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Title: 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 STEM careers, biology majors need a range of transferrable skills, yet skill development is often a relatively underdeveloped facet of the undergraduate curriculum. Here, 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 interpreted and implemented by faculty. Over 600 college biology educators representing over 250 institutions, including 73 community colleges, contributed to the development and validation of the guide. Our grassroots approach during the development phase engaged over 200 educators over the course of five iterative rounds of review and revision. We then gathered evidence of the BioSkills Guide's content validity using a national survey of over 400 educators. Across the 77 outcomes in the final draft, rates of respondent support for outcomes were high (73.5% - 99.5%). Our national sample included college biology educators across a range of course levels, subdisciplines of biology, and institution types. We envision the BioSkills Guide supporting a variety of applications in undergraduate biology, including backward design of individual lessons and courses, competency assessment development, curriculum mapping and planning, and resource development for less well-defined competencies.

INTRODUCTION

Undergraduate biology students pursue a wide variety of career paths. Approximately 46% of undergraduates majoring in life sciences-related fields go on to STEM or STEM-related occupations, including research, engineering, management, and healthcare (Landivar, 2013). The over 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; Strada Education Network, 2018; Twenge & Donnelly, 2016), it follows that biology programs should include training in transferrable skills that will help students thrive in their post-college pursuits, in or out of STEM.

Employers across fields routinely rank skills such as collaboration, communication, and problem-solving at the top of the list of desirable employee traits (NACE, 2018; Strauss, 2017), 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 (Camilli & Hira, 2019; Cappelli, 2015), college courses are nonetheless a natural environment for skills development because of the opportunities to practice and receive formative feedback from experts (Hora, 2018).

Numerous national reports have pushed STEM educators to reexamine how skills are integrated into undergraduate STEM coursework (NASEM, 2016; NRC, 2003, 2012b). In biology, these recommendations are crystalized in the 2011 report “Vision and Change in Undergraduate Biology Education: A Call to Action” (AAAS, 2011). The recommendations of Vision and Change emerged from discussions among over 500 stakeholders in undergraduate biology education. To prepare students for modern careers, the report urges biology educators to frame discussions of curricula around five core concepts (i.e. big ideas) and six core competencies (i.e. skills, listed in Table 1).

The Vision and Change curricular framework has been embraced by the larger biology community (AAAS, 2019), but descriptions of the concepts and competencies were left intentionally brief to encourage educators to have ongoing conversations about implementation. Since then, two groups have unpacked the core concepts into more detailed frameworks (Brownell, Freeman, Wenderoth, & Crowe, 2014; Cary & Branchaw, 2017). For competencies, biology education researchers have enumerated a variety of skill subsets, including: process skills (Coil, Wenderoth, Cunningham, & Dirks, 2010), experimentation (Pelaez et al., 2017), scientific literacy (Gormally, Brickman, & Lutz, 2012), responsible conduct of research (Diaz-Martinez et al., 2019), quantitative reasoning (Durán & Marshall, 2018; Stanhope et al., 2017), bioinformatics (Wilson Sayres et al., 2018), data science (Kjelvik & Schultheis, 2019), data communication (Angra & Gardner, 2016), modeling (Diaz Eaton et al., 2019; Quillin & Thomas, 2015), the interdisciplinary nature of science (Tripp & Shortlidge, 2019), and scientific writing (Timmerman, Strickland, Johnson, & Payne, 2011). Efforts to define general or STEM-wide education goals for college graduates can also inform how we teach competencies in biology, such as the Association of American College & University VALUE rubrics (Rhodes, 2010) and more targeted work on information literacy (Association of College and Research Libraries, 2015), communication (Mercer-Mapstone & Kuchel, 2017), and process skills (Cole, Lantz, Ruder, Reynders, &

Stanford, 2018; Understanding Science, 2016). 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.

So, with the overarching goal of improving biology undergraduates' acquisition of skills for careers and life, we set out to expand the six Vision and Change core competencies into measurable learning outcomes that describe what a general biology major should be able to *do* by the time they graduate. We call this collection of learning outcomes the "BioSkills Guide". 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.

We describe here the iterative, mixed-methods approach we used to develop and establish content validity of the BioSkills Guide. Here, evidence of validity was collected via a national survey, intended to determine whether we had reached sufficient consensus among college biology educators (similar to the approach taken by Brownell, Freeman, et al., 2014; and Cary & Branchaw, 2017). The final draft of the BioSkills Guide contains 77 measurable learning outcomes (20 program-level and 57 course-level) that elaborate the six Vision and Change core competencies. Both the BioSkills Guide and an "expanded BioSkills Guide", which contains illustrative examples of skill-building activities intended to support student mastery of the learning outcomes, are available in Supplemental Materials. 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 and an evaluative validation phase (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 round tables (Table 2). During the validation phase we used a web survey to measure support for the final draft among the broader biology education community. This study was approved by the University of Washington, Human Subjects Division as exempt (STUDY00001746).

Development Phase

The initial draft of the BioSkills Guide was developed at a large, public research university in the Northwest as part of routine departmental curriculum 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 round table at a national biology education conference (additional details in Supplemental Materials).

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 from our advisory board in writing and via a virtual meeting. To review Version II of the guide, we collected written feedback on outcome importance, clarity, and completeness at a workshop of biology faculty, postdocs, and graduate students. The final three rounds were larger in scale, and each included surveys to gather feedback on outcome importance, ease of understanding, completeness, and categorization from at least 21 college biology educators (5-19 per learning outcome per round) (Table 2, Supplemental Table 4). We recruited respondents at regional and national biology education meetings and through regional biology education networks. We gathered additional input on Version III-V drafts using four workshops, one round table, and 14 one-on-one interviews (additional details in Supplemental Materials).

At the end of each round of review, we compiled and summarized all relevant data (e.g. workshop, interview, round table, survey) from that round into a single document to inform revisions. This document was then reviewed by committee (two authors, AWC and AJC, for Versions I-III revisions; three authors, AWC, AJC and JCH, for Versions IV-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 low support despite revisions to improve ease of reading or possible concerns about challenge level. Low support was inferred from low survey ratings (ranging from 50-88% percent support, with an average of 73.5%) combined with qualitative feedback indicating the outcome was too specialized or at too high of a challenge level for an undergraduate general biology major or that the outcome could not be readily assessed. In general, we identified problems in the drafts by looking at outcomes that had low support or low consensus (e.g., a mixture of low and high ratings). We then used qualitative feedback from survey comments, workshops, round tables and interviews to inform revisions.

Validation Phase

Before proceeding with the national survey, we first conducted a "pilot" validation on a smaller pool of biology educators (n=20). After reviewing the results, we made a final revision to a single outcome, and then progressed to the national validation survey (additional details in Supplemental Materials).

For national validation, we invited participation through direct emails and numerous listservs: Society for Advancement of Biology Education Research (SABER), Partnership for Undergraduate Life Sciences Education (PULSE) 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 this snowball approach and the expected overlap of many of these lists, it is not possible to estimate the total number of people who were invited to participate. A total of 397 people completed enough of the survey to be retained for analysis (i.e. they completed the majority of the outcomes for at least one competency), and 350 completed all assigned questions. We combined pilot and national validation survey data (n=417 total, 211-237 per outcome) for the survey data analysis described below.

Survey Design

We employed five surveys over the course of this project (three in the development phase and two in the validation phase, see Table 2). Surveys were designed and administered following best practices in survey design and the principles of social exchange theory (Dillman, Smyth, & Christian, 2014). In order to participate in any of the surveys, respondents must have served as instructor-of-record of a college-level biology course. For development phase surveys, respondents rated each learning outcome on bipolar 5-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 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 entire questionnaires for Version V review and national validation can be found in Supplemental Materials.

Survey Data Analysis

We calculated and visualized descriptive statistics of survey responses and respondent demographics in R version 3.5.1 (R Core Team, 2018) using the tidyverse, ggmap, maps, ggthemes, ggpubr, and wesanderson packages (Arnold, 2019; Kahle & Wickham, 2013; Kassambara, 2018; Ram & Wickham, 2018; Wickham, 2016). 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 calculated the percent of respondents who ‘Supported’ the outcome or found the outcome easy to understand as the percent of respondents who selected one of the two positive responses (‘Very Important’/’Important’ or ‘Very Easy’/’Easy’, respectively) out of all respondents who reviewed that outcome. We also calculated the percent of respondents who indicated that the outcome was accurately categorized within its competency or program-level learning outcome (not shown). We read and summarized the open-ended comments to inform revisions (during development phase) or to summarize suggestions of missing outcomes (during validation phase). We summarized responses to demographic questions by calculating the frequency and percent of respondents who selected different responses for each question. For all participants, we determined the Carnegie classification of their institution type, minority-serving institution status, and geographic location by matching their institution name with the 2015 Carnegie dataset (Indiana University Center for Postsecondary Research, 2016). We then mapped participant locations using their institution's city and state GPS coordinates, obtained via the Google API (Kahle & Wickham, 2013).

Statistical Models of Learning Outcome Ratings

We used cross-classified random effects binary logistic regression models to predict the logit of the probability that a particular respondent will support a particular learning outcome (Raudenbush & Bryk, 2002). The binary dependent variable 'Support' was coded as described above. We investigated six categorical independent variables: (1) the competency associated with the learning outcome (see 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 discipline-based education research (DBER), (4) is currently engaged in 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). After cleaning (described further in Supplemental Materials), our analytic dataset contained responses from 346 out of 417 initial respondents, comprising 15,321 importance ratings across 77 learning outcomes.

For each model, we calculated the proportion of variance in the dependent variable that was due to random effects. The significance of categorical independent variables with two levels (e.g., experience with DBER) was assessed using the z-statistic associated with that variable's regression coefficient. We tested the joint significance of categorical independent variables with three or more levels (e.g., institution type) using the Wald Chi-squared statistic. We used predicted probabilities for interpretation of interactions, with non-overlapping 95% confidence intervals interpreted as statistically significant differences. We additionally calculated the Akaike information criterion (AIC) and performed the likelihood ratio (LR) test for all models. Additional details on data cleaning and statistical modeling approach can be found in Supplemental Materials.

Aligning Examples with Learning Outcomes

During initial drafting, several faculty working groups 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 re-aligning examples in keeping with outcome revisions. Example additions drew from conversations with biology educators throughout the development phase. Two authors (AWC and AJC), 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 JCH) 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

Soliciting and incorporating feedback from participants with diverse professional expertise in undergraduate biology education was essential to ensure the BioSkills Guide was useful on a broad scale. The initial draft of the guide was crafted by faculty and expanded to include input from 51 unique participants from at least 8 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 under-sampled groups (Figure 3C, Supplemental Tables 2-3).

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 round table 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 effective at gauging faculty perceptions of competencies. The survey therefore enabled us to quantitatively assess areas of strength and weakness within drafts quickly and across a broader population. Using both quantitative and qualitative feedback, every outcome was revised for 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 skill itself). We kept this structure to better support backward design (Wiggins & McTighe, 1998). Second, the guide has a two-tiered structure: each core competency contains 2-6 *program-level* learning outcomes, and each program-level learning outcome contains 2-6 *course-level* learning outcomes (this organization is represented 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* (four-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 curricula (AAAS, 2011). A similar approach was taken during development of the BioCore Guide for the core concepts, based on their finding that the vast majority of colleges offer a general biology degree (Brownell, Freeman, et al., 2014). 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 use of models was revised to “describe why biologists use simplified representations…”).

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. However, throughout the development of this resource through workshops, round tables, and informal conversations we found that the term "skill" was more immediately recognizable (to non-education experts) and less frequently unintentionally swapped with the term "concept" (especially when talking about "concepts and competencies"). We thus decided to name the resource the "BioSkills Guide".

National Validation of the BioSkills Guide

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 Version V review. Specifically, the lowest rated outcome from the Version V survey had 72.7% support (Figure 2, Supplemental Table 4). The previous minimums were 16.7% and 50% for Versions III and IV surveys, respectively. Furthermore, all outcomes were rated 'Easy' or 'Very Easy' to understand by the majority of respondents (Supplemental Figure 2, 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 3, Supplemental Table 6), including respondents representing a range of community colleges and minority-serving institutions (Figure 3C, 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, 7). We additionally inferred "Support" for each outcome by calculating the percent of respondents who reviewed it who rated it as 'Important' or 'Very Important'. Support ranged from 74.3-99.6%, with a mean of 91.9% (Figure 2, 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 them rate the outcomes, we asked respondents to describe any essential learning outcomes that were missing from the guide (summarized in Supplemental Table 8).

Interpreting Predictive Models of Learning Outcome Ratings

We were interested in whether respondents with certain demographics differed in their support of learning outcomes from different competencies, so we examined the interaction of learning outcome competency and each of five respondent demographic variables. Specifically, we hypothesized that differences in respondent training (i.e. experience in DBER, experience in ecology/evolution, familiarity with Vision and Change) or professional culture (i.e. institution type, current engagement in disciplinary biology research) would affect their perceptions of the usefulness or feasibility of different types of skills (i.e. outcomes in different competencies). We estimated multi-level generalized linear models to ask if the variation in outcome support could be explained, in part, by differences among learning outcomes in different competencies, differences among respondents with different demographics, and/or interactions of particular types of respondents with particular competencies.

By examining a model containing just random effects for learning outcome and respondent, we found that 16% of the variance in learning outcome support was due to the learning outcomes themselves (e.g., wording, content; Model 0, Supplemental Table 9). By adding competency to the model (Model 1), this variance dropped to 11% of total variance, a reduction of 36%. Thus, the competency in which an outcome is nested explains a considerable amount of the variance in support among outcomes. However, comparing predicted probabilities of support based on competency, support was quite high across the board (ranging from 94.2% to 99.1% support) even when significant differences existed (Figure 4A). For example, support for Modeling outcomes (94.4%) was significantly lower than support for Process of Science outcomes (98.6%) and Quantitative Reasoning outcomes (99.1%), but both differences were less than 5 percentage points. We concluded that although competency explains a significant percent of the observed variation, the variation itself is small, so this finding may not be of practical importance.

When interpreting models including interactions of competency with each of the five respondent demographic variables (Models 12-16), we found that respondents' support of outcomes within each competency differed significantly based on their institution type ($p<.01$; Model 12), experience in DBER ($p<.001$; Model 13), and current engagement in biology research ($p<.01$; Model 14) (Supplemental Tables 10-14). By examining the predicted probabilities, however, we again found that despite these significant interactions, the magnitudes of differences in support for each combination of competency and respondent demographic were small (Figure 4B). For example, respondents who have experience with DBER exhibit similarly high support for Modeling (97.3%), Quantitative Reasoning (98.3%), Process of Science (98.7%), and Communication and Collaboration (98.0%) outcomes. In contrast, respondents who do not have experience with DBER are statistically significantly less likely to support Modeling outcomes (92.8%) than Quantitative Reasoning (98.8%), Process of Science (99.2%), or Communication and Collaboration (98.6%) outcomes ($p<.05$). However, the average predicted outcome support rates were uniformly above 90% for all respondent groups and competencies, and the greatest differences observed was 6.4%, thus we do not believe the observed differences are meaningful in practice.

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 Materials).

Process of Science

The Process of Science outcomes are presented in a particular order; however, in practice, they are applied in a non-linear fashion. For example, scientific thinking and information literacy include foundational scientific skills 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 authentic 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 skills; however, many of these skills can also be learned by engaging with scientific literature and existing datasets. 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 coursework. In summary, the outcomes presented here can be included in nearly any biology course to support the development of strong quantitative skills.

Modeling

Models are representations of reality that allow scientists to simplify complex and dynamic biological structures, mechanisms, and systems. Biologists routinely use models qualitatively 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 their own applications, strengths, and limitations which must be evaluated by the user. The Modeling outcomes can be practiced using an array of different model types: mathematical (e.g., equations and charts), computational (e.g., simulations and animations), conceptual (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 multi-faceted 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), in non-STEM fields (e.g., humanities, social sciences), as well as input from those outside of 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 skills needed to communicate with diverse groups.

Communication & Collaboration

Communication and collaboration are essential components of the scientific process. These outcomes include skills 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 training in this competency to thoughtfully and effectively work and communicate with others.

Science & 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 Materials). 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 over 600 college biology educators, we have developed and gathered evidence of 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 support suggests that we successfully recruited and applied input from a range of educators during the development phase. As the broadest skill-focused learning outcome framework for undergraduate biology education to date, the BioSkills Guide provides insight on the array of competencies that biology educators believe all biology majors should acquire during college. We believe it will be helpful in supporting 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. While we detected several statistically significant interactions of competency with particular respondent demographics, we feel that no differences were large enough to be meaningful on a practical level. In other words, differences in the perceived importance of particular outcomes by less than 10% of individuals among various educator populations are unlikely to sway departmental curricular decisions.

The results of our statistical analyses suggest that (a) there was not sufficient variation in our dataset to detect substantial differences, (b) educators from different backgrounds (at least those investigated in this study) think similarly about competencies, or (c) a combination of these two. In support of (a), 51 out of 77 outcomes had greater than 90% support, likely due to our intentional study design of iteratively revising outcomes to reach consensus. Additionally, it is reasonable that college biology educators are more culturally alike than different given similarities in training (Grunspan, Kline, & Brownell, 2018). Thus, we believe the most likely explanation for the small observed differences is a combination of study design and educator similarities.

We could not help but note that where demographic by competency interactions existed, trends, albeit small, consistently pointed toward differences in support for the competency Modeling (Figure 4B). Further work is needed to determine if this trend is supported, but we offer a hypothesis based on observations made over the course of this project: 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 personal 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 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”) that we believe is consistent with the learning outcomes presented in the BioSkills Guide. Although numerous modeling practices have been developed and evaluated in the context of undergraduate biology courses (for example, see Bergan-Roller, Galt, Chizinski, Helikar, & Dauer, 2018; Bierema, Schwarz, & Stoltzfus, 2017; Dauer, Momsen, Speth, Makohon-Moore, & Long, 2013; Hester et al., 2018; Luckie, Harrison, & Ebert-May, 2011; Zagallo, Meddleton, & Bolger, 2016), ongoing efforts should continue to expand awareness of the value, relevance, and possible implementations of modeling in college biology.

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 practitioners 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 authentic 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. Additional insight into this question was gained through qualitative approaches (interviews and a round table). Roundtable and interview participants reiterated that the skills developed during authentic 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 skill sets. Furthermore, numerous participants indicated the outcome was important for supporting continued efforts to systematically include research in undergraduate curricula (also see, Cooper, Soneral, & Brownell, 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 & 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 skill for doing science (NRC, 2012a; Passmore, Stewart, & Cartier, 2009; Svoboda & Passmore, 2013). Proponents of incorporating drawing into the undergraduate biology curriculum have made similar arguments to expand this competency (Quillin & Thomas, 2015). Moreover, 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), and evolution (Speth et al., 2014). 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, to the exclusion of other types of models. 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 can be used 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., Gouvea, Sawtelle, Geller, & Turpen, 2013; NAE & NRC, 2014; Project Kaleidoscope, 2011), and discussions at two round tables 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 & Shortlidge, 2019). 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 & Collaboration

The faculty team who composed the initial draft of the BioSkills Guide expanded the Communication & 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, Price, & Steinman, 2013; Mercer-Mapstone & 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, since 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 of outcomes. First of all, most authentic scientific tasks (e.g., presenting data, building models of interdisciplinary 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, Freeman, et al., 2014; Cary & 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 skill of modeling but also conceptual understandings of systems and the transformation of matter and energy (Bergan-Roller et al., 2018; Dauer et al., 2013). 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 (Cary & Branchaw, 2017; Dirks & Knight, 2016).

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 skill and how students develop these skills over time. To assist in this work, there are a number of resources focusing on particular competencies (for example, see Angra & Gardner, 2016; Diaz-Martinez et al., 2019; Diaz Eaton et al., 2019; Pelaez et al., 2017; Quillin & Thomas, 2015; Tripp & Shortlidge, 2019; Wilson Sayres et al., 2018), all of which describe specific competencies in further detail than is contained in the BioSkills Guide. Additionally, work in K-12 education, and more recently higher education, developing learning progressions could guide future investigations of competency scaffolding (Scott, Wenderoth, & Doherty, 2019).

Given that over 50% of STEM majors attend a community college during their undergraduate career (NSF NCSES, 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 3C, 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 *four-year* degree, we were able to develop widely relevant outcomes by identifying connections between each competency and current teaching practices of two-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 (Corwin, Kiser, LoRe, Miller, & Aikens, 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 datasets" rather than "describe how biologists answer research questions using… large datasets…") 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 educator perceptions will evolve in response to the changing nature of biology and the scientific job market.

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 four-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” 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 Materials) can be used for planning new lessons and for recognizing skills 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 skills development (Marbach-Ad, Hunt, & Thompson, 2019) and encourage them to align their time and effort with faculty priorities.

The BioSkills learning outcomes may be especially relevant for the design of high-impact practices, such as course-based undergraduate research experiences, service learning, and internships (Auchincloss et al., 2014; Brownell & Kloser, 2015; Kuh, 2008), which already emphasize skill building, 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 & 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 curriculum review. For some competencies, such as Process of Science, a number of high-quality assessments have been developed (for example, (Brownell, Wenderoth, et al., 2014; Dasgupta, Anderson, & Pelaez, 2014; Deane, Nomme, Jeffery, Pollock, & Birol, 2016; Gormally et al., 2012; Sirum & Humburg, 2011; Timmerman et al., 2011); for a general discussion of assessing CUREs see (Shortlidge & 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. As an analogy, 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 or instructor, the end goal remains the same: better integration of competency teaching in undergraduate biology education. With more intentional and effective skills training, biology graduates will be more fully prepared for their next steps, whether those steps are in biology, STEM more generally, or outside of STEM completely. The six core competencies encompass essential skills needed in competitive careers and also in the daily life of a scientifically literate citizen. We have developed and gathered 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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FIGURE LEGENDS

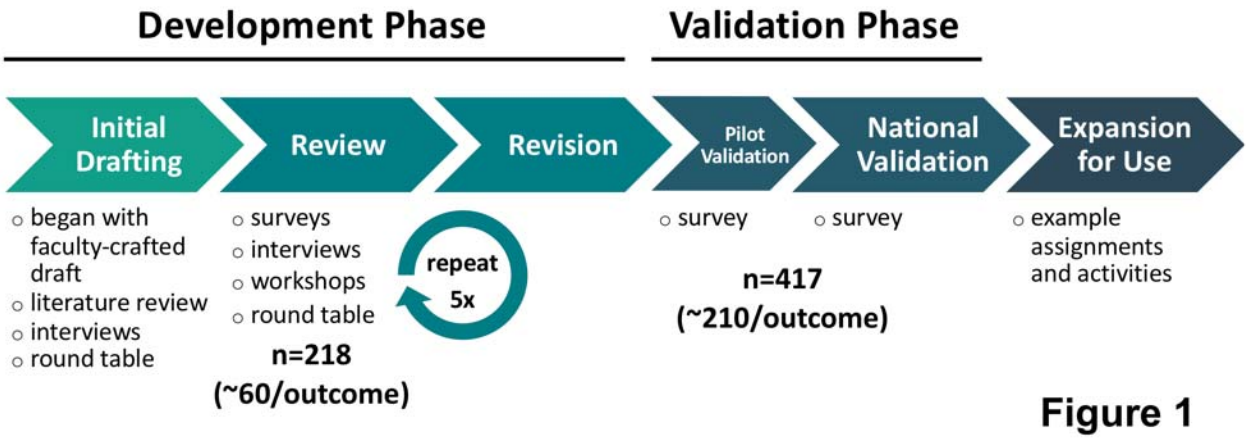

Figure 1. BioSkills Guide methods overview.
Initial drafting included all work to generate BioSkills Guide Version I. Five rounds of review and revision were carried out on Versions I-V. Pilot validation evaluated Version VI. National validation evaluated final version of BioSkills Guide.

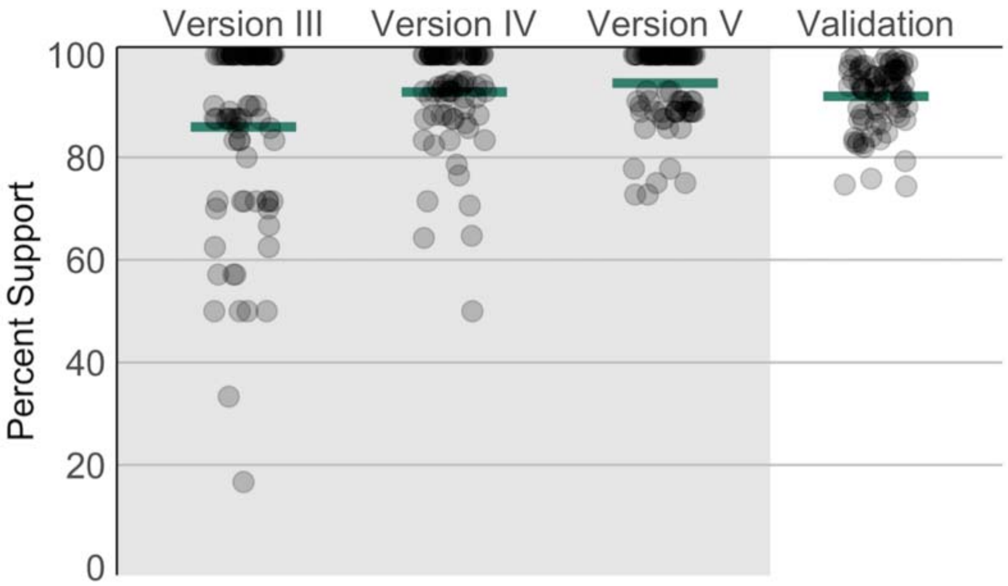

Figure 2

Figure 2. 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. Each circle represents a single learning outcome. Horizontal lines indicate means across all outcomes from that survey. Points are jittered to reveal distribution. This data is represented in tabular form in Table 3.

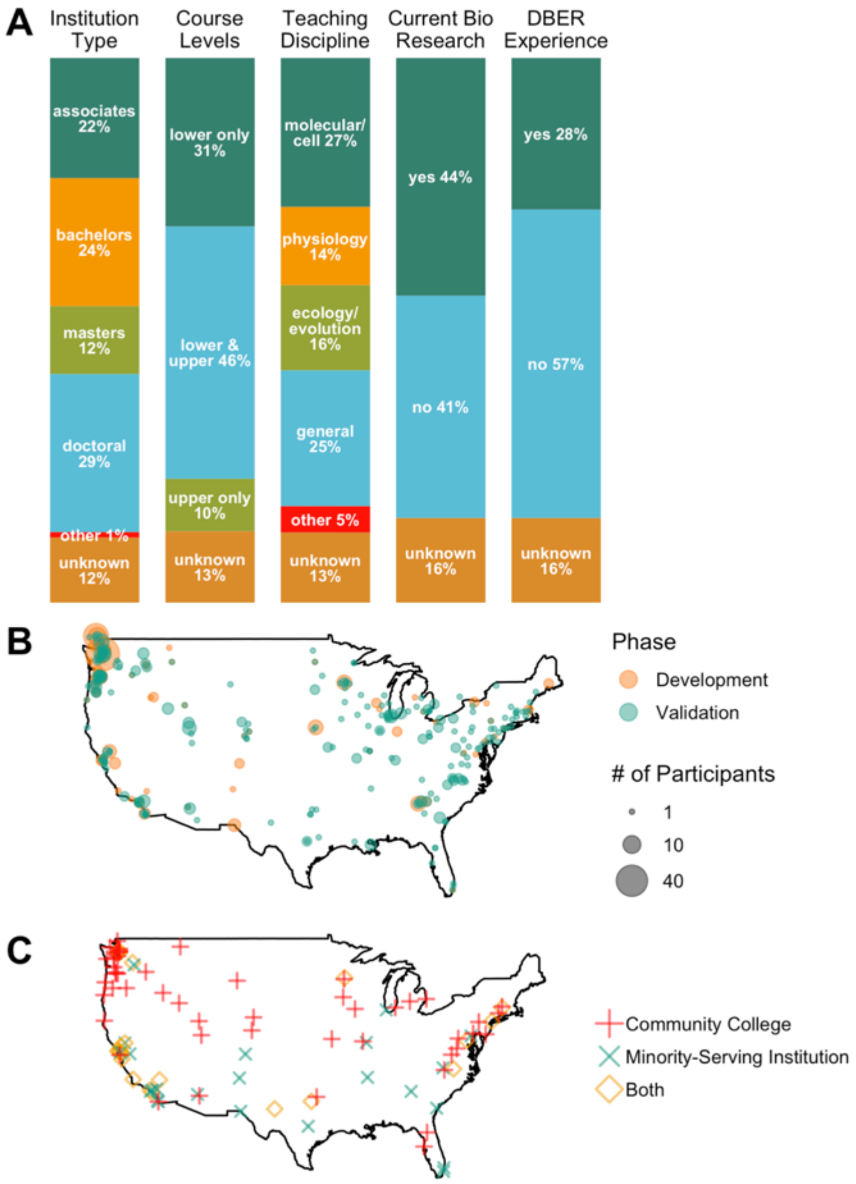

Figure 3

Figure 3. 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 Discipline-Based Education Research (DBER) was inferred from fields of current research and graduate training. **(B) Geographic distribution of participants**. 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 US and British Columbia are shown. Additional participants came from Alaska, Alberta, Hawaii, India, Puerto Rico, and Scotland (8 institutions). **(C) Geographic distribution of participants from community colleges and minority-serving institutions.** 73 unique community colleges and 49 unique minority-serving institutions (46 shown, not shown: MSIs in Alaska and Puerto Rico). 23 institutions were classified as both community colleges and minority-serving institutions.

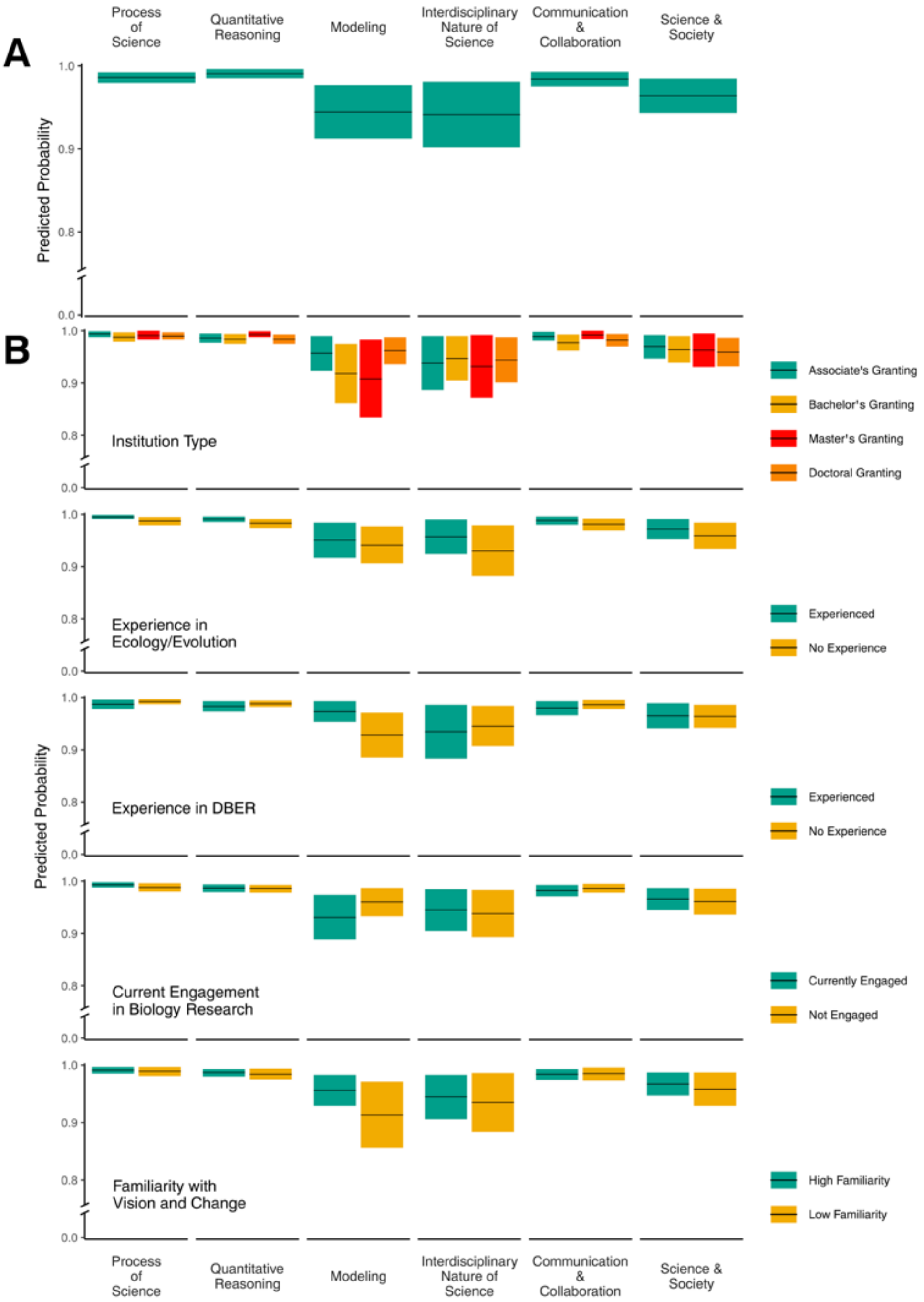

Figure 4

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 or **(B)** respondents in various demographic groups. Predicted probabilities were calculated using multi-level, generalized linear models (see Methods and Supplemental Materials for details). Colored rectangles represent 95% confidence intervals. Note that y-axis has been truncated.

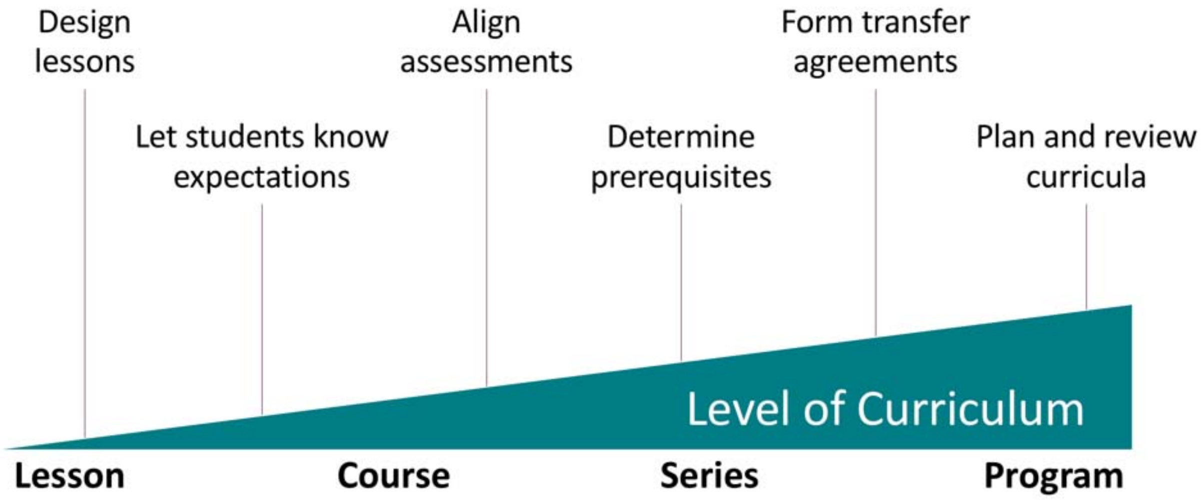

Figure 5

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

Table 1. Core Competencies.

[a] Adapted from Vision and Change (AAAS, 2011).

Core Competencies [a]
1. Process of Science
2. Quantitative Reasoning
3. Modeling
4. Interdisciplinary Nature of Science
5. Communication & Collaboration
6. Science & Society

Table 2. Unique participants and institutions during BioSkills Guide development and validation.

[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 [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).

Phase	Round	Mode of Review	Number of Unique Participants	Number of Unique Institutions
Development	Initial Drafting	Faculty working groups + department round tables	20	1
		Literature review		
		Interviews with competency experts	11	4
		Round table	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
		Round table	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]	***87*** [c]
Validation	Pilot	Survey 4	20	11[b]
	National	Survey 5	397	220[b]
	Validation, Combined		***417***	***225*** [c]
All, Combined			***634*** [c]	***271*** [c]

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

[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. This data is visually represented in Figure 2.

[b] One outcome (out of 81 total) was mistakenly omitted from the Version III survey.

		Learning Outcome Support Levels [a]				
Phase	**Round**	>90%	80-90%	70-80%	<70%	*Total*
Development	Version III	38	20	8	14	*80*[b]
	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	**51**	**22**	**4**	**0**	***77***

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

[a] All outcomes 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'.

Competency	Outcome [a]	Percent Support [b]	Mean [c]	Max [c]	Min [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 & 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.	75.5	4	5	1
Interdisc. 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
Interdisc. Nature of Science	Describe examples of real-world problems that are tc complex to be solved by applying biological approach alone.	74	4	5	1