to improve individual and team work.	93.5	4.3	5	1
3.1	Evaluate feedback from others and revise work or behavior appropriately.	94.3	4.4	5	1
3.2	Critique others' work and ideas constructively and respectfully.	94.8	4.4	5	1
4	METACOGNITION Reflect on your own learning, performance, and achievements.	92.2	4.5	5	1
4.1	Evaluate your own understanding and skill level.	93.5	4.4	5	1
4.2	Assess personal progress and contributions to your team and generate a plan to change your behavior as needed.	89.5	4.3	5	1

Science & Society

Outcome #	Outcome	% Support	Mean	Max	Min
1	ETHICS Demonstrate the ability to critically analyze ethical issues in the conduct of science.	92.3	4.5	5	1
1.1	Identify and evaluate ethical considerations (e.g., use of animal or human subjects, conflicts of interest, confirmation bias) in a given research study.	90.8	4.3	5	1
1.2	Critique how ethical controversies in biological research have been and can continue to be addressed by the scientific community.	87	4.2	5	1
2	SOCIETAL INFLUENCES Consider the potential impacts of outside influences (historical, cultural, political, technological) on how science is practiced.	82.7	4.2	5	1
2.1	Describe examples of how scientists' backgrounds and biases can influence science and how science is enhanced through diversity.	83.1	4.2	5	1
2.2	Identify and describe how systemic factors (e.g., socioeconomic, political) affect how and by whom science is conducted.	78.9	4.1	5	1
3	SCIENCE'S IMPACT ON SOCIETY Apply scientific reasoning in daily life and recognize the impacts of science on a local and global scale.	96.6	4.7	5	1
3.1	Apply evidence-based reasoning and biological knowledge in daily life (e.g., consuming popular media, deciding how to vote).	95.8	4.7	5	1
3.2	Use examples to describe the relevance of science in everyday experiences.	94.1	4.5	5	1
3.3	Identify and describe the broader societal impacts of biological research on different stakeholders.	89	4.3	5	1
3.4	Describe the roles scientists have in facilitating public understanding of science.	86.9	4.2	5	1

Supplemental Table 8. Skills that validation survey respondents suggested were missing from the BioSkills Guide.

[a] Skills are summarized from comments in national validation survey. Annotations indicate that multiple people suggested adding that skill (i.e. "x2" indicates two respondents). In most cases, suggested skills are more specific or more challenging versions of existing outcomes in the BioSkills Guide.

Core Competency	Missing Essential Skill [a]
Process of Science	Distinguish between the terms "hypothesis", "theory", and "fact".
	Describe how paradigms shift in biology.
	Describe the differences between various types of scientific literature.
	Identify assumptions and biases in scientific arguments.
	Use observation in the process of science and explain its importance. (x4)
	Entrepreneurialism.
Quantitative Reasoning	Do simple calculations without the use of a calculator.
	Use logic in the process of science (i.e. planning and implementing studies, writing, forming arguments).
	Consider hypotheses when designing and interpreting statistical tests.
	Identify the limitations of quantitative results.
	Use computational tools to analyze large datasets. (x2)
	Be familiar with and be able to self-teach a variety of scientific software programs. (x2)
Modeling	Define what a model is and the different ways we model biological phenomenon.
	Identify alternative assumptions that could be included in a model.
	Consider model biases.
	Construct simple quantitative models based on data.
	Project the implications of alternative model assumptions.
	Identify the objectives of a model before beginning construction.
	Build models that integrate multiple processes (e.g. positive and negative feedback loops).
Interdisciplinary Nature of Science	Describe the limits of science in addressing political or ethical issues. (x2)
	Consider differences in epistemology during interdisciplinary conversations.
Communication & Collaboration	Use a variety of modes to communicate science to a wide audience, including individuals with disabilities.
	Communicate science accurately and with sound logic.
	Write about science in plain language.
	Listen to and consider opposing views while maintaining respect and civility.
	Work productively in teams with people who have different abilities.
	Identify barriers to collaboration.
	Develop study habits that work well with your learning style.
	Evaluate use of prior knowledge.
Science & Society	Act ethically in academics and other work settings (cheating, plagiarism). (x4)
	Describe the strengths and limitations of the peer review process.
	Describe and critique the treatment of minority groups in biological and medical research. (x2)
	Explain why biology cannot be used to define race.
	Reflect on and describe the perceptions of science by the general public. (x2)

Supplemental Table 9. Sensitivity analysis comparing learning outcome support for respondents retained or excluded in RQ2 analysis.

[a] All models contained respondent and learning outcome as random effects. Additional fixed effects added to models are indicated in left column. Likelihood Ratio (LR) tests were used to determine whether a model including learning outcomes and respondents as random effects has a better fit than a model that does not include these random effects. LR tests revealed that models with random effects were a better fit in all cases.

Model [a]	AIC
Random effects only (SA0)	7652.64
Exclusion indicator only (SA1)	7651.33
Competency only (SA2)	7629.10
Competency + Exclusion indicator (SA3)	7627.81
Competency X Exclusion indicator interaction (SA4)	7628.82

Supplemental Table 10. RQ2 descriptive statistics: Distribution of respondent characteristics.

[a] Total n for RQ2 was 346 respondents. Details of data processing are in Methods and Supplemental Methods.

Demographic	Response	n [a] (%)
Institution Type	Associate's Granting	82 (23.7%)
	Bachelor's Granting	95 (27.5%)
	Master's Granting	50 (14.4%)
	Doctoral Granting	119 (34.4%)
Discipline-Based Education Research Experience	No DBER Experience	232 (67.0%)
	DBER Experience	114 (33.0%)
Currently Engaged in Biology Research	Not Currently Engaged in Biology Research	167 (48.3%)
	Current Research in Biology	179 (51.7%)
Experience with Ecology/Evolution Research	No Ecology/Evolution Experience	218 (63.0%)
	Ecology/Evolution Experience	128 (37.0%)
Familiarity with Vision and Change	Low Familiarity	102 (29.5%)
	High Familiarity	244 (70.5%)

Supplemental Table 11. RQ2 descriptive statistics: Number of learning outcomes per competency.

[a] 77 total outcomes.

		n[a] (%)
Competency	Process of Science	23 (29.9%)
	Quantitative Reasoning	13 (16.9%)
	Modeling	10 (13.0%)
	Interdisciplinary Nature of Science	7 (9.1%)
	Communication & Collaboration	13 (16.9%)
	Science & Society	11 (14.3%)

Supplemental Table 12. Details of cross-classified multilevel binary logistic regression models of competency and respondent demographics predicting learning outcome support.

[a] Best fitting models for each research question are shown. Both models contained respondent and learning outcome as random effects. Additional fixed effects in models are indicated in top row. For RQ2a, the initial complex model used 'Support' as the dependent variable and included a random effect for learning outcome, a random effect for respondent, and a fixed effect for learning outcome competency. For RQ2b, the initial complex model used 'Support' as the dependent variable and included a random effect for learning outcome, a random effect for respondent, and five interactions as fixed effects: competency X institution type, competency X experience in DBER, competency X engagement in disciplinary biology research, competency X experience in ecology/evolution, and competency X Vision and Change familiarity.

[b] OR = odds ratio, SE = standard error. *** p < 0.001; ** p < 0.01; * p <0.05.

[c] ref = reference category. Quantitative reasoning was used as Competency reference category because it was the most highly rated overall.

[d] For categorical variables with three or more categories (i.e. Competency, Institution Type), the Wald Chi-squared Test evaluates the joint significance of all coefficients for that variable (e.g., tests whether or not all coefficients related to Competency are significant overall). Furthermore, interpreting individual coefficients is not recommended for logistic regression models (Long & Freese, 2014; Mustillo, Lizardo, & McVeigh, 2018). Instead, for interpretation, see predicted probabilities (Figure 4) and Wald Chi-squared Test.

[e] AIC = Akaike's Information Criterion. AIC for model with random effects only = 6412.06.

[f] A significant Likelihood Ratio test indicates that a model including learning outcomes and respondents as random effects is a better fit than a model that does not include these random effects. LR test for model with only random effects = 1856.24***. LR tests revealed that models with random effects were a better fit in all cases.

Model [a]		**Main Effect: Competency (RQ2a)**		**Interactions with Competency: Institution Type, Discipline-Based Education Research, Biology Research; Main Effect: Eco/Evo Experience (RQ2b)**	
		OR [b]	***SE* [b]**	**OR**	***SE***
Competency, ref [c]= Quantitative Reasoning	Process of Science	0.672	*0.235*	1.003	*0.494*
	Modeling	0.162 ***	*0.066*	0.197**	*0.109*
	Interdisciplinary Nature of Science	0.153 ***	*0.069*	0.215**	*0.124*
	Communication & Collaboration	0.585	*0.227*	1.086	*0.576*
	Science & Society	0.254 ***	*0.102*	0.202**	*0.109*
Institution Type, ref = Doctoral Granting	Associate's Granting			2.079	*0.995*
	Bachelor's Granting			0.634	*0.260*
	Master's Granting			0.760	*0.401*
Competency X Institution Type, ref = Quantitative Reasoning X Doctoral Granting	Process of Sci. X Associate's Granting			0.455	*0.209*
	Process of Sci. X Bachelor's Granting			1.521	*0.559*
	Process of Sci. X Master's Granting			3.093*	*1.587*
	Modeling X Associate's Granting			0.532	*0.256*
	Modeling X Bachelor's Granting			0.819	*0.310*
	Modeling X Master's Granting			0.562	*0.277*
	Interdisc. Nature of Sci. X Associate's Granting			0.429	*0.203*
	Interdisc. Nature of Sci. X Bachelor's Granting			1.661	*0.652*
	Interdisc. Nature of Sci. X Master's Granting			0.976	*0.482*
	Communic. & Collabor. X Associate's Granting			0.633	*0.306*

	Communic. & Collabor. X Bachelor's Granting			1.286	*0.481*
	Communic. & Collabor. X Master's Granting			2.745	*1.474*
	Sci. & Society X Associate's Granting			0.815	*0.372*
	Sci. & Society X Bachelor's Granting			1.694	*0.636*
	Sci. & Society X Master's Granting			1.388	*0.692*
Discipline-Based Education Research, ref = No Experience	Experience in Discipline-Based Education Research			0.750	*0.274*
Competency X Discipline-Based Education Research, ref = Quantitative Reasoning X No Experience	Process of Sci. X Experience			0.983	*0.332*
	Modeling X Experience			4.021***	*1.478*
	Interdisc. Nature of Sci. X Experience			1.139	*0.408*
	Communication & Collaboration X Experience			0.823	*0.285*
	Sci. & Society X Experience			1.809	*0.621*
Biology Research, ref = Not Currently Engaged	Currently Engaged in Biology Research			2.226*	*0.880*
Competency X Biology Research, ref = Quantitative Reasoning X Not Currently Engaged	Process of Sci. X Currently Engaged			0.375**	*0.138*
	Modeling X Currently Engaged			0.505	*0.201*
	Interdisc. Nature of Sci. X Currently Engaged			0.479	*0.181*
	Communic. & Collabor. X Currently Engaged			0.287**	*0.112*
	Sci. & Society X Currently Engaged			0.690	*0.265*
Ecology/ Evolution, ref = No Experience	Eco/Evo Experience			1.632*	*0.384*
Constant		105.201***	*32.446*	68.839***	*33.421*
Wald Chi-squared Test [d]		*Competency, χ^2=37.82****		*Competency x Institution Type, χ^2=35.76*** *Competency x Discipline-Based Education Research, χ^2=27.06**** *Competency x Biology Research, χ^2=13.89**	
ΔAIC (relative to model with only random effects) [e]		-22.21		-52.18	
Likelihood Ratio Test [f]		1678.50***		1648.14***	

Supplemental Material 5. Supplemental Methods.

Workshop and Round Table Design and Implementation

We employed 5 workshops and 2 round tables over the course of the development phase (Table 2). Workshops were held at biology education learning community meetings at universities around the Northwest United States and British Columbia, unless specified otherwise. During workshops, we instructed participants to self-select into six smaller groups based on which competency they wished to focus on. We then directed groups to brainstorm outcomes essential to their competency, with the goal of eliciting a range of perspectives and ideas. Next we provided handouts of the current draft of learning outcomes for their competency and asked groups to discuss and record: (1) whether each outcome was important for a graduating general biology major (yes/no/maybe), (2) any essential outcomes they felt were missing, and (3) any comments on the wording or content of the draft.

Round tables were held at national biology education research meetings and used to collect targeted feedback on parts of the BioSkills Guide for which it was more difficult to find appropriate revisions. During round tables, we also instructed participants to talk in groups, but the topic of discussion and specific instructions varied depending on the issue at hand (elaborated in detailed descriptions below). We transcribed and summarized all written feedback from workshops and round tables for use during revision sessions.

Interview Design and Implementation

We conducted 25 interviews over the course of the development phase (Table 2). Interviews were either semi-structured or unstructured depending on their purpose (elaborated in detailed descriptions below). We conducted interviews in a variety of settings depending on participant availability (in person, video chat, or over the phone). When possible, the interviews were recorded, otherwise the interviewer took notes during the interview and expanded upon them immediately after the interview. Detailed notes and recordings (when available) from interviews were analyzed to identify major themes that then informed revisions.

Detailed Description of the Initial Drafting of the BioSkills Guide

The initial draft of the BioSkills Guide was composed by a group of 8 biology faculty members at a large, public research university in the Northwest United States. This work was initiated at an all-faculty departmental meeting where the Vision and Change core competencies were presented and discussed, along with several other guiding documents related to science competencies (e.g., AAMC & HHMI, 2009; NRC, 2012). Four department competency priorities were selected and broadly defined: Process of Science, Quantitative Reasoning (which included some Modeling), Communication & Collaboration, and Science & Society. Interdisciplinary Nature of Science was understood to run through all four competencies. Four working groups of two faculty each then drafted learning outcomes for one of the four competencies. Drafts were then shared with members of other working groups and 12 additional interested faculty, postdocs, and grad students at a series of departmental round table meetings (n=20 participants total, 5-12 per competency, Table 2). Participants suggested additions and changes, which the working groups used to revise the drafts.

We built on this initial draft by aligning it with Vision and Change and broader work in biology education research. We began by drafting learning outcomes for Interdisciplinary Nature of Science, disentangling Modeling outcomes from Quantitative Reasoning outcomes, and checking for gaps in coverage within the remaining competencies. We accomplished these tasks by reviewing the literature, leading unstructured interviews with competency experts (n=11), and hosting a round table at a national biology education research meeting (n≈24; see note about estimation in Table 2). At the round table, we asked participants to discuss and record suggestions for priorities and appropriate challenge level for the Interdisciplinary Nature of Science competency. We recruited competency experts for interviews based on their history of publication or conference presentations in areas related to underdeveloped portions of the guide (i.e. Modeling, Interdisciplinary Nature of Science, and Science and Society). Finally, we revised learning outcomes for all six competencies to a common tone and formatting. The initial draft ("Version I") contained 86 outcomes: 23 "program-level" and 63 "course-level" (see Supplemental Figure 1 for overview of guide structure).

Detailed Description of the Process of Iterative Review and Revision of the BioSkills Guide
After initial drafting was complete, Version I learning outcomes were reviewed by our project advisory board, who then provided written feedback. We then clarified feedback via a virtual meeting. Two authors (AWC, AJC) discussed all feedback and collectively decided to add one outcome, remove one outcome, and revise 30 outcomes (Supplemental Table 1).

To assess Version II of the BioSkills Guide, we led the first of five workshops (n≈30; see note about estimation in Table 2). Participants were primarily biology instructors and postdocs, but also included some graduate students and undergraduates. Feedback from the workshop was discussed by two authors (AWC, AJC). We decided to remove seven outcomes, add two outcomes, and revise 57 outcomes (Supplemental Table 1). Additionally, workshop participants raised concerns about the order of outcomes within the guide, leading to some rearrangements of outcomes within competencies.

Version III was reviewed via web survey (n=21 total, n=6-10 per competency) and a small workshop (n=6 total, n=2 per competency) (Table 2). Of the 81 outcomes in Version III, we removed six, added three, and revised 57 to generate Version IV (Supplemental Table 1).

Version IV was reviewed via web survey (n=45 total, n=12-19 per competency), workshop (n=32 total, n=4-6 per competency), a round table (n=21), and interviews (n=14) (Table 2). The workshop was held at a regional meeting of biology community college instructors (approximately 66% of participants were from community colleges). During the round table, we asked participants to split into groups focusing on one of four areas of low consensus (based on mixed survey ratings and comments: Modeling, Interdisciplinary Nature of Science, a Process of Science outcome on "doing research", and attitude-/affect-related outcomes) and instructed them to discuss and record ideas for revision.

We conducted interviews for different purposes with three different populations using an opportunistic sampling approach: competency experts (n=6), survey respondents (n=5), and community college faculty (n=3). We recruited competency experts to provide guidance on revising outcomes for less frequently taught or understood competencies (e.g., Modeling, Interdisciplinary Nature of Science), where survey ratings were low or mixed, but comments did not suggest specific revisions. These interviews were unstructured to allow competency experts to direct the conversation to what they felt was most essential about that competency and therefore must be retained during revision. Interviews with past survey respondents were semi-structured, with questions varying depending on which competencies they had reviewed. The purpose of these interviews was to gain additional insight on learning outcomes with low ratings and determine what about the outcomes should be revised (e.g., level of challenge, unclear terminology). Interviews with community college faculty were unstructured and involved asking participants to comment on the outcomes and identify points of connection (or lack thereof) between the BioSkills Guide and their own classroom practices. The purpose of these interviews was to identify areas of the guide that required revision to be valuable in a two-year setting. Feedback on Version IV prompted us to remove four outcomes, add six, and revise 64.

Version V was reviewed via web survey (n=27 total, n=8-14 per competency) and two workshops (n=21 and n=8 total, with n=2-5 per competency). As a result, we removed three outcomes, added none, and revised 29 to generate Version VI.

Detailed Description of the Pilot Validation

A smaller-scale pilot validation was conducted to test the new questionnaire (which had been shortened and reformatted for validation phase) and our final draft of outcomes before inviting a large number of educators nationwide to participate. We invited 45 biology educators from the local Partnership for Undergraduate Life Sciences Education (PULSE) network to review Version VI outcomes via web survey. We chose this population because they represented a range of institution types and were expected to have spent time thinking deeply about the undergraduate biology curriculum, since they had participated in a PULSE workshop which includes professional development on Vision and Change recommendations. Twenty people completed the pilot validation survey (n=11-12 per competency, 44% participation rate). Of the 77 outcomes in Version VI, 74 had greater than 80% support (Table 3, Supplemental Table 4). Of the three remaining outcomes, support ranged from 73%-75%. Two of the three were from the Modeling competency and had been strongly advocated for in interviews with experts during review of Version IV. The third was revised, as described in Methods.

Missing Data and Sensitivity Analysis for Excluded Cases

Of our 417 initial respondents who rated at least one outcome (and thus were included in RQ1b), 71 did not provide all five demographic characteristics of interest (i.e. institution type, familiarity with Vision and Change, etc.), and therefore could not be included in our analyses for RQ2a and b. Of these 71 individuals, the majority (n=48) left the web survey before viewing all pages with their assigned outcomes (i.e. breakoff cases) and therefore never saw the demographic questions. Of the individuals that *did* view all pages with their assigned outcomes, 17 did not respond to all demographic questions required for RQ2, and 2 did not respond to any demographic questions at all. We also removed 4 individuals who indicated “other” for institution type.

As a sensitivity analysis, we evaluated whether or not the odds of supporting an outcome (i.e. the dependent variable in our RQ2 analyses) differed across respondents who were excluded from the RQ2 analysis (n=71) and respondents who were included in the RQ2 analysis (n=346). In other words, were respondents who supported competency learning outcomes less more likely to leave the survey early or skip demographic questions? We explored this question using backward model selection beginning with complex cross-classified multilevel binary logistic regression models predicting whether particular respondents will support particular learning outcomes, as described further in Methods. All models contained learning outcome and respondent as random effects (random intercepts).

We first fit a model containing one fixed effect: a binary “exclusion indicator” variable for whether or not a respondent was excluded from the RQ2 analysis (=0 if respondent was included; =1 if not). Removing this variable from the model did not affect model fit relative to a model with only random effects (SA1-SA0, ΔAIC = -1.31, Supplemental Table 9). Thus, respondents that were *excluded* from the RQ2 analysis did not differ in their odds of supporting a learning outcome compared to respondents that were *included* in the RQ2 analysis.

We then examined whether or not the odds of supporting learning outcomes for different competencies differed across respondents that were *excluded* from the RQ2 analysis and respondents that were *included* in the RQ2 analysis. We carried out backward model selection starting with a complex model (SA4) including the interaction between outcome competency (e.g., Process of Science, Modeling) and the exclusion indicator from SA1. The best fitting and most parsimonious model was the one with only competency as a fixed effect (SA2). Neither removing the competency X exclusion indicator interaction (SA4) nor removing the inclusion of the exclusion indicator as a fixed effect (SA3) affected model fit relative to a model with just competency as a fixed effect (SA2) (SA3-SA4, ΔAIC = -1.01; SA2-SA3, ΔAIC = 1.29; Supplemental Table 9). Thus, respondents that were *excluded* from the RQ2 analysis again did not differ in their odds of supporting a learning outcome compared to respondents that were *included* in the RQ2 analysis, within each competency (i.e., exclusion indicator x competency interaction) nor when including competency only as a main effect (i.e., no exclusion indicator x competency interaction).

Data Recoding for Statistical Models

After data processing as described above and in Methods, we recoded variables as follows: Three respondents who indicated “other” for institution type (out of 7 total) were recoded based on Carnegie classification of institution name provided or description of institution in comments (e.g., “we are part of a larger R1, but our campus strictly grants Associate’s degrees” was assigned to “Associate’s Granting”). The remaining four respondents were removed from analysis as mentioned above. Vision and Change familiarity was recoded to a binary variable: ‘Extremely’ or ‘Very Familiar’ were recoded as ‘High Familiarity’ and ‘Somewhat’, ‘Slightly’, or ‘Not at All Familiar’ were recoded as ‘Low Familiarity’. Experience in Discipline-Based Education Research and Experience in Ecology/Evolution Research were coded as binary variables based on selecting the corresponding field when answering questions about field of current research and/or field of graduate training. Current engagement in biology research was coded as a binary variable based on selecting a disciplinary biology field (e.g., “Molecular/Cell/Developmental Biology”, “Physiology”, “Ecology/Evolutionary Biology”) when answering question about field of current research. Finally, importance ratings for each course-level and program-level learning outcome were recoded: ‘Important’ or ‘Very Important’ were recoded as ‘Support’, and ‘Neither Important nor Unimportant’, ‘Unimportant’, or ‘Very Unimportant’ were recoded as ‘No Support’.

Supplemental References

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Supplemental Material 6. BioSkills development phase questionnaire.

Questionnaire used during development phase survey for review of Version V. Questionnaires for Versions III and IV were very similar, except for revision of learning outcomes.

BioSkills: Core Competencies Learning Outcomes

Welcome Page

Thank you for your help developing learning outcomes for the core competencies, or essential skills, for biology undergraduate education. Based on the recommendations of the 2011 AAAS report *Vision and Change in Undergraduate Biology Education*, this NSF-supported project is intended to use the perspectives and priorities of a wide range of biology educators to elaborate six "core competencies" (listed below) into measurable learning outcomes. The learning outcomes will be revised based on your and others' feedback, and then be made available to the biology education community as a resource to facilitate planning and assessment of skills training. It is essential that this work is done collaboratively to ensure the final set of learning outcomes (which we're calling the "BioSkills Guide") has broad utility for biology educators teaching at different institution types, course levels, and biology subdisciplines. Thank you for being a part of this work!

You will be asked to provide feedback on learning outcomes for just two of the six core competencies, although we would love your feedback on additional competencies if you have time. You do **not** need to have experience teaching the core competencies as long as you have served as instructor of record for a college-level biology course. Your feedback is valuable, and we sincerely appreciate all comments and suggestions.

You may exit and return to the survey as needed. The survey automatically resumes where you left off if you use the same browser and do not clear cookies. If you have any questions about the project or this survey, please do not hesitate to contact me, Dr. Alexa Clemmons (aclemmon@uw.edu), or Dr. Alison Crowe (acrowe@uw.edu).

Vision and Change Core Competencies

- **Process of Science**
- **Quantitative Reasoning**
- **Modeling & Simulations**
- **Interdisciplinary Nature of Science**
- **Communication & Collaboration**
- **Science & Society**

Have you ever served as the instructor of record for a college-level biology course?

- ○ Yes
- ○ No

Screened Out

Thank you for your interest in the BioSkills Guide! At this time we are soliciting feedback from college biology instructors, but in the future we plan to widen our scope.

If you would be interested in providing feedback then, please enter your email address. If you enter your email address we will also notify you when the BioSkills Guide is ready for distribution.

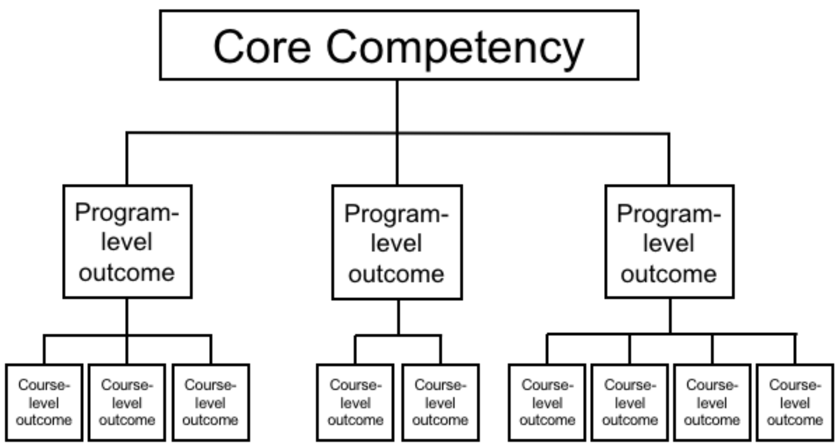
[ ]

Process of Science

[***After the welcome page, blocks of questions (each block corresponding to one of the six core competencies) were randomly assigned. All respondents were given 2 blocks of questions, with the option to complete additional.***]

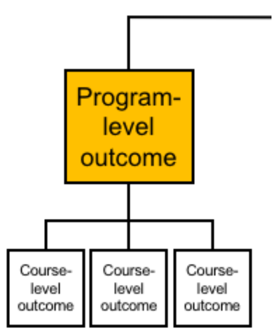
In this portion of the survey, we would like you to rate the importance and ease of understanding of our current draft of learning outcomes for one particular core competency: **Process of Science.** Later, you will be asked to comment on whether the outcomes are appropriately categorized under this competency.

In the current draft of the BioSkills Guide, each core competency contains multiple **program**-level learning outcomes. In addition, each program-level learning outcome contains multiple **course**-level learning outcomes. Throughout the survey, you will switch between evaluating program- and course-level outcomes. We will use the figure below to remind you of this structure and cue when you are switching between levels.



Important note: Please keep in mind that we intend for the BioSkills Guide to contain the learning outcomes that we, as a community, think all **graduating general biology majors** should achieve. Therefore, as you complete the survey, please rate the outcomes based on whether they are both desirable and reasonable to accomplish in a **four-year program**, not introductory courses alone (1-2 years only) or in a graduate program (5+ years).

Importance and Ease of Understanding: **Process of Science**



The next three questions will ask you to evaluate the following **program**-level outcome:

Scientific Thinking: Explain how science generates knowledge of the natural world.

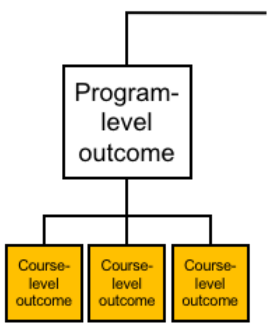
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Explain how scientists use inference, a skeptical mindset, and evidence-based reasoning to generate knowledge.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy

- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Describe the iterative nature of science and how new evidence can lead to the revision of scientific knowledge.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

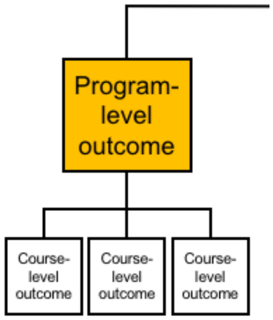
- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Importance and Ease of Understanding: **Process of Science**



The next three questions will ask you to evaluate the following **program**-level outcome:

Information Literacy: Locate, interpret, and evaluate scientific information.

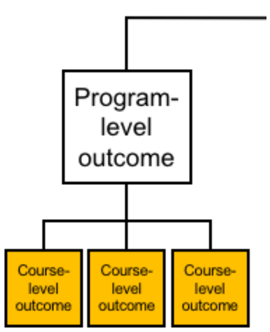
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Find and evaluate credibility of a variety of sources of scientific information, including popular science media and scientific journals.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Interpret, evaluate, and summarize evidence in primary literature.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Evaluate claims in scientific papers, popular science media, and other sources using evidence-based reasoning.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

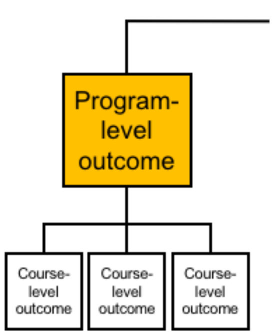
- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Importance and Ease of Understanding: **Process of Science**



The next three questions will ask you to evaluate the following **program**-level outcome:

Question Formulation: Pose testable questions and hypotheses to address gaps in knowledge.

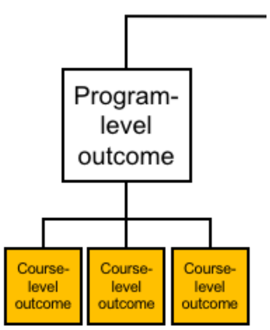
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Identify gaps in current understanding of a biological system or process and articulate what specific information is missing.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Develop questions based on your own or others' observations.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Formulate testable hypotheses and state their predictions.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

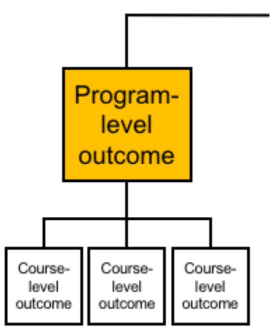
- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Importance and Ease of Understanding: **Process of Science**



The next three questions will ask you to evaluate the following **program**-level outcome:

Study Design: Plan, evaluate, and implement scientific investigations.

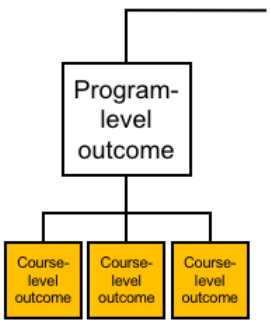
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Compare the strengths and limitations of various study designs.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Design controlled experiments, including appropriate data analysis plans.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Execute protocols and accurately record measurements and observations.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Identify methodological problems and suggest solutions or alternative approaches.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Evaluate and suggest best practices for responsible research conduct (e.g., data management, lab safety, proper citation of sources).

How important or unimportant is it for graduating general biology majors to achieve this outcome?

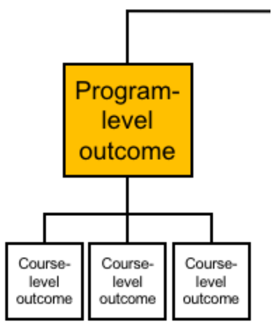
- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

○ Very Easy
○ Easy
○ Neither Easy Nor Difficult
○ Difficult
○ Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Importance and Ease of Understanding: **Process of Science**



The next three questions will ask you to evaluate the following **program**-level outcome:

Data Interpretation & Evaluation: Interpret, evaluate, and draw conclusions from data in order to make evidence-based arguments about the natural world.

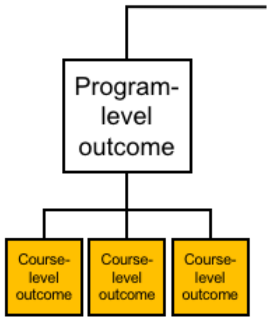
How important or unimportant is it for graduating general biology majors to achieve this outcome?

○ Very Important
○ Important
○ Neither Important Nor Unimportant
○ Unimportant
○ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

○ Very Easy
○ Easy
○ Neither Easy Nor Difficult
○ Difficult
○ Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Analyze data and summarize resulting patterns.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Describe sources of error and uncertainty in data.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Engage in data-driven argumentation using your own and others' findings.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Relate conclusions to original hypothesis and suggest future research directions based on findings.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

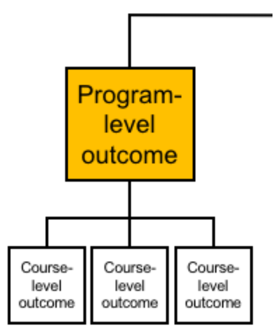
- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Importance and Ease of Understanding: **Process of Science**



The next three questions will ask you to evaluate the following **program**-level outcome:

Doing Research: Integrate process of science skills to address a research question in a course-based or independent research experience.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

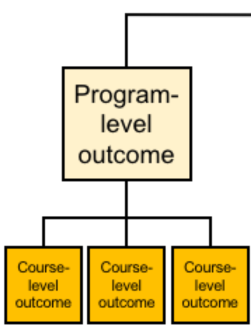
- Very Important

- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



Next, we would like you to indicate whether the current categorization of **course**-level outcomes within program-level outcomes makes sense to you. You will also be asked to suggest missing outcomes.

Some related outcomes may currently be categorized under other competencies. If you would like to see a complete draft of the BioSkills Guide for context, please click here. This is a preliminary draft, and we ask that you *please do not share it with others until it is published.*

Categorization: **Process of Science**

Currently, we have categorized each of the course-level outcomes listed below under the program-level outcome:

Scientific Thinking: Explain how science generates knowledge of the natural world.

In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No

	Yes	No
Explain how scientists use inference, a skeptical mindset, and evidence-based reasoning to generate knowledge.	○	○
Describe the iterative nature of science and how new evidence can lead to the revision of scientific knowledge.	○	○

Program-level outcome:

Information Literacy: Locate, interpret, and evaluate scientific information.

In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Find and evaluate credibility of a variety of sources of scientific information, including popular science media and scientific journals.	○	○
Interpret, evaluate, and summarize evidence in primary literature.	○	○
Evaluate claims in scientific papers, popular science media, and other sources using evidence-based reasoning.	○	○

Program-level outcome:

Question Formulation: Pose testable questions and hypotheses to address gaps in knowledge.

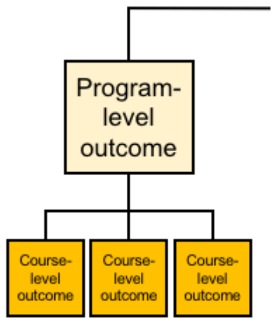
In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Identify gaps in current understanding of a biological system or process and articulate what specific information is missing.	○	○
Develop questions based on your own or others' observations.	○	○
Formulate testable hypotheses and state their predictions.	○	○

Optional: Please share any comments you have on the categorization of these outcomes, including any suggestions for alternative categorization if applicable.

Do you think any essential **course**-level outcomes are missing from this list?

Categorization: **Process of Science**



Currently, we have categorized each of the course-level outcomes listed below under the program-level outcome:

Study Design: Plan, evaluate, and implement scientific investigations.

In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Compare the strengths and limitations of various study designs.	○	○
Design controlled experiments, including appropriate data analysis plans.	○	○
Execute protocols and accurately record measurements and observations.	○	○
Identify methodological problems and suggest solutions or alternative approaches.	○	○
Evaluate and suggest best practices for responsible research conduct (e.g., data management, lab safety, proper citation of sources).	○	○

Currently, we have categorized each of the course-level outcomes listed below under the program-level outcome:

Data Interpretation & Evaluation: Interpret, evaluate, and draw conclusions from data in order to make evidence-based arguments about the natural world.

In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

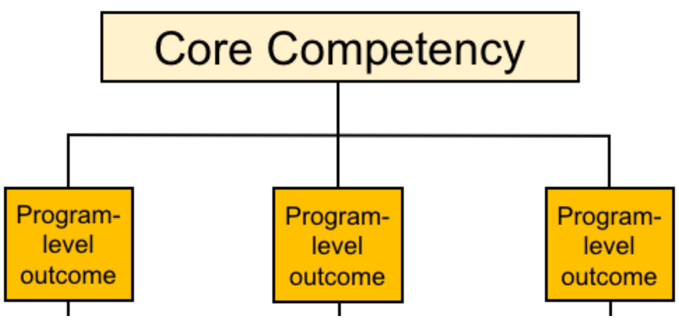
	Yes	No
Analyze data and summarize resulting patterns.	○	○

	Yes	No
Describe sources of error and uncertainty in data.	O	O
Engage in data-driven argumentation using your own and others' findings.	O	O
Relate conclusions to original hypothesis and suggest future research directions based on findings.	O	O

Optional: Please share any comments you have on the categorization of these outcomes, including any suggestions for alternative categorization if applicable.

Do you think any essential **course**-level outcomes are missing from this list?

Categorization: **Process of Science**



Next, we would like you to indicate if you think any of the **program**-level learning outcomes are currently miscategorized.

If you would like to see the complete, preliminary draft of the BioSkills Guide for context, please click here. As a reminder, the other core competencies are: **Quantitative Reasoning, Modeling & Simulations, Interdisciplinary Nature of Science, Communication & Collaboration, and Science & Society.**

Currently, we have categorized the program-level outcomes listed below under the core competency:

Process of Science

In your opinion, is it accurate to categorize each of the following **program**-level outcomes under this core competency?

	Yes	No

	Yes	No
Scientific Thinking: Explain how science generates knowledge of the natural world.	○	○
Information Literacy: Locate, interpret, and evaluate scientific information.	○	○
Question Formulation: Pose testable questions and hypotheses to address gaps in knowledge.	○	○
Study Design: Plan, evaluate, and implement scientific investigations.	○	○
Data Interpretation & Evaluation: Interpret, evaluate, and draw conclusions from data in order to make evidence-based arguments about the natural world.	○	○
Doing Research: Integrate process of science skills to address a research question in a course-based or independent research experience.	○	○

Optional: Please share any comments you have on the categorization of these outcomes, including any suggestions for alternative categorization if applicable.

You have now reviewed all of the program-level learning outcomes and course-level learning outcomes for this core competency.

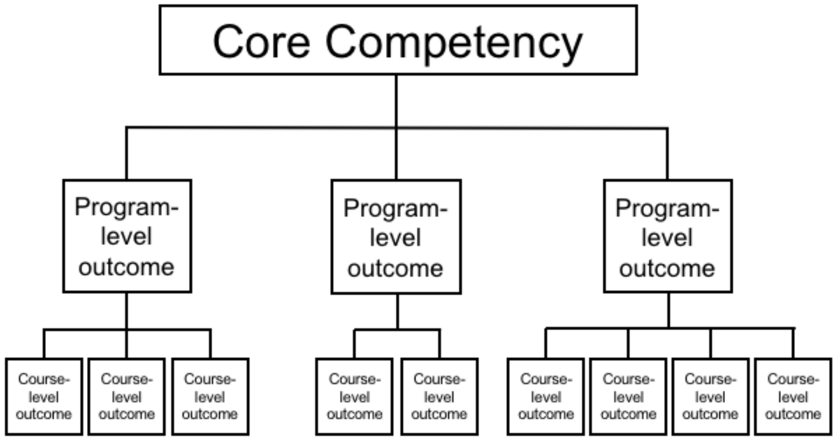
Given this review, do you think any essential **program**-level learning outcomes are missing from the **Process of Science** core competency?

Optional: Please share any other feedback on the **Process of Science** core competency.

Quantitative Reasoning

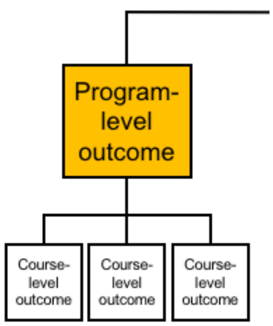
In this portion of the survey, we would like you to rate the importance and ease of understanding of our current draft of learning outcomes for one particular core competency: **Quantitative Reasoning.** Later, you will be asked to comment on whether the outcomes are appropriately categorized under this competency.

In the current draft of the BioSkills Guide, each core competency contains multiple **program**-level learning outcomes. In addition, each program-level learning outcome contains multiple **course**-level learning outcomes. Throughout the survey, you will switch between evaluating program- and course-level outcomes. We will use the figure below to remind you of this structure and cue when you are switching between levels.



Important note: Please keep in mind that we intend for the BioSkills Guide to contain the learning outcomes that we, as a community, think all **graduating general biology majors** should achieve. Therefore, as you complete the survey, please rate the outcomes based on whether they are both desirable and reasonable to accomplish in a **four-year program**, not introductory courses alone (1-2 years only) or in a graduate program (5+ years).

Importance and Ease of Understanding: **Quantitative Reasoning**



The next three questions will ask you to evaluate the following **program**-level outcome:

Numeracy: Use basic mathematics (e.g., algebra, probability, unit conversions) in biological contexts.

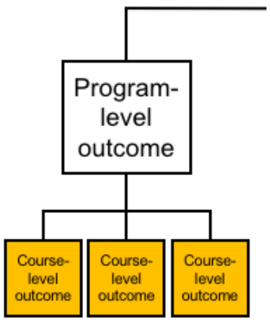
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Describe how quantitative reasoning helps biologists understand the natural world.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Perform basic calculations (e.g., percentages, frequencies, rates, means).

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- ○ Very Important
- ○ Important
- ○ Neither Important Nor Unimportant
- ○ Unimportant
- ○ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- ○ Very Easy
- ○ Easy
- ○ Neither Easy Nor Difficult
- ○ Difficult
- ○ Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Select and apply appropriate equations to solve problems (e.g., Hardy-Weinberg equations, Nernst equation, logistic population growth).

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- ○ Very Important
- ○ Important
- ○ Neither Important Nor Unimportant
- ○ Unimportant
- ○ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- ○ Very Easy

- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Interpret and manipulate mathematical relationships (e.g., scale, ratios, units) to make quantitative comparisons.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Use probability to reason about biological processes and about statistical analyses.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important

- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Use rough estimates informed by biological knowledge to check quantitative work.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

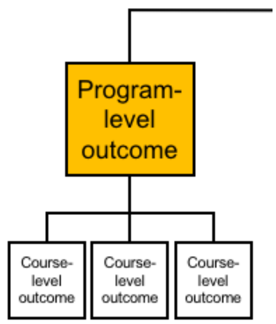
- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Importance and Ease of Understanding: **Quantitative Reasoning**



The next three questions will ask you to evaluate the following **program**-level outcome:

Quantitative & Computational Data Analysis: Apply the tools of graphing, statistics, and data science to analyze biological data.

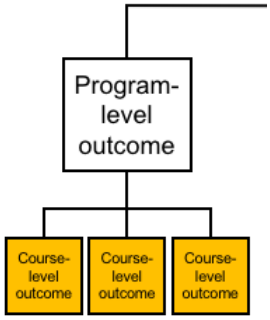
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- ◯ Very Important
- ◯ Important
- ◯ Neither Important Nor Unimportant
- ◯ Unimportant
- ◯ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- ◯ Very Easy
- ◯ Easy
- ◯ Neither Easy Nor Difficult
- ◯ Difficult
- ◯ Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Record, organize, and annotate simple data sets.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Create and interpret informative graphs and other data visualizations.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant

- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Select, carry out, and interpret statistical analyses.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Describe examples of how scientists use databases, large data sets, and data science tools to answer a variety of biological questions.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Explain the biological meaning of quantitative results.

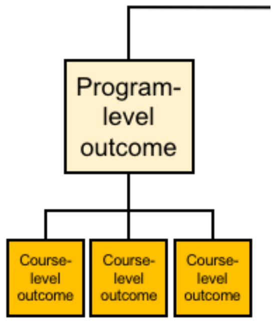
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



Next, we would like you to indicate whether the current categorization of **course**-level outcomes within program-level outcomes makes sense to you. You will also be asked to suggest missing outcomes.

Some related outcomes may currently be categorized under other competencies. If you would like to see a complete draft of the BioSkills Guide for context, please click here. This is a preliminary draft, and we ask that you *please do not share it with others until it is published.*

Categorization: **Quantitative Reasoning**

Currently, we have categorized each of the course-level outcomes listed below under the program-level outcome:

Numeracy: Use basic mathematics (e.g., algebra, probability, unit conversions) in biological contexts.

In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Describe how quantitative reasoning helps biologists understand the natural world.	○	○
Perform basic calculations (e.g., percentages, frequencies, rates, means).	○	○
Select and apply appropriate equations to solve problems (e.g., Hardy-Weinberg equations, Nernst equation, logistic population growth).	○	○
Interpret and manipulate mathematical relationships (e.g., scale, ratios, units) to make quantitative comparisons.	○	○
Use probability to reason about biological processes and about statistical analyses.	○	○
Use rough estimates informed by biological knowledge to check quantitative work.	○	○

Program-level outcome:

Quantitative & Computational Data Analysis: Apply the tools of graphing, statistics, and data science to analyze biological data.

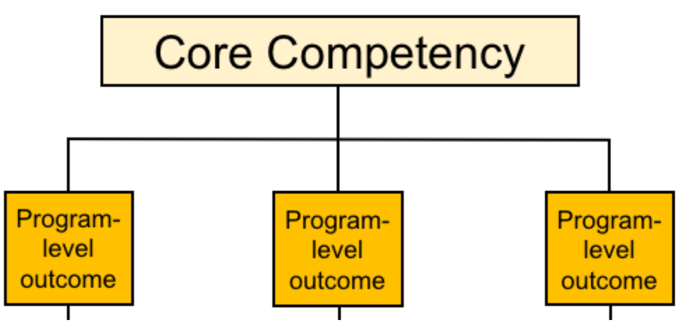
In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Record, organize, and annotate simple data sets.	O	O
Create and interpret informative graphs and other data visualizations.	O	O
Select, carry out, and interpret statistical analyses.	O	O
Describe examples of how scientists use databases, large data sets, and data science tools to answer a variety of biological questions.	O	O
Explain the biological meaning of quantitative results.	O	O

Optional: Please share any comments you have on the categorization of these outcomes, including any suggestions for alternative categorization if applicable.

Do you think any essential **course**-level outcomes are missing from this list?

Categorization: **Quantitative Reasoning**



Next, we would like you to indicate if you think any of the **program**-level learning outcomes are currently miscategorized.

If you would like to see the complete, preliminary draft of the BioSkills Guide for context, please click here. As a reminder, the other core competencies are: **Process of Science, Modeling & Simulations, Interdisciplinary Nature of Science, Communication & Collaboration, and Science & Society.**

Currently, we have categorized the program-level outcomes listed below under the core competency:

Quantitative Reasoning

In your opinion, is it accurate to categorize each of the following program-level outcomes under this core competency?

	Yes	No
Numeracy: Use basic mathematics (e.g., algebra, probability, unit conversions) in biological contexts.	O	O
Quantitative & Computational Data Analysis: Apply the tools of graphing, statistics, and data science to analyze biological data.	O	O

Optional: Please share any comments you have on the categorization of these outcomes, including any suggestions for alternative categorization if applicable.

You have now reviewed all of the program-level learning outcomes and course-level learning outcomes for this core competency.

Given this review, do you think any essential **program**-level learning outcomes are missing from the **Quantitative Reasoning** core competency?

Optional: Please share any other feedback on the **Quantitative Reasoning** core competency.

Option to Continue

Thank you for all of your feedback so far! We know that your time is valuable. We would love your feedback on additional outcomes, if you have the time.

Would you like to evaluate another set of outcomes?

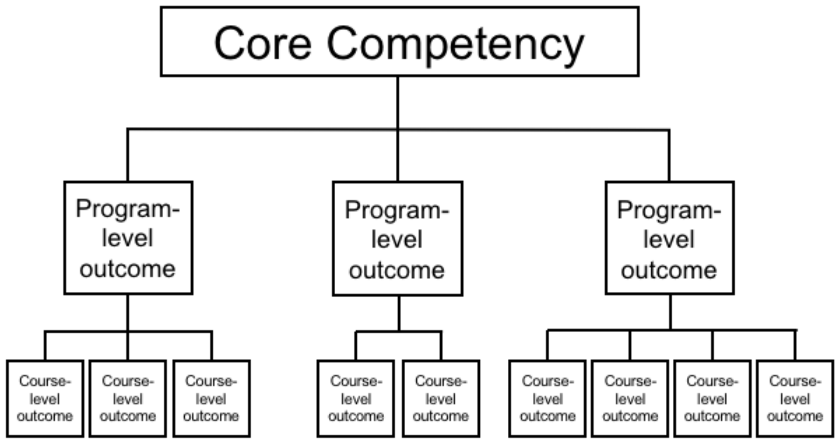
[***This question was shown after first 2 randomly assigned blocks of questions, and then subsequently after each additional block of questions until all 6 blocks were complete.***]

- O Yes
- O No

Modeling & Simulation

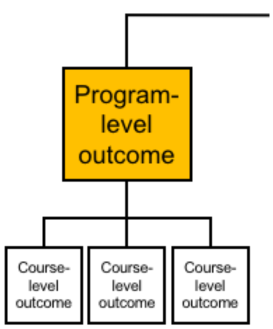
In this portion of the survey, we would like you to rate the importance and ease of understanding of our current draft of learning outcomes for one particular core competency: **Modeling and Simulations.** Later, you will be asked to comment on whether the outcomes are appropriately categorized under this competency.

In the current draft of the BioSkills Guide, each core competency contains multiple **program**-level learning outcomes. In addition, each program-level learning outcome contains multiple **course**-level learning outcomes. Throughout the survey, you will switch between evaluating program- and course-level outcomes. We will use the figure below to remind you of this structure and cue when you are switching between levels.



Important note: Please keep in mind that we intend for the BioSkills Guide to contain the learning outcomes that we, as a community, think all **graduating general biology majors** should achieve. Therefore, as you complete the survey, please rate the outcomes based on whether they are both desirable and reasonable to accomplish in a **four-year program**, not introductory courses alone (1-2 years only) or in a graduate program (5+ years).

Importance and Ease of Understanding: **Modeling & Simulations**



The next three questions will ask you to evaluate the following **program**-level outcome:

Purpose of Models: Recognize the important roles that scientific models of many different types (conceptual, mathematical, physical, etc.) play in predicting and communicating biological phenomena.

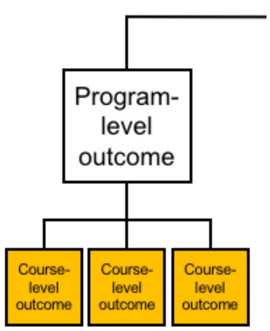
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Describe how and why scientists use simplified representations (models) of biological systems when solving problems and communicating ideas.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Given two models of the same biological process or system, compare their strengths, limitations, and assumptions.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

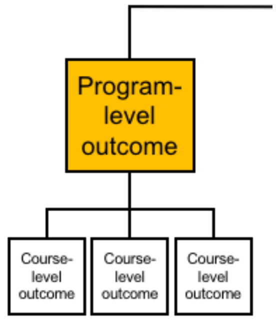
- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Importance and Ease of Understanding: **Modeling & Simulations**



The next three questions will ask you to evaluate the following **program**-level outcome:

Model Application: Make inferences and solve problems using models and simulations.

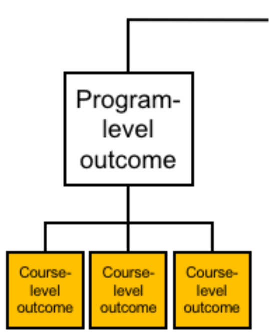
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Summarize relationships and trends that can be inferred from a given model or simulation.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- ◯ Very Important
- ◯ Important
- ◯ Neither Important Nor Unimportant
- ◯ Unimportant
- ◯ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- ◯ Very Easy
- ◯ Easy
- ◯ Neither Easy Nor Difficult
- ◯ Difficult
- ◯ Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Use models and simulations to make predictions and refine hypotheses.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

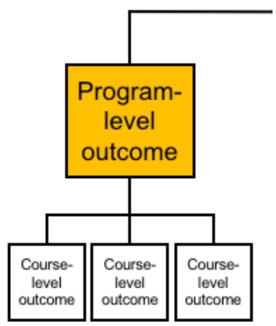
- ◯ Very Important
- ◯ Important
- ◯ Neither Important Nor Unimportant
- ◯ Unimportant
- ◯ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- ◯ Very Easy
- ◯ Easy
- ◯ Neither Easy Nor Difficult
- ◯ Difficult
- ◯ Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Importance and Ease of Understanding: **Modeling & Simulations**



The next three questions will ask you to evaluate the following **program**-level outcome:

Modeling: Build and evaluate models of biological systems.

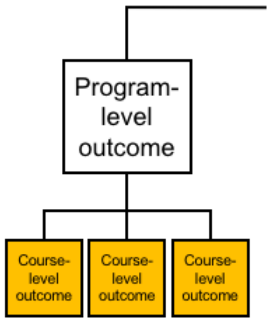
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Build and revise conceptual models (e.g., diagrams, concept maps, flow charts) to propose how a biological system or process works.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Identify important components of a system and describe how they influence each other (e.g., positively or negatively).

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important

- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Using instructor-provided tools, set parameters of mathematical or computational models and interpret output.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Evaluate models by comparing their predictions with empirical data.

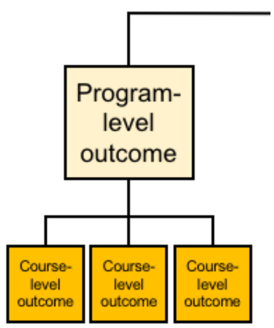
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



Next, we would like you to indicate whether the current categorization of **course**-level outcomes within program-level outcomes makes sense to you. You will also be asked to suggest missing outcomes.

Some related outcomes may currently be categorized under other competencies. If you would like to see a complete draft of the BioSkills Guide for context, please click here. This is a preliminary draft, and we ask that you *please do not share it with others until it is published.*

Categorization: **Modeling & Simulations**

Currently, we have categorized each of the course-level outcomes listed below under the program-level outcome:

Purpose of Models: Recognize the important roles that scientific models of many different types (conceptual, mathematical, physical, etc.) play in predicting and communicating biological phenomena.

In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Describe how and why scientists use simplified representations (models) of biological systems when solving problems and communicating ideas.	○	○
Given two models of the same biological process or system, compare their strengths, limitations, and assumptions.	○	○

Program-level outcome:

Model Application: Make inferences and solve problems using models and simulations.

In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Summarize relationships and trends that can be inferred from a given model or simulation.	○	○
Use models and simulations to make predictions and refine hypotheses.	○	○

Program-level outcome:

Modeling: Build and evaluate models of biological systems.

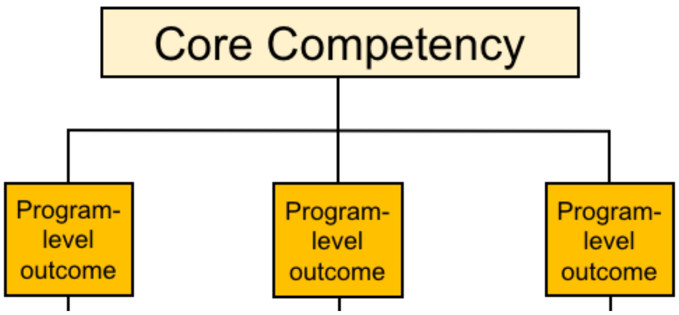
In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Build and revise conceptual models (e.g., diagrams, concept maps, flow charts) to propose how a biological system or process works.	○	○
Identify important components of a system and describe how they influence each other (e.g., positively or negatively).	○	○
Using instructor-provided tools, set parameters of mathematical or computational models and interpret output.	○	○
Evaluate models by comparing their predictions with empirical data.	○	○

Optional: Please share any comments you have on the categorization of these outcomes, including any suggestions for alternative categorization if applicable.

Do you think any essential **course**-level outcomes are missing from this list?

Categorization: **Modeling & Simulations**



Next, we would like you to indicate if you think any of the **program**-level learning outcomes are currently miscategorized.

If you would like to see the complete, preliminary draft of the BioSkills Guide for context, please click here. As a reminder, the other core competencies are: **Process of Science, Quantitative Reasoning, Interdisciplinary Nature of Science, Communication & Collaboration, and Science & Society.**

Currently, we have categorized the program-level outcomes listed below under the core competency:

Modeling & Simulations

In your opinion, is it accurate to categorize each of the following program-level outcomes under this core competency?

	Yes	No
Purpose of Models: Recognize the important roles that scientific models of many different types (conceptual, mathematical, physical, etc.) play in predicting and communicating biological phenomena.	○	○
Model Application: Make inferences and solve problems using models and simulations.	○	○
Modeling: Build and evaluate models of biological systems.	○	○

Optional: Please share any comments you have on the categorization of these outcomes, including any suggestions for alternative categorization if applicable.

You have now reviewed all of the program-level learning outcomes and course-level learning outcomes for this core competency.

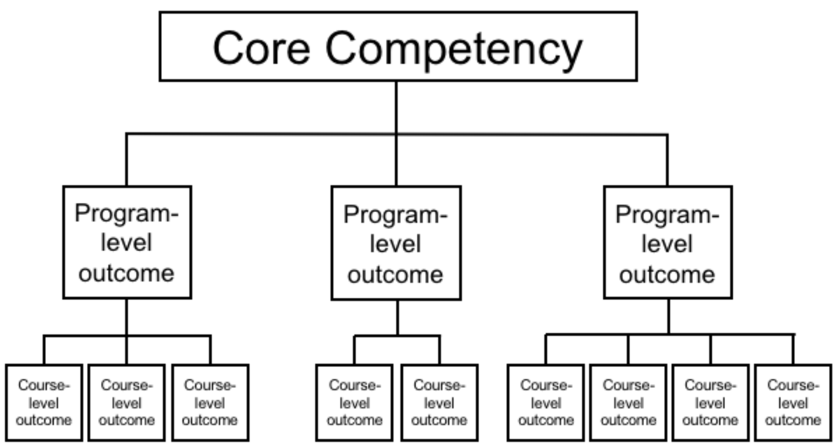
Given this review, do you think there are any essential **program**-level learning outcomes missing from the **Modeling & Simulations** core competency?

Optional: Please share any other feedback on the **Modeling & Simulations** core competency.

Interdisciplinary Nature of Science

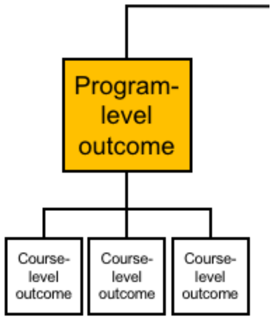
In this portion of the survey, we would like you to rate the importance and ease of understanding of our current draft of learning outcomes for one particular core competency: **Interdisciplinary Nature of Science.** Later, you will be asked to comment on whether the outcomes are appropriately categorized under this competency.

In the current draft of the BioSkills Guide, each core competency contains multiple **program**-level learning outcomes. In addition, each program-level learning outcome contains multiple **course**-level learning outcomes. Throughout the survey, you will switch between evaluating program- and course-level outcomes. We will use the figure below to remind you of this structure and cue when you are switching between levels.



Important note: Please keep in mind that we intend for the BioSkills Guide to contain the learning outcomes that we, as a community, think all **graduating general biology majors** should achieve. Therefore, as you complete the survey, please rate the outcomes based on whether they are both desirable and reasonable to accomplish in a **four-year program**, not introductory courses alone (1-2 years only) or in a graduate program (5+ years).

Importance and Ease of Understanding: **Interdisciplinary Nature of Science**



The next three questions will ask you to evaluate the following **program**-level outcome:

Connecting Scientific Knowledge: Integrate concepts from other STEM disciplines (e.g., chemistry, physics) and across multiple fields of biology (e.g., cell biology, ecology).

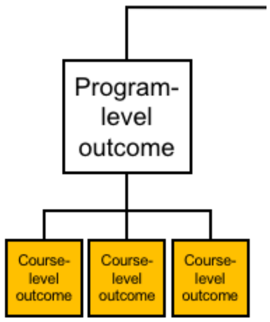
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Given a biological problem, identify relevant concepts from other disciplines.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Build models or explanations of simple biological processes that include concepts from multiple fields of biology and/or other STEM disciplines.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important

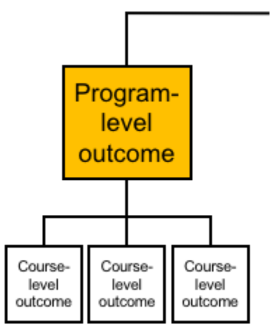
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Importance and Ease of Understanding: **Interdisciplinary Nature of Science**



The next three questions will ask you to evaluate the following **program**-level outcome:

Interdisciplinary Problem Solving: Consider interdisciplinary solutions to real-world problems.

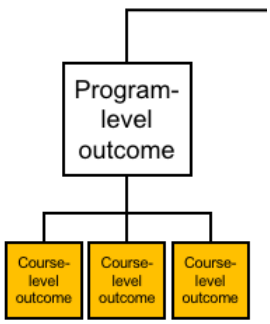
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Describe examples of real-world problems that are too complex to be solved by applying biological approaches alone.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Suggest how collaborators in other disciplines could contribute to solutions of real-world problems.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Be able to explain biological concepts, data, and methods, including their limitations, using language understandable by collaborators in other disciplines.

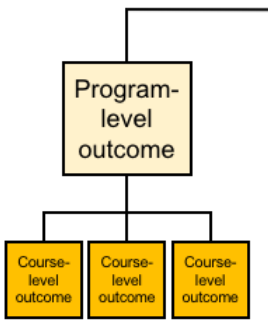
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



Next, we would like you to indicate whether the current categorization of **course**-level outcomes within program-level outcomes makes sense to you. You will also be asked to suggest missing outcomes.

Some related outcomes may currently be categorized under other competencies. If you would like to see a complete draft of the BioSkills Guide for context, please click here. This is a preliminary draft, and we ask that you *please do not share it with others until it is published.*

Categorization: **Interdisciplinary Nature of Science**

Currently, we have categorized each of the course-level outcomes listed below under the program-level outcome:

Connecting Scientific Knowledge: Integrate concepts from other STEM disciplines (e.g., chemistry, physics) and across multiple fields of biology (e.g., cell biology, ecology).

In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Given a biological problem, identify relevant concepts from other disciplines.	O	O
Build models or explanations of simple biological processes that include concepts from multiple fields of biology and/or other STEM disciplines.	O	O

Program-level outcome:

Interdisciplinary Problem Solving: Consider interdisciplinary solutions to real-world problems.

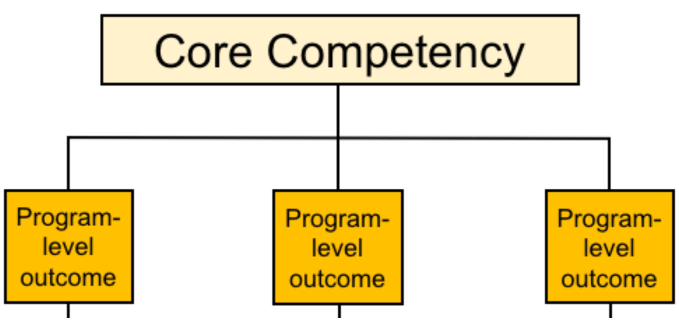
In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Describe examples of real-world problems that are too complex to be solved by applying biological approaches alone.	○	○
Suggest how collaborators in other disciplines could contribute to solutions of real-world problems.	○	○
Be able to explain biological concepts, data, and methods, including their limitations, using language understandable by collaborators in other disciplines.	○	○

Optional: Please share any comments you have on the categorization of these outcomes, including any suggestions for alternative categorization if applicable.

Do you think any essential **course**-level outcomes are missing from this list?

Categorization: **Interdisciplinary Nature of Science**



Next, we would like you to indicate if you think any of the **program**-level learning outcomes are currently miscategorized.

If you would like to see the complete, preliminary draft of the BioSkills Guide for context, please click here. As a reminder, the other core competencies are: **Process of Science, Quantitative Reasoning, Modeling & Simulations, Communication & Collaboration, and Science & Society.**

Currently, we have categorized the program-level outcomes listed below under the core competency:

Interdisciplinary Nature of Science

In your opinion, is it accurate to categorize each of the following program-level outcomes under this core competency?

	Yes	No
Connecting Scientific Knowledge: Integrate concepts from other STEM disciplines (e.g., chemistry, physics) and across multiple fields of biology (e.g., cell biology, ecology).	O	O
Interdisciplinary Problem Solving: Consider interdisciplinary solutions to real-world problems.	O	O

Optional: Please share any comments you have on the categorization of these outcomes, including any suggestions for alternative categorization if applicable.

You have now reviewed all of the program-level learning outcomes and course-level learning outcomes for this core competency.

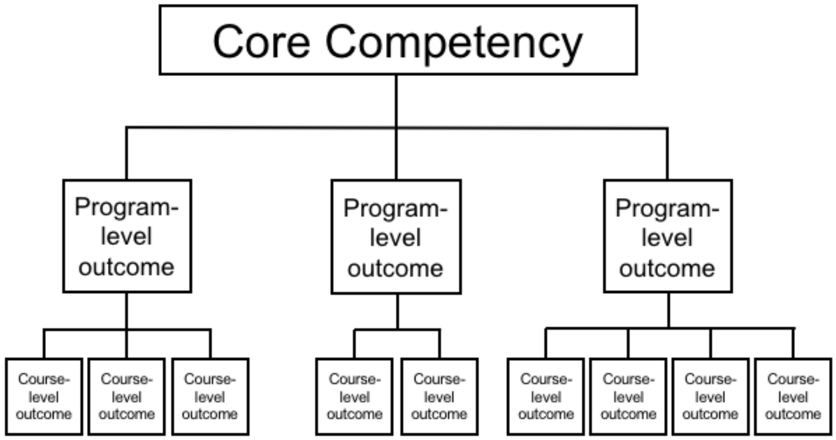
Given this review, do you think there are any essential **program**-level learning outcomes missing from the **Interdisciplinary Nature of Science** core competency?

Optional: Please share any other feedback on the **Interdisciplinary Nature of Science** core competency.

Communication & Collaboration

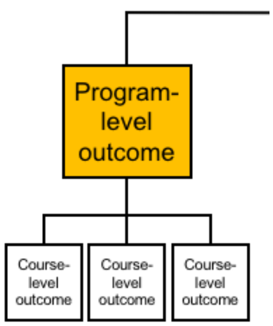
In this portion of the survey, we would like you to rate the importance and ease of understanding of our current draft of learning outcomes for one particular core competency: **Communication & Collaboration.** Later, you will be asked to comment on whether the outcomes are appropriately categorized under this competency.

In the current draft of the BioSkills Guide, each core competency contains multiple **program**-level learning outcomes. In addition, each program-level learning outcome contains multiple **course**-level learning outcomes. Throughout the survey, you will switch between evaluating program- and course-level outcomes. We will use the figure below to remind you of this structure and cue when you are switching between levels.



Important note: Please keep in mind that we intend for the BioSkills Guide to contain the learning outcomes that we, as a community, think all **graduating general biology majors** should achieve. Therefore, as you complete the survey, please rate the outcomes based on whether they are both desirable and reasonable to accomplish in a **four-year program**, not introductory courses alone (1-2 years only) or in a graduate program (5+ years).

Importance and Ease of Understanding: **Communication & Collaboration**



The next three questions will ask you to evaluate the following **program**-level outcome:

Communication: Share ideas, data, and findings with others clearly and accurately.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

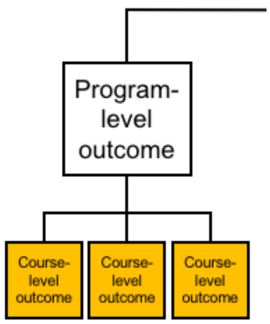
- ○ Very Important
- ○ Important
- ○ Neither Important Nor Unimportant
- ○ Unimportant
- ○ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- ○ Very Easy

- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Use an appropriate voice to communicate science to targeted audiences (e.g., general public, biology experts, collaborators in other disciplines).

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Use multiple modes to communicate science (e.g., oral, written, visual).

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- ◯ Very Important
- ◯ Important
- ◯ Neither Important Nor Unimportant
- ◯ Unimportant
- ◯ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- ◯ Very Easy
- ◯ Easy
- ◯ Neither Easy Nor Difficult
- ◯ Difficult
- ◯ Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Describe the purpose and parts of different forms of scientific communication (e.g., journal articles, posters, grant proposals).

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- ◯ Very Important
- ◯ Important
- ◯ Neither Important Nor Unimportant
- ◯ Unimportant
- ◯ Very Unimportant

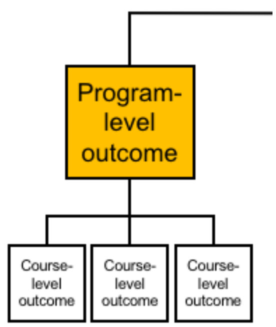
How easy or difficult is it for **you** to understand this outcome?

- ◯ Very Easy
- ◯ Easy
- ◯ Neither Easy Nor Difficult
- ◯ Difficult

◯ Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Importance and Ease of Understanding: **Communication & Collaboration**



The next three questions will ask you to evaluate the following **program**-level outcome:

Collaboration: Work productively in teams with people who have diverse backgrounds, skill sets, and perspectives.

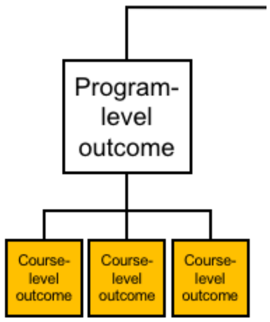
How important or unimportant is it for graduating general biology majors to achieve this outcome?

◯ Very Important
◯ Important
◯ Neither Important Nor Unimportant
◯ Unimportant
◯ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

◯ Very Easy
◯ Easy
◯ Neither Easy Nor Difficult
◯ Difficult
◯ Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Break team projects into tasks and decide how they can be productively shared.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Work with teammates to establish and periodically update group expectations (e.g., project timeline, rules for group interactions).

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Elicit, listen to, and incorporate ideas from teammates with diverse perspectives and backgrounds.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Work effectively with teammates to complete projects.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

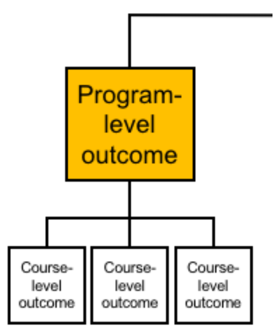
- ○ Very Important
- ○ Important
- ○ Neither Important Nor Unimportant
- ○ Unimportant
- ○ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- ○ Very Easy
- ○ Easy
- ○ Neither Easy Nor Difficult
- ○ Difficult
- ○ Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Importance and Ease of Understanding: **Communication & Collaboration**



The next three questions will ask you to evaluate the following **program**-level outcome:

Collegial Review: Provide and respond to constructive feedback in order to improve individual and team work.

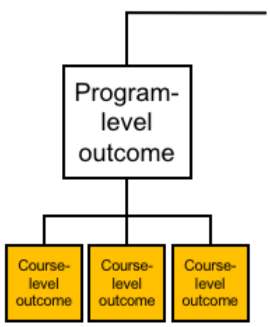
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Evaluate feedback from others and revise work or behavior appropriately.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy

- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Critique others' work and ideas constructively and respectfully.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

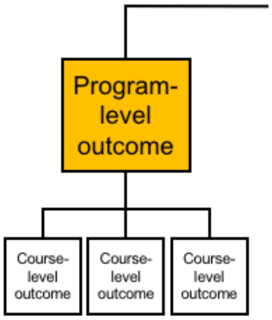
- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Importance and Ease of Understanding: **Communication & Collaboration**



The next three questions will ask you to evaluate the following **program**-level outcome:

Metacognition: Reflect on your own learning, performance, and achievements.

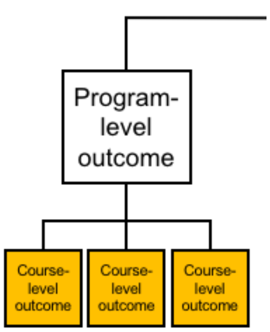
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Evaluate your own understanding and skill level.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Assess personal progress and contributions to your team and generate a plan to change your behavior as needed.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

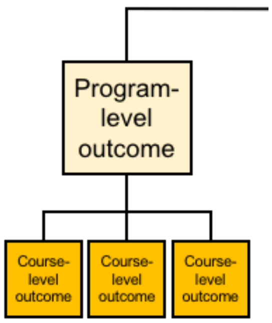
- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult

◯ Very Difficult

Please share any feedback you have about the content or wording of this outcome.



Next, we would like you to indicate whether the current categorization of **course**-level outcomes within program-level outcomes makes sense to you. You will also be asked to suggest missing outcomes.

Some related outcomes may currently be categorized under other competencies. If you would like to see a complete draft of the BioSkills Guide for context, please click here. This is a preliminary draft, and we ask that you *please do not share it with others until it is published.*

Categorization: **Communication & Collaboration**

Currently, we have categorized each of the course-level outcomes listed below under the program-level outcome:

Communication: Share ideas, data, and findings with others clearly and accurately.

In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Use an appropriate voice to communicate science to targeted audiences (e.g., general public, biology experts, collaborators in other disciplines).	◯	◯
Use multiple modes to communicate science (e.g., oral, written, visual).	◯	◯
Describe the purpose and parts of different forms of scientific communication (e.g., journal articles, posters, grant proposals).	◯	◯

Program-level outcome:

Collaboration: Work productively in teams with people who have diverse backgrounds, skill sets, and perspectives.

In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Break team projects into tasks and decide how they can be productively shared.	O	O
Work with teammates to establish and periodically update group expectations (e.g., project timeline, rules for group interactions).	O	O
Elicit, listen to, and incorporate ideas from teammates with diverse perspectives and backgrounds.	O	O
Work effectively with teammates to complete projects.	O	O

Program-level outcome:

Collegial Review: Provide and respond to constructive feedback in order to improve individual and team work.

In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Evaluate feedback from others and revise work or behavior appropriately.	O	O
Critique others' work and ideas constructively and respectfully.	O	O

Program-level outcome:

Metacognition: Reflect on your own learning, performance, and achievements.

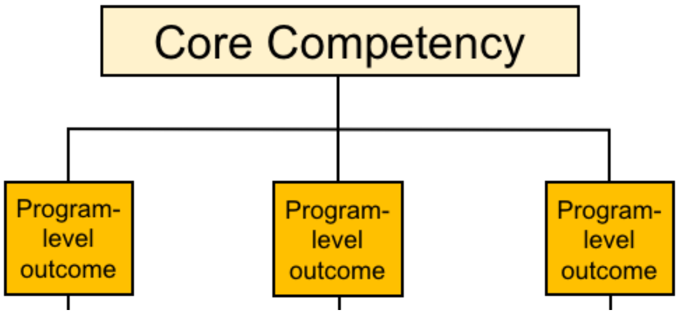
In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Evaluate your own understanding and skill level.	O	O
Assess personal progress and contributions to your team and generate a plan to change your behavior as needed.	O	O

Optional: Please share any comments you have on the categorization of these outcomes, including any suggestions for alternative categorization if applicable.

Do you think any essential **course**-level outcomes are missing from this list?

Categorization: **Communication & Collaboration**



Next, we would like you to indicate if you think any of the **program**-level learning outcomes are currently miscategorized.

If you would like to see the complete, preliminary draft of the BioSkills Guide for context, please click here. As a reminder, the other core competencies are: **Process of Science, Quantitative Reasoning, Modeling & Simulations, Interdisciplinary Nature of Science, and Science & Society.**

Currently, we have categorized the program-level outcomes listed below under the core competency:

Communication & Collaboration

In your opinion, is it accurate to categorize each of the following program-level outcomes under this core competency?

	Yes	No
Communication: Share ideas, data, and findings with others clearly and accurately.	○	○
Collaboration: Work productively in teams with people who have diverse backgrounds, skill sets, and perspectives.	○	○
Collegial Review: Provide and respond to constructive feedback in order to improve individual and team work.	○	○
Metacognition: Reflect on your own learning, performance, and achievements.	○	○

Optional: Please share any comments you have on the categorization of these outcomes, including any suggestions for alternative categorization if applicable.

You have now reviewed all of the program-level learning outcomes and course-level learning outcomes for this core competency.

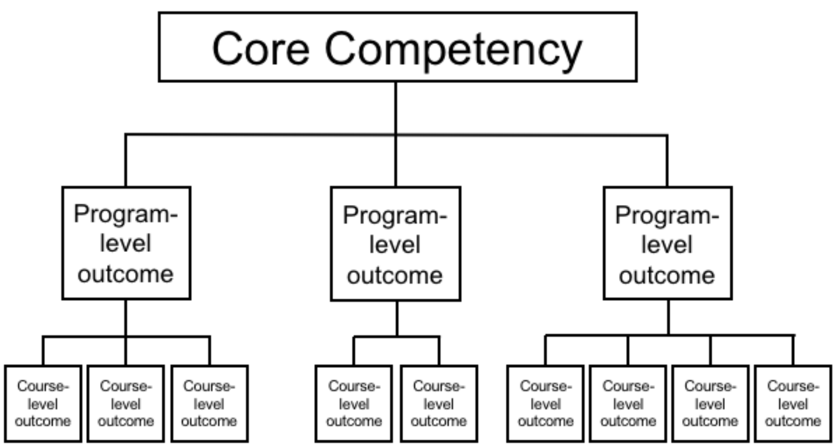
Given this review, do you think any essential **program**-level learning outcomes are missing from the **Communication & Collaboration** core competency?

Optional: Please share any other feedback on the **Communication & Collaboration** core competency.

Science & Society

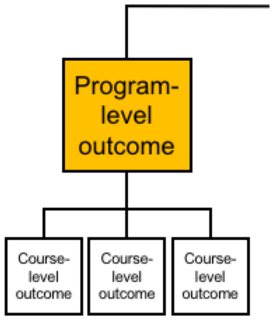
In this portion of the survey, we would like you to rate the importance and ease of understanding of our current draft of learning outcomes for one particular core competency: **Science & Society.** Later, you will be asked to comment on whether the outcomes are appropriately categorized under this competency.

In the current draft of the BioSkills Guide, each core competency contains multiple **program**-level learning outcomes. In addition, each program-level learning outcome contains multiple **course**-level learning outcomes. Throughout the survey, you will switch between evaluating program- and course-level outcomes. We will use the figure below to remind you of this structure and cue when you are switching between levels.



Important note: Please keep in mind that we intend for the BioSkills Guide to contain the learning outcomes that we, as a community, think all **graduating general biology majors** should achieve. Therefore, as you complete the survey, please rate the outcomes based on whether they are both desirable and reasonable to accomplish in a **four-year program**, not introductory courses alone (1-2 years only) or in a graduate program (5+ years).

Importance and Ease of Understanding: **Science & Society**



The next three questions will ask you to evaluate the following **program**-level outcome:

Ethics: Demonstrate the ability to think critically about ethical issues in the conduct of science.

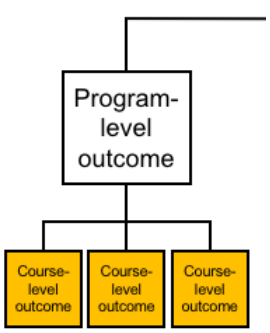
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Evaluate ethical considerations (e.g., use of animal or human subjects, conflicts of interest, biased study design) in a given research study.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- ○ Very Important
- ○ Important
- ○ Neither Important Nor Unimportant
- ○ Unimportant
- ○ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- ○ Very Easy
- ○ Easy
- ○ Neither Easy Nor Difficult
- ○ Difficult
- ○ Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Provide examples of ethical controversies in biological research and critique how they have been addressed by the scientific community.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- ○ Very Important
- ○ Important
- ○ Neither Important Nor Unimportant
- ○ Unimportant
- ○ Very Unimportant

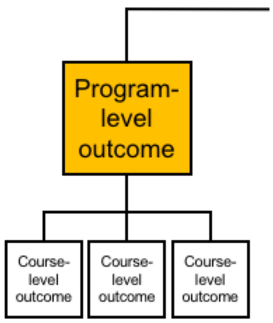
How easy or difficult is it for **you** to understand this outcome?

- ○ Very Easy
- ○ Easy
- ○ Neither Easy Nor Difficult
- ○ Difficult

○ Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Importance and Ease of Understanding: **Science & Society**



The next three questions will ask you to evaluate the following **program**-level outcome:

Societal Influences: Consider the potential impacts of outside influences (historical, cultural, political, technological) on how science is practiced.

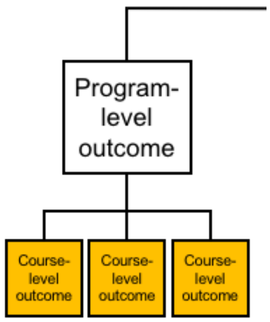
How important or unimportant is it for graduating general biology majors to achieve this outcome?

○ Very Important
○ Important
○ Neither Important Nor Unimportant
○ Unimportant
○ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

○ Very Easy
○ Easy
○ Neither Easy Nor Difficult
○ Difficult
○ Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Describe examples of how scientists' backgrounds and biases can influence science and how science is enhanced through diversity.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- ○ Very Important
- ○ Important
- ○ Neither Important Nor Unimportant
- ○ Unimportant
- ○ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- ○ Very Easy
- ○ Easy
- ○ Neither Easy Nor Difficult
- ○ Difficult
- ○ Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Identify and describe how systemic factors (e.g., socioeconomic, political) affect how and by whom science is conducted.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

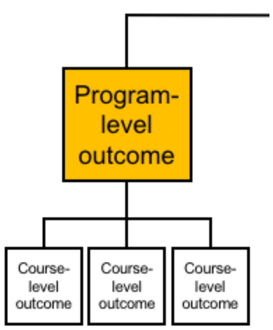
- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Importance and Ease of Understanding: **Science & Society**



The next three questions will ask you to evaluate the following **program**-level outcome:

Science's Impact on Society: Apply scientific reasoning in daily life and recognize the impacts of science on a local and global scale.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

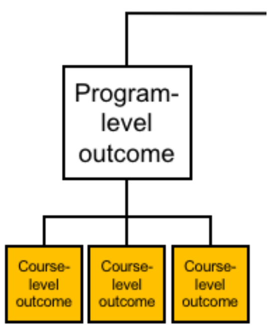
- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant

○ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

○ Very Easy
○ Easy
○ Neither Easy Nor Difficult
○ Difficult
○ Very Difficult

Please share any feedback you have about the content or wording of this outcome.



The next three questions will ask you to evaluate the following **course**-level outcome:

Apply evidence-based reasoning and biological knowledge in daily life (e.g., consuming popular media, deciding how to vote).

How important or unimportant is it for graduating general biology majors to achieve this outcome?

○ Very Important
○ Important
○ Neither Important Nor Unimportant
○ Unimportant
○ Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

○ Very Easy
○ Easy
○ Neither Easy Nor Difficult
○ Difficult
○ Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Use examples to describe the relevance of science in everyday experiences.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Identify and describe the broader societal impacts of biological research on different stakeholders.

How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.

Course-level outcome:

Describe the role scientists have in providing public access to scientific knowledge.

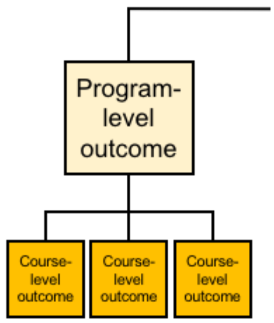
How important or unimportant is it for graduating general biology majors to achieve this outcome?

- Very Important
- Important
- Neither Important Nor Unimportant
- Unimportant
- Very Unimportant

How easy or difficult is it for **you** to understand this outcome?

- Very Easy
- Easy
- Neither Easy Nor Difficult
- Difficult
- Very Difficult

Please share any feedback you have about the content or wording of this outcome.



Next, we would like you to indicate whether the current categorization of **course**-level outcomes within program-level outcomes makes sense to you. You will also be asked to suggest missing outcomes.

Some related outcomes may currently be categorized under other competencies. If you would like to see a complete draft of the BioSkills Guide for context, please click here. This is a preliminary draft, and we ask that you *please do not share it with others until it is published*.

Categorization: **Science & Society**

Currently, we have categorized each of the course-level outcomes listed below under the program-level outcome:

Ethics: Demonstrate the ability to think critically about ethical issues in the conduct of science.

In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Evaluate ethical considerations (e.g., use of animal or human subjects, conflicts of interest, biased study design) in a given research study.	○	○
Provide examples of ethical controversies in biological research and critique how they have been addressed by the scientific community.	○	○

Program-level outcome:

Societal Influences: Consider the potential impacts of outside influences (historical, cultural, political, technological) on how science is practiced.

In your opinion, is it accurate to categorize the following course-level outcome under this program-level outcome?

	Yes	No
Describe examples of how scientists' backgrounds and biases can influence science and how science is enhanced through diversity.	○	○

	Yes	No
Identify and describe how systemic factors (e.g., socioeconomic, political) affect how and by whom science is conducted.	○	○

Program-level outcome:

Science's Impact on Society: Apply scientific reasoning in daily life and recognize the impacts of science on a local and global scale.

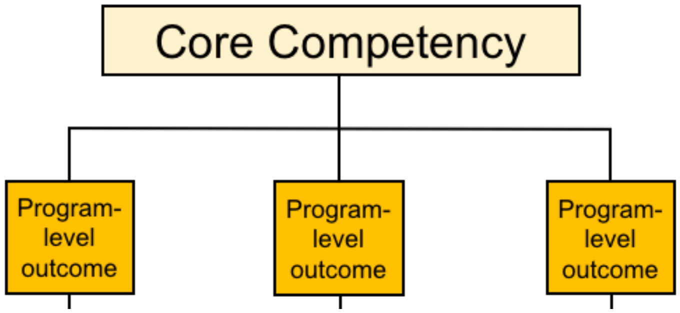
In your opinion, is it accurate to categorize each of the following course-level outcomes under this program-level outcome?

	Yes	No
Apply evidence-based reasoning and biological knowledge in daily life (e.g., consuming popular media, deciding how to vote).	○	○
Use examples to describe the relevance of science in everyday experiences.	○	○
Identify and describe the broader societal impacts of biological research on different stakeholders.	○	○
Describe the role scientists have in providing public access to scientific knowledge.	○	○

Optional: Please share any comments you have on the categorization of these outcomes, including any suggestions for alternative categorization if applicable.

Do you think any essential **course**-level outcomes are missing from this list?

Categorization: **Science & Society**



Next, we would like you to indicate if you think any of **program**-level learning outcomes are currently miscategorized.

If you would like to see the complete, preliminary draft of the BioSkills Guide for context, please click here. As a reminder, the other core competencies are: **Process of Science, Quantitative Reasoning, Modeling & Simulations, Interdisciplinary Nature of Science, and Communication & Collaboration.**

Currently, we have categorized the program-level outcomes listed below under the core competency:

Science & Society

In your opinion, is it accurate to categorize each of the following program-level outcomes under this core competency?

	Yes	No
Ethics: Demonstrate the ability to think critically about ethical issues in the conduct of science.	O	O
Societal Influences: Consider the potential impacts of outside influences (historical, cultural, political, technological) on how science is practiced.	O	O
Science's Impact on Society: Apply scientific reasoning in daily life and recognize the impacts of science on a local and global scale.	O	O

Optional: Please share any comments you have on the categorization of these outcomes, including any suggestions for alternative categorization if applicable.

You have now reviewed all of the program-level learning outcomes and course-level learning outcomes for this core competency.

Given this review, do you think any essential **program**-level learning outcomes are missing from the **Science & Society** core competency?

Optional: Please share any other feedback on the **Science & Society** core competency.

Demographics

Demographic Questions

We ask that you complete the following demographic questions so that we can determine if we are gathering feedback from a representative population. We will not link specific responses with any individual identifying information when sharing the results of this survey.

What is the name of your current institution? (This will be used to gather additional institutional demographic information.)

____

Which of the following best describes your institution type?

- ○ Associate's Degree-Granting
- ○ Bachelor's Degree-Granting
- ○ Master's Degree-Granting
- ○ Doctoral Degree-Granting
- ○ ________ Other (please specify):

Which of the following best describes your current position?

- ○ Graduate Student
- ○ Postdoc
- ○ Lecturer or Instructor
- ○ Assistant, Associate, or Full Professor
- ○ Staff
- ○ ________ Other (please specify):

In your current position, what is your primary responsibility?

- ○ Teaching
- ○ Research
- ○ Teaching and Research Equally
- ○ ________ Other (please describe briefly)

What is the focus of your current research, if applicable? (please select all that apply)

- ☐ I am not currently engaged in research
- ☐ Molecular/Cellular/Developmental Biology
- ☐ Physiology
- ☐ Ecology/Evolutionary Biology
- ☐ Discipline-Based Education Research
- ☐ ________ Other (please specify):

What is or was the focus of your graduate training? (please select all that apply)

- ☐ Molecular/Cellular/Developmental Biology
- ☐ Physiology
- ☐ Ecology/Evolutionary Biology
- ☐ Discipline-Based Education Research
- ☐ ____________ Other (please specify):

What is the primary focus of the majority of biology courses that you teach? (please select one)

- ○ Molecular/Cellular/Developmental Biology
- ○ Physiology
- ○ Ecology/Evolutionary Biology
- ○ General Biology
- ○ ____________ Other (please specify):

In an average academic year when you are teaching, how many of your courses are at each of the following academic levels?

- [0] Non-Majors Lower-Level (100-200 level)
- [0] Majors Lower-Level (100-200 level)
- [0] Upper-Level (300-400 level)
- [0] Graduate-Level (500+ level)

How familiar are you with the *Vision and Change* report issued by the AAAS in 2011?

- ○ Extremely Familiar
- ○ Very Familiar
- ○ Somewhat Familiar
- ○ Slightly Familiar
- ○ Not At All Familiar

Have you previously provided feedback on the BioSkills Guide?

- ○ Yes
- ○ No

Please indicate your interest in any of the following forms of follow-up communication (please select all the apply)

- ☐ I would like to be sent a letter documenting my participation in this biology education activity for my records.
- ☐ I would like to be sent a copy of the final version of the BioSkills Guide once it is ready.

☐ It would be OK if you contacted me in the future to follow up on my answers to this survey.

If you checked any of the options in the preceding question, please enter your email address.

Optional: Please share any final comments you have about this survey or the BioSkills guide in general.

We are looking for more reviewers! If you have colleagues who would be interested in participating, we would be grateful if you shared this survey link with them:

bit.ly/BiologySkillsSurvey

Alternatively, you may enter their contact info (name and/or email address) and we will send them an invitation.

Supplemental Material 7. BioSkills validation phase questionnaire.

Questionnaire used during national validation survey. Questionnaire for pilot validation was identical, except for wording of one learning outcome.

BioSkills: Core Competency Learning Outcomes

Welcome Page

Based on the recommendations of "Vision and Change in Undergraduate Biology Education: A Call to Action", this NSF-supported project is intended to use the perspectives and priorities of a wide range of biology educators to unpack six "core competencies" (listed below) into measurable learning outcomes. Once completed, these learning outcomes will be made available to the community as a resource for planning and assessment of skills training in undergraduate biology. To date, we have used feedback from over 200 biology educators to develop and iteratively revise this set of learning outcomes, which we're collectively calling the "BioSkills Guide". To determine if the BioSkills Guide has broad support, we are asking a range of biology educators to rate the importance of the outcomes for a graduating general biology major.

Vision and Change Core Competencies

- **Process of Science**
- **Quantitative Reasoning**
- **Modeling & Simulation**
- **Interdisciplinary Nature of Science**
- **Communication & Collaboration**
- **Science & Society**

Thank you in advance for being a part of this work. The survey is expected to take ~15 minutes, and you can leave and return to the survey as needed until February 11 (your progress will save in your browser). Within the survey, you will find multiple links to download a copy of the BioSkills Guide for your personal use. If you have any questions about the project or this survey, please do not hesitate to contact me, Dr. Alexa Clemmons, or Dr. Alison Crowe.

Contact information:

Alexa Clemmons, Ph.D. (project lead)
Postdoctoral Research Associate
Biology Education Research Group
Department of Biology
University of Washington
aclemmon@uw.edu

Alison Crowe, Ph.D.
Principal Lecturer
Biology Education Research Group
Department of Biology
University of Washington
acrowe@uw.edu

Have you ever served as the instructor of record for a college-level life sciences course?

- ○ Yes
- ○ No

Screened Out

Thank you for your interest in the BioSkills Guide! At this time we are soliciting feedback from college biology instructors, but in the future we plan to widen our scope.

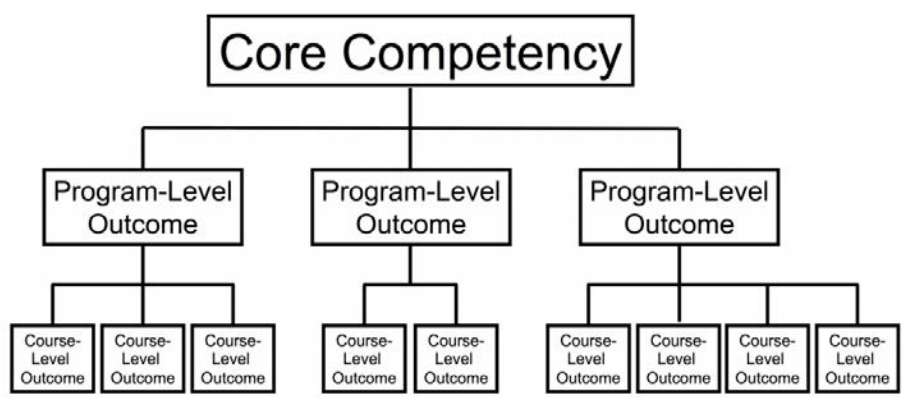
If you would be interested in providing feedback then, please enter your email address. If you enter your email address we will also notify you when the BioSkills Guide is ready for distribution.

Instructions

Instructions

You will be asked to review two or three randomly assigned core competencies, although we would love your feedback on additional competencies if you have the time**.** You do **not** need to have experience teaching the particular core competencies you are rating.

In the current draft of the BioSkills Guide, each core competency contains multiple **program**-level learning outcomes. In addition, each program-level learning outcome contains multiple **course**-level learning outcomes. Throughout the survey, you will switch between evaluating program- and course-level outcomes. We will use the figure below to remind you of this structure and cue when the survey is switching between levels.



Important note: We intend for the BioSkills Guide to contain the learning outcomes that we, as a community, think all graduating general biology majors should achieve. **Therefore, please rate the outcomes based on whether they are important and reasonable to accomplish <u>over the course of a four-year general biology program</u>**, not introductory courses alone (1-2 years only) or in a graduate program (5+ years). Additionally, please evaluate the outcomes independently, not relative to one another (i.e. you are rating not ranking the outcomes).

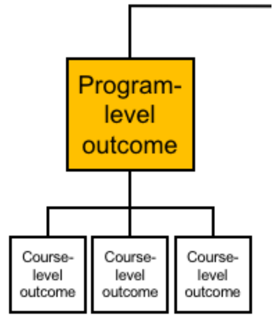
[***Following the instructions, blocks of questions (each block corresponding to one of the six core competencies) were randomly assigned. All respondents were given 3 blocks of questions, with the option to complete additional.***]

Process of Science

In this portion of the survey, we would like you to rate the importance of learning outcomes for one particular core competency: **Process of Science.** Please rate the outcomes based on whether they are important to accomplish over the course of a **four-year general biology program**. Additionally, please evaluate the outcomes independently, not relative to one another.

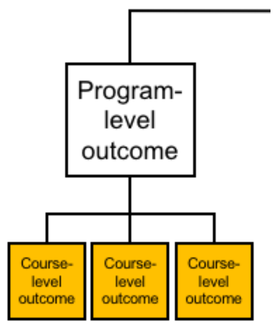
If you would like to see the entire BioSkills Guide for context, click here. Please do not share this draft with others.

Process of Science



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Scientific Thinking: Explain how science generates knowledge of the natural world.	O	O	O	O	O



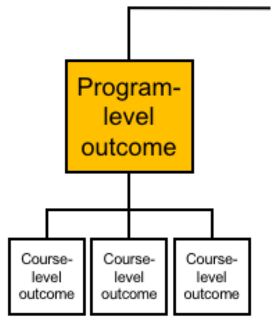
Each of the following course-level outcomes are classified under the **Scientific Thinking** program-level outcome.

How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Explain how scientists use inference and evidence-based reasoning to generate knowledge.	O	O	O	O	O
Describe the iterative nature of science and how new evidence can lead to the revision of scientific knowledge.	O	O	O	O	O

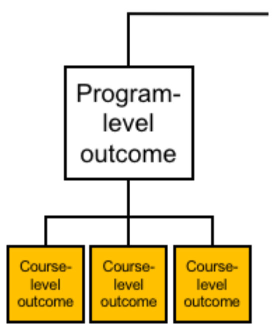
Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Information Literacy: Locate, interpret, and evaluate scientific information.	O	O	O	O	O



Each of the following course-level outcomes are classified under the **Information Literacy** program-level outcome.

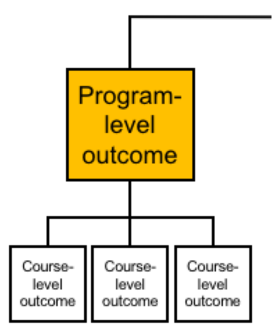
How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Find and evaluate the credibility of a variety of sources of scientific information, including popular science media and scientific journals.	○	○	○	○	○
Interpret, summarize, and evaluate evidence in primary literature.	○	○	○	○	○
Evaluate claims in scientific papers, popular science media, and other sources using evidence-based reasoning.	○	○	○	○	○

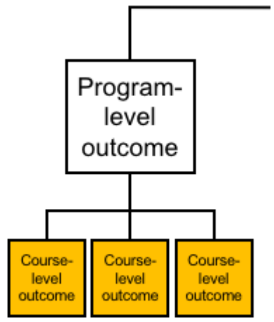
○ Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Question Formulation: Pose testable questions and hypotheses to address gaps in knowledge.	○	○	○	○	○



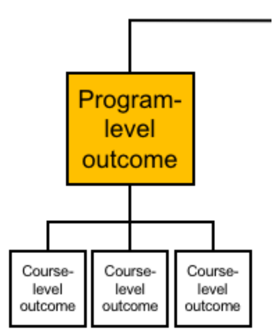
Each of the following course-level outcomes are classified under the **Question Formulation** program-level outcome.

How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Recognize gaps in our current understanding of a biological system or process and identify what specific information is missing.	O	O	O	O	O
Develop research questions based on your own or others' observations.	O	O	O	O	O
Formulate testable hypotheses and state their predictions.	O	O	O	O	O

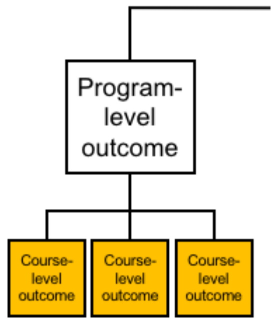
O Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Study Design: Plan, evaluate, and implement scientific investigations.	○	○	○	○	○



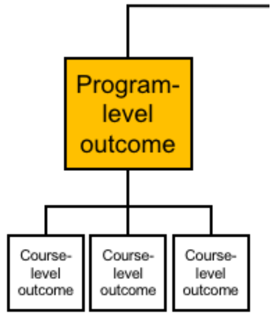
Each of the following course-level outcomes are classified under the **Study Design** program-level outcome.

How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Compare the strengths and limitations of various study designs.	○	○	○	○	○
Design controlled experiments, including plans for analyzing the data.	○	○	○	○	○
Execute protocols and accurately record measurements and observations.	○	○	○	○	○
Identify methodological problems and suggest how to troubleshoot them.	○	○	○	○	○
Evaluate and suggest best practices for responsible research conduct (e.g., lab safety, record keeping, proper citation of sources).	○	○	○	○	○

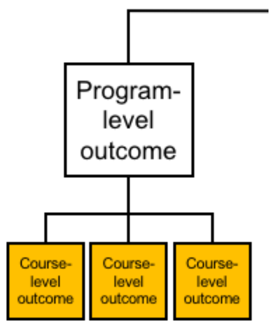
○ Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Data Interpretation & Evaluation: Interpret, evaluate, and draw conclusions from data in order to make evidence-based arguments about the natural world.	O	O	O	O	O



Each of the following course-level outcomes are classified under the **Data Interpretation & Evaluation** program-level outcome.

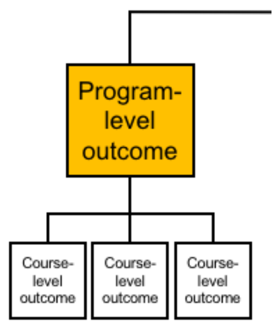
How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Analyze data, summarize resulting patterns, and draw appropriate conclusions.	O	O	O	O	O
Describe sources of error and uncertainty in data.	O	O	O	O	O
Make evidence-based arguments using your own and others' findings.	O	O	O	O	O

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Relate conclusions to original hypothesis, consider alternative hypotheses, and suggest future research directions based on findings.	O	O	O	O	O

O Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Doing Research: Apply science process skills to address a research question in a course-based or independent research experience.	O	O	O	O	O

O Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.

Process of Science

You have now reviewed all of the program-level and course-level learning outcomes (displayed below) for this core competency.

PROCESS OF SCIENCE	
Program-Level Learning Outcomes	**Course-Level Learning Outcomes**
SCIENTIFIC THINKING Explain how science generates knowledge of the natural world.	Explain how scientists use inference and evidence-based reasoning to generate knowledge.
	Describe the iterative nature of science and how new evidence can lead to the revision of scientific knowledge.
INFORMATION LITERACY Locate, interpret, and evaluate scientific information.	Find and evaluate the credibility of a variety of sources of scientific information, including popular science media and scientific journals.
	Interpret, summarize, and evaluate evidence in primary literature.
	Evaluate claims in scientific papers, popular science media, and other sources using evidence-based reasoning.
QUESTION FORMULATION Pose testable questions and hypotheses to address gaps in knowledge.	Recognize gaps in our current understanding of a biological system or process and identify what specific information is missing.
	Develop research questions based on your own or others' observations.
	Formulate testable hypotheses and state their predictions.
STUDY DESIGN Plan, evaluate, and implement scientific investigations.	Compare the strengths and limitations of various study designs.
	Design controlled experiments, including plans for analyzing the data.
	Execute protocols and accurately record measurements and observations.
	Identify methodological problems and suggest how to troubleshoot them.
	Evaluate and suggest best practices for responsible research conduct (e.g., lab safety, record keeping, proper citation of sources).
DATA INTERPRETATION & EVALUATION Interpret, evaluate, and draw conclusions from data in order to make evidence-based arguments about the natural world.	Analyze data, summarize resulting patterns, and draw appropriate conclusions.
	Describe sources of error and uncertainty in data.
	Make evidence-based arguments using your own and others' findings.
	Relate conclusions to original hypothesis, consider alternative hypotheses, and suggest future research directions based on findings.
DOING RESEARCH Apply science process skills to address a research question in a course-based or independent research experience.	

○ Optional: Given this review, please click here if you believe there are essential learning outcomes missing from the Process of Science core competency.

Please share any essential learning outcomes you believe are missing from this core competency.

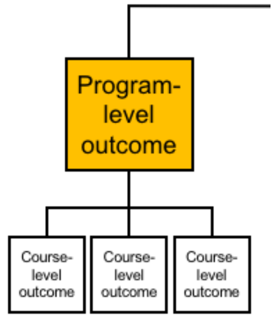
Optional: Please share any other feedback on the **Process of Science** core competency.

Quantitative Reasoning

In this portion of the survey, we would like you to rate the importance of learning outcomes for one particular core competency: **Quantitative Reasoning.** Please rate the outcomes based on whether they are important to accomplish over the course of a **four-year general biology program**. Additionally, please evaluate the outcomes independently, not relative to one another.

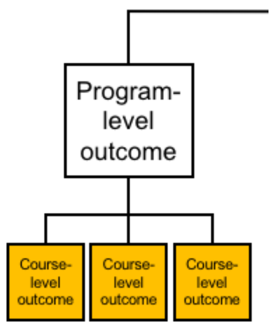
If you would like to see the entire BioSkills Guide for context, click here. Please do not share this draft with others.

Quantitative Reasoning



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Numeracy: Use basic mathematics (e.g., algebra, probability, unit conversions) in biological contexts.	O	O	O	O	O



Each of the following course-level outcomes are classified under the **Numeracy** program-level outcome.

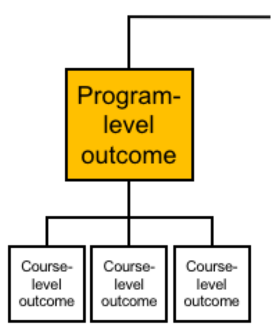
How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Perform basic calculations (e.g., percentages, frequencies, rates, means).	O	O	O	O	O
Select and apply appropriate equations (e.g., Hardy-Weinberg, Nernst, Gibbs free energy) to solve problems.	O	O	O	O	O

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Interpret and manipulate mathematical relationships (e.g., scale, ratios, units) to make quantitative comparisons.	O	O	O	O	O
Use probability and understanding of biological variability to reason about biological processes and statistical analyses.	O	O	O	O	O
Use rough estimates informed by biological knowledge to check quantitative work.	O	O	O	O	O
Describe how quantitative reasoning helps biologists understand the natural world.	O	O	O	O	O

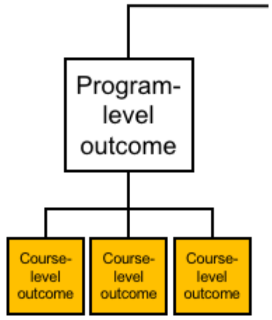
O Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Quantitative & Computational Data Analysis: Apply the tools of graphing, statistics, and data science to analyze biological data.	O	O	O	O	O



Each of the following course-level outcomes are classified under the **Quantitative & Computational Data Analysis** program-level outcome.

How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Record, organize, and annotate simple data sets.	○	○	○	○	○
Create and interpret informative graphs and other data visualizations.	○	○	○	○	○
Select, carry out, and interpret statistical analyses.	○	○	○	○	○
Describe how biologists answer research questions using databases, large data sets, and data science tools.	○	○	○	○	○
Interpret the biological meaning of quantitative results.	○	○	○	○	○

○ Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.

Quantitative Reasoning

You have now reviewed all of the program-level and course-level learning outcomes (displayed below) for this core competency.

QUANTITATIVE REASONING	
Program-Level Learning Outcomes	**Course-Level Learning Outcomes**
NUMERACY Use basic mathematics (e.g., algebra, probability, unit conversions) in biological contexts.	Perform basic calculations (e.g., percentages, frequencies, rates, means).
	Select and apply appropriate equations (e.g., Hardy-Weinberg, Nernst, Gibbs free energy) to solve problems.
	Interpret and manipulate mathematical relationships (e.g., scale, ratios, units) to make quantitative comparisons.
	Use probability and understanding of biological variability to reason about biological processes and statistical analyses.
	Use rough estimates informed by biological knowledge to check quantitative work.
	Describe how quantitative reasoning helps biologists understand the natural world.
QUANTITATIVE & COMPUTATIONAL DATA ANALYSIS Apply the tools of graphing, statistics, and data science to analyze biological data.	Record, organize, and annotate simple data sets.
	Create and interpret informative graphs and other data visualizations.
	Select, carry out, and interpret statistical analyses.
	Describe how biologists answer research questions using databases, large data sets, and data science tools.
	Interpret the biological meaning of quantitative results.

○ Optional: Given this review, please click here if you believe there are essential learning outcomes missing from the Quantitative Reasoning core competency.

Please share any essential learning outcomes you believe are missing from this core competency.

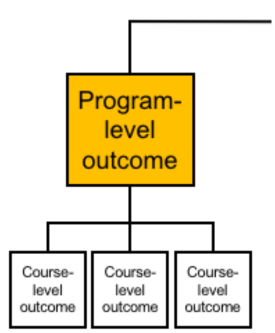
Optional: Please share any other feedback on the **Quantitative Reasoning** core competency.

Modeling & Simulation

In this portion of the survey, we would like you to rate the importance of learning outcomes for one particular core competency: **Modeling & Simulation.** Please rate the outcomes based on whether they are important to accomplish over the course of a **four-year general biology program**. Additionally, please evaluate the outcomes independently, not relative to one another.

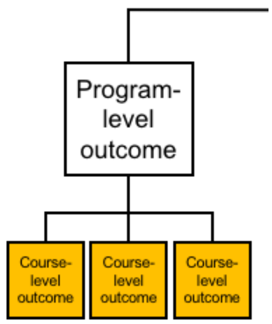
If you would like to see the entire BioSkills Guide for context, click here. Please do not share this draft with others.

Modeling & Simulation



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Purpose of Models: Recognize the important roles that scientific models, of many different types (conceptual, mathematical, physical, etc.), play in predicting and communicating biological phenomena.	○	○	○	○	○



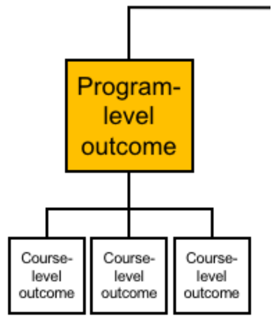
Each of the following course-level outcomes are classified under the **Purpose of Models** program-level outcome.

How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Describe why biologists use simplified representations (models) when solving problems and communicating ideas.	○	○	○	○	○
Given two models of the same biological process or system, compare their strengths, limitations, and assumptions.	○	○	○	○	○

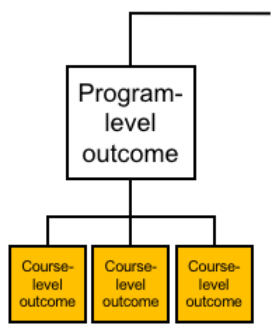
○ Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Model Application: Make inferences and solve problems using models and simulations.	O	O	O	O	O



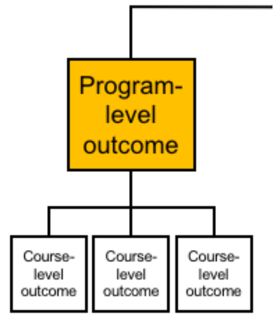
Each of the following course-level outcomes are classified under the **Model Application** program-level outcome.

How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Summarize relationships and trends that can be inferred from a given model or simulation.	O	O	O	O	O
Use models and simulations to make predictions and refine hypotheses.	O	O	O	O	O

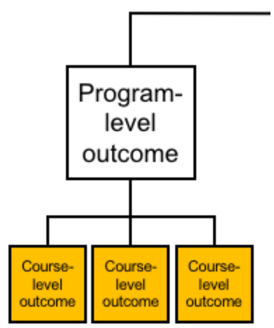
O Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Modeling: Build and evaluate models of biological systems.	O	O	O	O	O



Each of the following course-level outcomes are classified under the **Modeling** program-level outcome.

How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Build and revise conceptual models (e.g., diagrams, concept maps, flow charts) to propose how a biological system or process works.	O	O	O	O	O
Identify important components of a system and describe how they influence each other (e.g., positively or negatively).	O	O	O	O	O

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Evaluate conceptual, mathematical, or computational models by comparing their predictions with empirical data.	O	O	O	O	O

O Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.

Modeling & Simulation

You have now reviewed all of the program-level and course-level learning outcomes (displayed below) for this core competency.

MODELING & SIMULATION	
Program-Level Learning Outcomes	Course-Level Learning Outcomes
PURPOSE OF MODELS Recognize the important roles that scientific models, of many different types (conceptual, mathematical, physical, etc.), play in predicting and communicating biological phenomena.	Describe why biologists use simplified representations (models) when solving problems and communicating ideas.
	Given two models of the same biological process or system, compare their strengths, limitations, and assumptions.
MODEL APPLICATION Make inferences and solve problems using models and simulations.	Summarize relationships and trends that can be inferred from a given model or simulation.
	Use models and simulations to make predictions and refine hypotheses.
MODELING Build and evaluate models of biological systems.	Build and revise conceptual models (e.g., diagrams, concept maps, flow charts) to propose how a biological system or process works.
	Identify important components of a system and describe how they influence each other (e.g., positively or negatively).
	Evaluate conceptual, mathematical, or computational models by comparing their predictions with empirical data.

O Optional: Given this review, please click here if you believe there are essential learning outcomes missing from the Modeling & Simulation core competency.

Please share any essential learning outcomes you believe are missing from this core competency.

Optional: Please share any other feedback on the **Modeling & Simulation** core competency.

Option to Continue

Thank you for all of your feedback so far! We know that your time is valuable. We would love your feedback on additional outcomes, if you have the time.

Would you like to evaluate another set of outcomes?

[***This question was shown after first 3 randomly assigned blocks of questions, and then subsequently after each additional block of questions until all 6 blocks were complete.***]

○ Yes

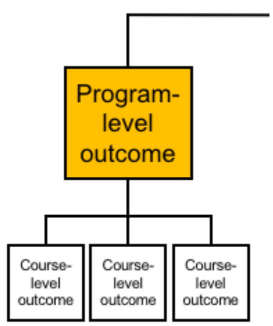
○ No

Interdisciplinary Nature of Science

In this portion of the survey, we would like you to rate the importance of learning outcomes for one particular core competency: **Interdisciplinary Nature of Science.** Please rate the outcomes based on whether they are important to accomplish over the course of a **four-year general biology program**. Additionally, please evaluate the outcomes independently, not relative to one another.

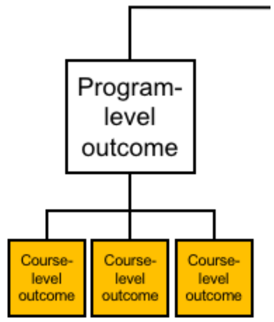
If you would like to see the entire BioSkills Guide for context, click here. Please do not share this draft with others.

Interdisciplinary Nature of Science



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Connecting Scientific Knowledge: Integrate concepts across other STEM disciplines (e.g., chemistry, physics) and multiple fields of biology (e.g., cell biology, ecology).	○	○	○	○	○



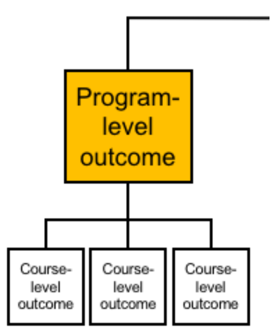
Each of the following course-level outcomes are classified under the **Connecting Scientific Knowledge** program-level outcome.

How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Given a biological problem, identify relevant concepts from other STEM disciplines or fields of biology.	○	○	○	○	○
Build models or explanations of simple biological processes that include concepts from other STEM disciplines or multiple fields of biology.	○	○	○	○	○

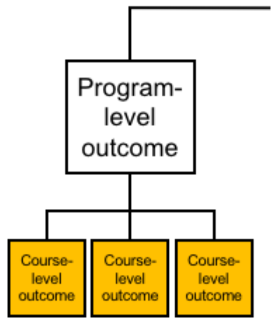
○ Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Interdisciplinary Problem Solving: Consider interdisciplinary solutions to real-world problems.	O	O	O	O	O



Each of the following course-level outcomes are classified under the **Interdisciplinary Problem Solving** program-level outcome.

How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Describe examples of real-world problems that are too complex to be solved by applying biological approaches alone.	O	O	O	O	O
Suggest how collaborators in STEM and non-STEM disciplines could contribute to solutions of real-world problems.	O	O	O	O	O
Be able to explain biological concepts, data, and methods, including their limitations, using language understandable by collaborators in other disciplines.	O	O	O	O	O

O Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.

Interdisciplinary Nature of Science

You have now reviewed all of the program-level and course-level learning outcomes (displayed below) for this core competency.

INTERDISCIPLINARY NATURE OF SCIENCE	
Program-Level Learning Outcomes	**Course-Level Learning Outcomes**
CONNECTING SCIENTIFIC KNOWLEDGE Integrate concepts across other STEM disciplines (e.g., chemistry, physics) and multiple fields of biology (e.g., cell biology, ecology).	Given a biological problem, identify relevant concepts from other STEM disciplines or fields of biology.
	Build models or explanations of simple biological processes that include concepts from other STEM disciplines or multiple fields of biology.
INTERDISCIPLINARY PROBLEM SOLVING Consider interdisciplinary solutions to real-world problems.	Describe examples of real-world problems that are too complex to be solved by applying biological approaches alone.
	Suggest how collaborators in STEM and non-STEM disciplines could contribute to solutions of real-world problems.
	Be able to explain biological concepts, data, and methods, including their limitations, using language understandable by collaborators in other disciplines.

○ Optional: Given this review, please click here if you believe there are essential learning outcomes missing from the Interdisciplinary Nature of Science core competency.

Please share any essential learning outcomes you believe are missing from this core competency.

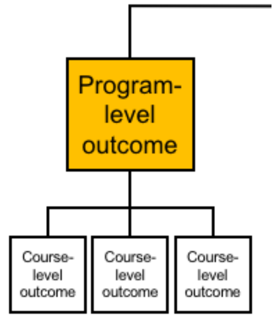
Optional: Please share any other feedback on the **Interdisciplinary Nature of Science** core competency.

Communication & Collaboration

In this portion of the survey, we would like you to rate the importance of learning outcomes for one particular core competency: **Communication & Collaboration.** Please rate the outcomes based on whether they are important to accomplish over the course of a **four-year general biology program**. Additionally, please evaluate the outcomes independently, not relative to one another.

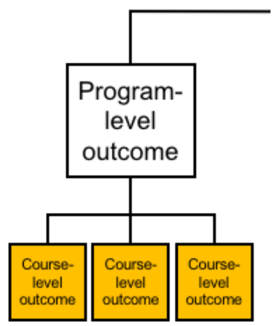
If you would like to see the entire BioSkills Guide for context, click here. Please do not share this draft with others.

Communication & Collaboration



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Communication: Share ideas, data, and findings with others clearly and accurately.	O	O	O	O	O



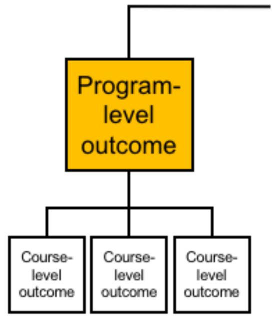
Each of the following course-level outcomes are classified under the **Communication** program-level outcome.

How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Use appropriate language and style to communicate science effectively to targeted audiences (e.g., general public, biology experts, collaborators in other disciplines).	O	O	O	O	O
Use a variety of modes to communicate science (e.g., oral, written, visual).	O	O	O	O	O

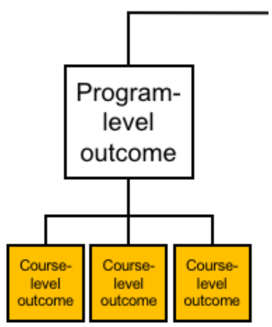
O Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Collaboration: Work productively in teams with people who have diverse backgrounds, skill sets, and perspectives.	○	○	○	○	○



Each of the following course-level outcomes are classified under the **Collaboration** program-level outcome.

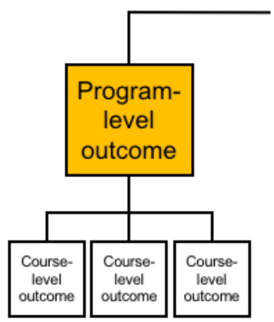
How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Work with teammates to establish and periodically update group plans and expectations (e.g., team goals, project timeline, rules for group interactions, individual and collaborative tasks).	○	○	○	○	○

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Elicit, listen to, and incorporate ideas from teammates with different perspectives and backgrounds.	○	○	○	○	○
Work effectively with teammates to complete projects.	○	○	○	○	○

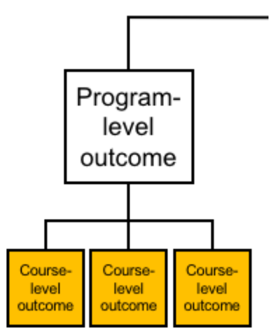
○ Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Collegial Review: Provide and respond to constructive feedback in order to improve individual and team work.	○	○	○	○	○



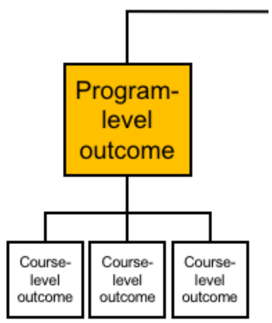
Each of the following course-level outcomes are classified under the **Collegial Review** program-level outcome.

How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Evaluate feedback from others and revise work or behavior appropriately.	O	O	O	O	O
Critique others' work and ideas constructively and respectfully.	O	O	O	O	O

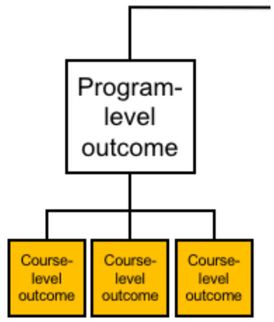
O Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Metacognition: Reflect on your own learning, performance, and achievements.	O	O	O	O	O



Each of the following course-level outcomes are classified under the **Metacognition** program-level outcome.

How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Evaluate your own understanding and skill level.	○	○	○	○	○
Assess personal progress and contributions to your team and generate a plan to change your behavior as needed.	○	○	○	○	○

○ Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.

Communication & Collaboration

You have now reviewed all of the program-level and course-level learning outcomes (displayed below) for this core competency.

COMMUNICATION & COLLABORATION	
Program-Level Learning Outcomes	**Course-Level Learning Outcomes**
COMMUNICATION Share ideas, data, and findings with others clearly and accurately.	Use appropriate language and style to communicate science effectively to targeted audiences (e.g., general public, biology experts, collaborators in other disciplines).
	Use a variety of modes to communicate science (e.g., oral, written, visual).
COLLABORATION Work productively in teams with people who have diverse backgrounds, skill sets, and perspectives.	Work with teammates to establish and periodically update group plans and expectations (e.g., team goals, project timeline, rules for group interactions, individual and collaborative tasks).
	Elicit, listen to, and incorporate ideas from teammates with different perspectives and backgrounds.
	Work effectively with teammates to complete projects.
COLLEGIAL REVIEW Provide and respond to constructive feedback in order to improve individual and team work.	Evaluate feedback from others and revise work or behavior appropriately.
	Critique others' work and ideas constructively and respectfully.
METACOGNITION Reflect on your own learning, performance, and achievements.	Evaluate your own understanding and skill level.
	Assess personal progress and contributions to your team and generate a plan to change your behavior as needed.

○ Optional: Given this review, please click here if you believe there are essential learning outcomes missing from the Communication & Collaboration core competency.

Please share any essential learning outcomes you believe are missing from this core competency.

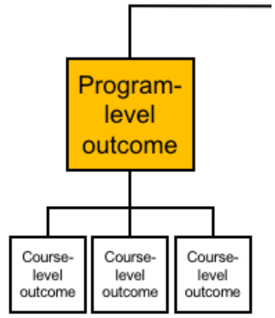
Optional: Please share any other feedback on the **Communication & Collaboration** core competency.

Science & Society

In this portion of the survey, we would like you to rate the importance of learning outcomes for one particular core competency: **Science & Society.** Please rate the outcomes based on whether they are important to accomplish over the course of a **four-year general biology program**. Additionally, please evaluate the outcomes independently, not relative to one another.

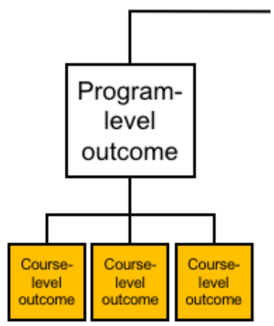
If you would like to see the entire BioSkills Guide for context, click here. Please do not share this draft with others.

Science & Society



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Ethics: Demonstrate the ability to critically analyze ethical issues in the conduct of science.	O	O	O	O	O



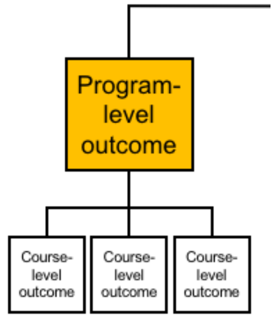
Each of the following course-level outcomes are classified under the **Ethics** program-level outcome.

How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Identify and evaluate ethical considerations (e.g., use of animal or human subjects, conflicts of interest, confirmation bias) in a given research study.	O	O	O	O	O
Critique how ethical controversies in biological research have been and can continue to be addressed by the scientific community.	O	O	O	O	O

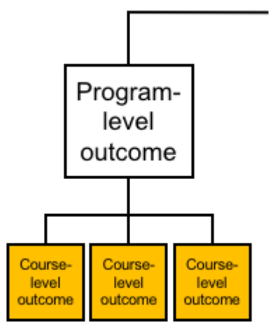
O Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Societal Influences: Consider the potential impacts of outside influences (historical, cultural, political, technological) on how science is practiced.	○	○	○	○	○



Each of the following course-level outcomes are classified under the **Societal Influences** program-level outcome.

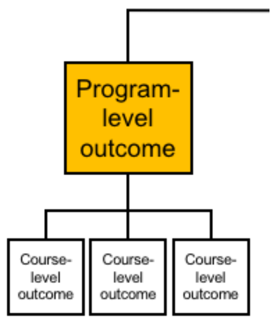
How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Describe examples of how scientists' backgrounds and biases can influence science and how science is enhanced through diversity.	○	○	○	○	○

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Identify and describe how systemic factors (e.g., socioeconomic, political) affect how and by whom science is conducted.	O	O	O	O	O

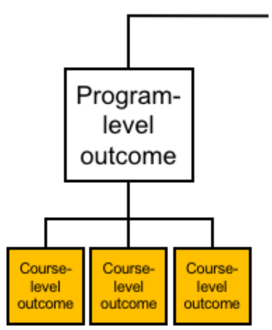
O Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.



How important or unimportant is it for graduating general biology majors to achieve the following **program-level** outcome?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Science's Impact on Society: Apply scientific reasoning in daily life and recognize the impacts of science on a local and global scale.	O	O	O	O	O



Each of the following course-level outcomes are classified under the **Science's Impact on Society** program-level outcome.

How important or unimportant is it for graduating general biology majors to achieve the following **course-level** outcomes?

	Very Unimportant	Unimportant	Neither Important Nor Unimportant	Important	Very Important
Apply evidence-based reasoning and biological knowledge in daily life (e.g., consuming popular media, deciding how to vote).	○	○	○	○	○
Use examples to describe the relevance of science in everyday experiences.	○	○	○	○	○
Identify and describe the broader societal impacts of biological research on different stakeholders.	○	○	○	○	○
Describe the roles scientists have in facilitating public understanding of science.	○	○	○	○	○

○ Click here if you would like to comment on the content or wording of the above outcomes.

Please share any feedback you have about the content or wording of these outcomes.

Science & Society

You have now reviewed all of the program-level and course-level learning outcomes (displayed below) for this core competency.

SCIENCE & SOCIETY	
Program-Level Learning Outcomes	**Course-Level Learning Outcomes**
ETHICS Demonstrate the ability to critically analyze ethical issues in the conduct of science.	Identify and evaluate ethical considerations (e.g., use of animal or human subjects, conflicts of interest, confirmation bias) in a given research study.
	Critique how ethical controversies in biological research have been and can continue to be addressed by the scientific community.
SOCIETAL INFLUENCES Consider the potential impacts of outside influences (historical, cultural, political, technological) on how science is practiced.	Describe examples of how scientists' backgrounds and biases can influence science and how science is enhanced through diversity.
	Identify and describe how systemic factors (e.g., socioeconomic, political) affect how and by whom science is conducted.
SCIENCE'S IMPACT ON SOCIETY Apply scientific reasoning in daily life and recognize the impacts of science on a local and global scale.	Apply evidence-based reasoning and biological knowledge in daily life (e.g., consuming popular media, deciding how to vote).
	Use examples to describe the relevance of science in everyday experiences.
	Identify and describe the broader societal impacts of biological research on different stakeholders.
	Describe the roles scientists have in facilitating public understanding of science.

- Optional: Given this review, please click here if you believe there are essential learning outcomes missing from the Science & Society core competency.

Please share any essential learning outcomes you believe are missing from this core competency.

Optional: Please share any other feedback on the **Science & Society** core competency.

Demographics

Demographic Questions

We ask that you complete the following demographic questions so that we can determine if we have surveyed a representative population. We will not link specific responses with any individual identifying information when sharing the results of this survey.

What is the name of your current institution? (This will be used to gather additional institutional demographic information.)

Which of the following best describes your institution type?

- Associate's Degree-Granting
- Bachelor's Degree-Granting
- Master's Degree-Granting
- Doctoral Degree-Granting
- Other (please specify):

Which of the following best describes your current position?

- Graduate Student
- Postdoc
- Lecturer or Instructor
- Assistant, Associate, or Full Professor
- Staff
- Other (please specify):

In your current position, what is your primary responsibility?

- Teaching
- Research
- Teaching and Research Equally
- Other (please describe briefly)

What is the focus of your current research, if applicable? (please select all that apply)

- ☐ I am not currently engaged in research
- ☐ Molecular/Cellular/Developmental Biology
- ☐ Physiology
- ☐ Ecology/Evolutionary Biology
- ☐ Discipline-Based Education Research
- ☐ ____________ Other (please specify):

What is or was the focus of your graduate training? (please select all that apply)

- ☐ Molecular/Cellular/Developmental Biology
- ☐ Physiology
- ☐ Ecology/Evolutionary Biology
- ☐ Discipline-Based Education Research
- ☐ ____________ Other (please specify):

What is the primary focus of the majority of biology courses that you teach? (please select one)

- ○ Molecular/Cellular/Developmental Biology
- ○ Physiology
- ○ Ecology/Evolutionary Biology
- ○ General Biology
- ○ ____________ Other (please specify):

In an average academic year when you are teaching, how many of your courses are at each of the following academic levels?

- [0] Non-Majors Lower-Level (100-200 level)
- [0] Majors Lower-Level (100-200 level)
- [0] Upper-Level (300-400 level)
- [0] Graduate-Level (500+ level)

How familiar are you with the *Vision and Change* report issued by the AAAS in 2011?

- ○ Extremely Familiar
- ○ Very Familiar
- ○ Somewhat Familiar
- ○ Slightly Familiar
- ○ Not At All Familiar

What is your gender?

- ○ Female
- ○ Male

○ [ ] Other identity (please specify)

Have you previously provided feedback on the BioSkills Guide?

○ Yes
○ No

Would you like to be sent a copy of the final version of the BioSkills Guide once it is ready?

○ Yes
○ No

If you answered yes to the preceding question, please enter your email address.

[ ]

Optional: Please share any final comments you have about this survey or the BioSkills guide in general.

[ ]

Optional: We are looking for more participants! If you have colleagues who would be interested in participating, we would be grateful if you shared this survey link with them:

https://uwbiology.co1.qualtrics.com/jfe/form/SV_d0wvusxksI1cxtb

Alternatively, you can enter their name and email address below, and we will send them an invitation.

[ ]