It's in the Syllabus: What Syllabi Tell us about Introductory Biology Courses

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ABSTRACT
Biology education researchers seek to improve biology education, particularly at the introductory level, yet there is little documentation about what is actually happening in introductory biology. To characterize the landscape of learning expectations for introductory biology, we analyzed course-level learning objectives (n = 1108) and course schedules from 188 nonmajor, mixed major, and major introductory biology syllabi. We analyzed syllabi collected from a diverse range of U.S. institution types to uncover insights about instructional design decisions for introductory biology. Our analysis revealed two distinct nonmajor course types: content and issues-based courses. We found syllabi tend to focus on low-cognitive skills and factual content that is essentially a march in step with a typical textbook table of contents, rarely including core competencies or socioscientific issues (SSIs) other than in nonscience major issues-based courses. Our work contributes more evidence that faculty struggle to write course-level learning objectives. Our findings suggest that there is much work to do if Vision and Change are to become more than simply a vision–to be actualized as change–including developing CLOs for introductory biology as a first step toward creating actionable instructional change.

INTRODUCTION
"It's in the syllabus:" It's a phrase faculty used so frequently that it has become a meme. But what exactly *is* in the syllabus? According to a nationwide survey of 1000 college syllabi (Doolittle and Siudzinski, 2010) and another survey of 100 general education college courses (Eberly *et al.*, 2001), common syllabus ingredients include contact details, course topics, grading, and required texts. In introductory college biology, syllabi provide a useful tool to understand the content, skills, and socioscientific issues (SSIs; i.e., ethics, climate change, genetic testing), faculty are teaching biology majors and nonbiology majors. This is critical because there has been a consistent effort to improve the instruction of major introductory biology courses over the past 20 years.

Vision and Change (AAAS, 2011) was a particularly transformative event in life sciences education. Vision and Change provided a unifying framework of essential concepts and competency skills to set the stage for programmatic level learning in major introductory biology courses. Vision and Change offered faculty a way beyond "covering all the content" through this set of concepts and competency skills. This was the first step toward a unified, comprehensive course design for biology. BioCore Guide (Brownell *et al.*, 2014), BioSkills Guide (Clemmons *et al.*, 2020) and rubrics designed by Partnerships for Undergraduate Life Science Education (PULSE) supported putting this unifying framework into practice at the programmatic level (Dolan, 2012). However, there is no requirement that institutions of higher education must adopt or use these frameworks in their biology programs. In fact, recent work by

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Clark and Hsu (2023) indicates that at the programmatic level, many biology programs may be failing to use program learning objectives (PLOs) effectively to align with the tenets described in Vision and Change. More than half of the PLOs described low-order cognitive skills (LOCS) despite the Vision and Change charge to promote critical thinking and higher-order cognitive skills (HOCS; Clark and Hsu, 2023). What this means for course-level learning–and for nonmajor biology–remains unclear, because there is no equivalent consensus for general education courses for nonmajors. Consequently, understanding what is currently happening at the course level is important for future efforts for systemic curricular transformation–particularly at the introductory level for both nonmajor and major courses.

It is critical that we understand *what* introductory biology faculty are teaching major and nonmajor biology students at the course level and at the broader programmatic level. We hereby use nonmajor to mean nonbiology major undergraduates fulfilling a general education requirement. Orr *et al.* (2022) recently developed an evidence-based best practices guide to help faculty write learning objectives (LOs). They defined LOs as "declarative statements that identify what students are expected to know and do" (p. 1). Orr *et al.* (2022) distinguished between types of LOs based on their scope and context. For example, course-level learning objectives (CLOs) were identified as broad, course-specific and student-centered objectives. CLOs are one important aspect of syllabi that signal faculty intentions for instruction. In fact, CLOs represent the first step of the backward design approach (Wiggins & McTighe, 2005). Various tools help faculty write more effective learning outcomes. For example, Crowe *at el.* (2008) developed the Blooming Biology Tool to help faculty write higher-order cognitive learning outcomes. Yet, faculty continue to struggle to write effective CLOs that are testable, aligned with instructional LOs and consistent with Vision and Change (Momsen *et al.*, 2010; Clemmons *et al.*, 2020; Heil *et al.*, 2023). A recent analysis of CLOs from leading universities in the U.S. reported that nearly 90% of CLOs were poorly written, and 40% contained verbs or phrases like appreciate, consider, reflect, or observe that were not measurable (Schoepp, 2019). Further, instructional LOs from nonmajor biology courses rarely were aligned with a competency skill, were more likely to be lower-level (i.e., remember and understand), and were rarely tied to a socioscientific issue (Heil *et al.*, 2023). These findings were in stark contrast to recent reform efforts that emphasize incorporating SSIs as a lens for learning and infusing competency skill development in college biology instruction (AAAS, 2011; Rowe *et al.*, 2015; Gormally and Heil, 2022).

What exactly is in the syllabus? Are faculty getting any closer to articulating high-quality CLOs to achieve the goals of Vision and Change? We used course schedules and CLOs on course syllabi to help us characterize *what* and *how* faculty were teaching in introductory biology, focusing on: 1) characterizing the current state of CLOs, and 2) uncovering time spent on core concepts, SSIs and Vision and Change core competencies. We compared findings across nonmajor, mixed major, and major courses, noting similarities and differences between course types. To understand what we teach in introductory biology, we analyzed syllabi from nonmajor, mixed major, and major introductory biology courses to address the following research questions:

1. What core concepts – as outlined in popular introductory biology textbooks – and Vision and Change competencies do instructors state they teach on their introductory biology course syllabi, and how does it differ between nonmajor, mixed major, and major courses?
2. What SSIs do instructors prioritize on their introductory biology course syllabi and how does it differ between nonmajor, mixed major, and major courses?
3. What cognitive level, competencies and technical mistakes are most prevalent in introductory biology CLOs and how does it differ between nonmajor, mixed major, and major courses?

METHODS

Data Collection

To characterize the current state of instruction in introductory biology courses, we collected and characterized syllabi from nonmajor, mixed major, and major courses from a broad sample of institutions of higher education from the U.S. (the study was approved by I.R.B.). We distinguished between Carnegie classification (Table 1). We collected syllabi from 2-y institutions (nonmajor = 19%, mixed-major = 20%, major = 24%), baccalaureate colleges (nonmajor = 10%, mixed-major = 12%, major = 13%), master's colleges and universities (nonmajor = 21%, mixed-major = 20%, major = 12%), and doctoral universities (nonmajor = 50%, mixed-major = 48%, major = 50%). We compared the demographics of our sample to the percentage of students enrolled in institutions of higher education (National Center for Education Statistics (NCES), 2017). This comparison revealed our sample to slightly underrepresent 2-y institutions and slightly overrepresent doctoral universities. We discuss the limitations of data collection in our Discussion. Our study was conducted during the height of the COVID-19 global pandemic. Similar to other studies during this time, we faced major challenges in recruiting participants to share their introductory biology syllabi. In particular, we experienced a low response rate among instructors who taught nonmajor courses, which led us to conduct a secondary search to address issues of underrepresentation in our sample.

Nonmajor Courses. We initially collected 27 syllabi from instructors teaching nonmajor biology courses from a survey distributed by Howard Hughes Medical Institute (HHMI) BioInteractive. Specifically, participants were recruited from the BioInteractive Higher Ed Newsletter Subscribers, the PULSE community, the Society for the Advancement of Biology Education Research, and the American Society for Cell Biology Education Group; interested individuals were encouraged to share the survey. The nonmajor syllabi collected in the initial HHMI survey overrepresented: 1) Master's and Baccalaureate colleges, and 2) institutions from the Northwest and Northeast U.S. Therefore, we collected an additional 42 nonmajor syllabi through a more targeted approach that strategically identified institutions (doctoral and 2-y) and regions (i.e., the Midwest, Southeast) through an internet search that were underrepresented in our original sample. Using this approach, we identified faculty from department websites who taught nonmajor courses from regions/institutions underrepresented in our initial sample. We then emailed these faculty to retrieve their syllabus for the course. In some cases, the faculty member was no

TABLE 1. Major, mixed major, and nonmajor biology syllabi were collected from a range of institution types

Carnegie classification	Nonmajor	Mixed majors	Majors	% students enrolled in US (NCES, 2017)
2-y Institution	**19%**	**20%**	**24%**	**30%**
Community college	19%	20%	24%	
Baccalaureate Colleges	**10%**	**12%**	**13%**	**14%**
Arts & Science focus	7%	12%	10%	
Diverse fields	3%	0%	3%	
Master's Colleges and Universities	**21%**	**20%**	**12%**	**22%**
Larger programs	13.5%	14%	7.5%	
Medium programs	4.5%	3%	4.5%	
Smaller programs	3%	3%	0%	
Doctoral universities	**50%**	**48%**	**50%**	**34%**
Very high research activity	43%	30%	47%	
High research activity	7%	10%	1.5%	
Doctoral/Professional University	0%	8%	1.5%	

longer teaching the course but offered the name and email address of the instructor who was teaching nonmajor courses. In the case of some 2-y colleges, we were also able to download syllabi for the courses directly through the campus syllabus systems. If no course list was available, we emailed an undergraduate coordinator for more information.

Mixed Major Courses. We collected 53 syllabi from instructors teaching mixed major courses from a survey distributed by HHMI Biointeractive. Instructors teaching these courses indicated a combination of biology majors and nonmajors in their courses, although did not specify the breakdown. Mixed major courses satisfied requirements for biology majors and general education requirements for nonmajors. To our knowledge, there is no literature that parses differences between the mixed major and its nonmajor and major courses counterparts. Therefore, we analyzed this course independently as its own course type because it serves both nonmajors and majors. Mixed major courses typically focused on either first-semester ($n = 40$) or second-semester introductory biology courses ($n = 13$). As a result, we analyzed mixed major first-semester and second-semester syllabi separately, recognizing the low sample size for second-semester mixed major syllabi.

Major Courses. We collected 66 syllabi from instructors teaching major biology courses using a survey distributed by HHMI BioInteractive. In the initial call, we collected 40 syllabi from first-semester introductory biology (i.e., BIO 1) and 16 syllabi from second-semester introductory biology (i.e., BIO 2). An additional 10 s-semester syllabi were collected via a second survey sent by HHMI to faculty who submitted a first-semester syllabus during the initial call. These additional 10 syllabi provided a clear picture of the entire introductory biology sequence at an institution. For institutions with quarter schedules (instead of semesters), we combined two quarters to form one syllabus for our analyses. For example, third and fourth-quarter syllabi were combined and analyzed as a second-semester syllabus.

Data Analysis

A deductive content analysis was used to systematically examine key documentation and determine meaning from the major, mixed major, and nonmajor syllabi and course schedules. Following the standard steps of content analysis (Gall *et al.*, 1996), we first determined the research questions, chose the documents for examination, developed, and refined a coding mechanism with a subset of CLOs ($n = 439$) and course schedules ($n = 69$), assessed for interrater reliability, analyzed, and then interpreted our findings. After an initial deductive analysis of the nonmajor syllabi, we noticed a wide range of variability among the courses. Therefore, we conducted an inductive content analysis to capture this variability and qualitatively distinguish between course types (Figure 1).

Topic Coverage. We analyzed course schedules from nonmajor, mixed-major, and major courses to initially characterize the presence/absence of content coverage of: 1) core concepts of biology, 2) Vision and Change competency skills, and 3) SSIs. We sorted topic coverage into seven core concepts based on the organization and content of two major introductory biology textbooks (Urry *et al.*, 2017; Freeman *et al.*, 2019). The core concepts were Molecules of Life, Cells, Genetics, Evolution, Diversity of Life, Plants, Animal Physiology, and Ecology. These core concepts align with a recent national effort to create consensus-based LOs for introductory biology courses (Hennessey and Freeman, 2024). We initially attempted to characterize course schedules using Vision and Change core concepts and the BioCore Guide (Brownell *et al.*, 2014). We found that topics communicated on course schedules were rarely specific enough to distinguish between Vision and Change core concepts. To code to this level of specificity, we would need context from assessments, lesson-level LOs, or classroom observations. This led us to use core concepts presented in popular textbooks for introductory biology.

Competency skills were identified from Vision and Change and BioSkills Guide (Clemmons *et al.*, 2020). SSIs represented biological content taught around issues relevant to students' lives (i.e., vaccines, climate change). Topics that fell outside these three areas (i.e., syllabus day, careers in biology) were classified as "other."

For our analysis, we distinguished between first-semester and second-semester introductory biology courses. Therefore, we characterized topic coverage for the following courses:

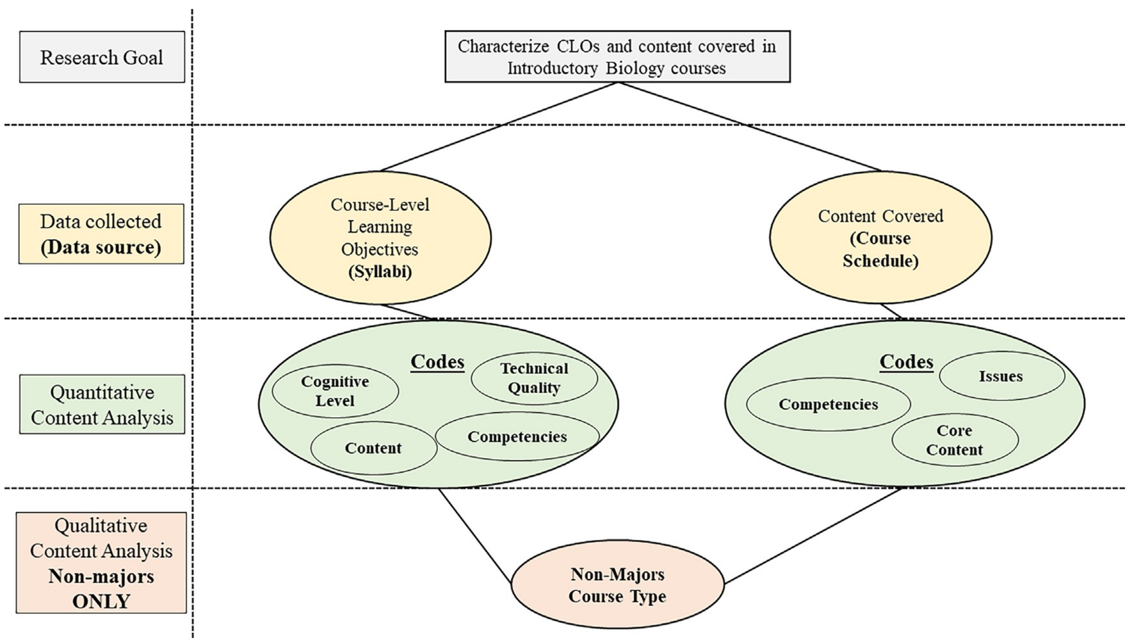

FIGURE 1. Schematic of research design, methodology, and data collected to characterize instructional decisions in introductory biology courses.

nonmajor content, nonmajor issues, first-semester mixed major, second-semester mixed major, first-semester major, and second-semester major courses. Then, the proportion of stated instructional time for each course focused on content, SSIs and competency skills was calculated by dividing the number of instructional days spent on a topic area by the total number of instructional days in a course. Stated instructional days represented the time on the course schedule that was spent teaching. As a result, exam days, holidays or class breaks were not counted in the analysis of instructional days. An example calculation for topic coverage is provided below:

Course A reported four instructional days on Mitosis and Meiosis (Cells) on its course schedule. The course totaled 32 instructional days.

$$\frac{\text{Four stated instructional days of Cells}}{\text{32 total instructional days}} \boxed{\times 100}$$

$$= \textbf{12.5\% of the course focused on Cells}$$

Among the syllabi, there was a lack of consensus in course schedules. Some instructors provided a topic for each lecture, and others indicated a topic for the week. The calculation above accounted for this variability by adjusting the instructional days to reflect how instructors presented their course schedules. In this way, our analysis focused on the intended or stated curriculum, not the realized curriculum – by characterizing content based on what was written on the course schedule.

Nonmajor Course Types. Unlike major and mixed-major courses, there was no consensus on what topics are covered in nonmajor courses. For the most part, major and mixed major syllabi and course schedules followed a predictable pattern of content that aligned with prominent textbooks and transformative initiatives such as Vision and Change. While some nonmajor courses resembled major and mixed major courses, others were fundamentally different (i.e., focusing on only a handful of SSIs in lieu of content).

To capture the variability among nonmajor course syllabi, we used an inductive content analysis during our initial analysis (Busch *et al.*, 2012). Two researchers (A.H. and J.O.) independently developed codes to capture variability observed in these nonmajor course syllabi. The research team developed multiple iterations of a codebook to characterize each syllabus based on the topics explicitly stated in the syllabus. Two nonmajor course types emerged from the inductive content analysis: 1) content courses and 2) issues-based courses (Table 2). For instance, course syllabi that expressed a march through core concepts were coded as content courses and syllabi that expressed teaching content through SSIs, case studies or service-learning were coded as issues-based courses. Once we identified nonmajor course types, we used these course descriptions to deepen our analysis of course topics and CLOs. We calculated Cohen's kappa scores to measure interrater reliability (Landis and Koch, 1977) for nonmajor course types to be 0.948 (SE ± 0.02), indicating strong agreement among paired observers. In

TABLE 2. Nonmajor biology course types identified from analysis of syllabi

Course type	Content covered
Content	Most - if not all - stated instruction focused on core concepts (e.g., cells, genetics)
Issues	Stated instruction focused on core concepts *and* SSIs, case studies, or service-learning components (e.g., cancer, climate change, microplastics, opioid campus awareness)

TABLE 3. Example code to determine cognitive level using Bloom's Taxonomy and competencies using Vision and Change and the BioSkill Guide (Clemmons *et al.*, 2020)

CLO: Students will be able to *critique* news reports about scientific discoveries			
Bloom's verb	**Cognitive level**	**Vision and change competency**	**Bioskill guide competency**
Critique	Level 5 (Evaluate)	Process of science	Information literacy

the case of disagreements, the researchers referred to the type of assessment to resolve coding disagreements. For instance, content courses were primarily assessed through tests and quizzes, and issues-based courses were more likely to use formative assessments and group projects.

CLOs Analysis. We used deductive content analysis to code CLOs for non-major (n = 439), mixed major (n = 254), and major courses (n = 415) for the following: 1) cognitive level according to Bloom's taxonomy, 2) Vision and Change core competencies as articulated in BioSkills (Clemmons *et al.*, 2020), and 3) technical quality using best practices (Schoepp, 2019; Orr *et al.*, 2022). Our analysis of CLOs mirrored a recent analysis of PLOs by Clark and Hsu (2023). Two researchers coded a subset of CLOs (n = 439) independently, and intercoder agreements are presented below for each analysis.

Cognitive Level According to Bloom's Taxonomy. Bloom's taxonomy of cognitive domains was used as a framework to classify the cognitive level of the CLOs. The original Bloom's cognitive domains were: knowledge, comprehension, application, analysis, synthesis and evaluation (Bloom, 1956). Anderson and Krathwohl (2001) revised Bloom's towards an instructor-friendly version that characterized lower-level cognitive skills (LOCS; understand and remember) and HOCS (apply, analyze, synthesize, create). Yet, there are disagreements about the cognitive order of measurable verbs. Stanny (2016) provided a review of 30 Bloom's taxonomy lists and determined the most common verbs in the revised cognitive levels. Our goal was to characterize the cognitive level of the stated verb in each CLOs- ultimately distinguishing between LOCS and HOCS. Therefore, we used the metaanalysis from Stanny (2016) to characterize the cognitive level of the stated verb in the CLO (Table 3). Occasionally, CLOs had more than one action verb present, and in these instances, we coded all verbs. Additionally, when verbs were not demonstrable or measurable (i.e., "appreciate scientific discoveries"), we coded the CLO as having no distinguishable cognitive level. However, we did distinguish unmeasurable verbs that focused on the affective domain (i.e., care, appreciate).

We calculated Cohen's kappa scores to measure interrater reliability (Landis and Koch, 1977) for cognitive level. Two researchers (A.H. & J.O.) coded a subset of CLOs (n = 437) for Bloom's cognitive level independently, and Cohen's kappa interrater was 1.00 (SE ± 0.0), indicating perfect agreement among paired observers. This high level of agreement among coders was a result of using an established resource (Stanny, 2016) to guide the analysis. We recognize that characterizing CLOs by their verbs only – without assessments – does not fully capture the cognitive level asked of the students. Future studies might characterize CLOs by evaluating verb use as well as sample assessments.

Competency Skills. Vision and Change identified core competencies needed for biology majors (AAAS, 2011), and the BioSkills Guide articulated these core competencies into CLOs (Clemmons *et al.*, 2020). We used both the broad Vision and Change competency skills and the more specific BioSkills core competencies to characterize competency skills present in CLOs and then compared this across course types (example in Table 3). We calculated Cohen's kappa scores to measure interrater reliability (Landis and Koch, 1977) for competency skills. Two researchers (A.H. & J.O.) coded a subset of CLOs (n = 418) for competency skills independently, and Cohen's kappa interrater was 0.95 (SE ± 0.01), indicating strong agreement among paired observers. With strong reliability between coders, only one coder was used for the remaining CLOs for competency skills.

Technical Quality. CLOs were characterized by adherence to best practices for writing learning outcomes (Orr *et al.*, 2022; Schoepp, 2019). We characterized the extent: 1) a complete course set of CLOs (meaning all CLOs present on a course's syllabus) and 2) individual CLOs:

- Stated the desired student performance/behavior using concrete action, or operational, verbs
- Used consistent introductory stems that were not overly wordy (i.e., students will be able to…)
  - Overly wordy stems contain unnecessary verbs to describe observable actions or skills (i.e., students will be able to demonstrate…)
- Used verbs that are measurable
- Included only one verb in the CLO

We characterized the common mistakes by reporting the most common violations and compared them across course types. We calculated Cohen's kappa scores to measure interrater reliability (Landis and Koch, 1977) for technical quality. Two researchers coded a subset of CLOs (n = 437) for technical quality independently, and Cohen's kappa interrater was 0.937 (SE ± 0.009), indicating strong agreement among paired observers. With strong reliability between coders, we used only one coder for the remaining CLOs for technical quality. We provide example CLOs from our data to highlight our coding for technical quality in Table 4.

RESULTS

Nonmajor Course Types

Using an inductive content analysis, we characterized the nonmajor course types based on themes that emerged from our analysis of course schedules. We found that 48% (n = 33) of nonmajor syllabi represented content-focused courses and 52% were issues-focused courses (n = 36).

Content course schedules focused almost entirely on core concepts outlined in introductory biology textbooks. Issues course schedules focused on core concepts areas *and* SSIs like plastics, climate change or cancer. Issue-focused courses tended to incorporate more formative assessments, such as reflections

TABLE 4. Examples from our data to show CLO adherence and violations of best practices

Violating best practices	Best practice(s) violated	Adhering to best practices
Students will be able to learn about biology and how it impacts their future careers	Unmeasurable verb (learn)	Students will be able to explain how biology impacts their future careers
Students will be introduced to the molecular basis of life to appreciate how it drives our natural world	Unmeasurable verb (be introduced) Using more than one verb (be introduced, appreciate)	Students will be able to evaluate how the molecular basis of life drives our natural world
Students will be able to demonstrate the ability to interpret scientific figures	Overly wordy stem (demonstrate the ability)	Students will be able to interpret scientific figures
The steps and function of the scientific methods	No verb; No stem	Students will be able to explain the steps and function of the scientific method

about case studies and low-stake group projects, than the content courses.

Topic Coverage

Our analysis uncovered the: 1) presence/absence of core concepts, 2) competency skills and 3) SSIs as stated on introductory nonmajor, mixed major, and major course schedules (Table 5). Then, we reported the percentage of stated instructional time spent on each core concept, competency skills, and SSIs for all course types (Table 6). Specific findings are presented below.

Nonmajor Topic Coverage. Nonmajor content-courses (n = 33) represented a survey of the core concepts outlined in introductory biology textbooks. In fact, six core concepts (Molecules of Life, Cells, Genetics, Evolution, Ecology, Diversity of Life) were each present on >65% of the nonmajor content syllabi analyzed. These same six core concepts accounted for nearly 90% of stated instructional time, as indicated by their course schedules (Tables 5 and 6). This focus on content left little room for competency skills and issues. Competency skills were present on 12.1% ($n = 4$) of course schedules and only accounted for <1% of stated instructional time. Similarly, SSIs were also present in 12.1% ($n = 4$) of nonmajor content syllabi and accounted for fewer than 2% of the stated instructional time.

Nonmajor issues-courses ($n = 35$) also represented a survey of the core concepts outlined in introductory biology textbooks. In fact, five core concepts (Molecules of Life, Cells, Genetics, Evolution, Ecology) were present on >50% of the syllabi analyzed. However, these same five concepts accounted for only 65% of stated instructional time. Thus, nonmajor issues courses spent approximately 25% less stated instructional time on content, which led to more time for issues and competency skill development. In fact, competency skills were present on 42% ($n = 14$) of the nonmajor issues' syllabi analyzed and covered 4.4% of stated instructional time. Nonmajor issues courses were recognized by their focus on SSIs; therefore, it is not surprising that 100% ($n = 35$) of these syllabi covered at least one issue. Nearly a third of stated instructional time (31.2%) focused on SSIs on nonmajor issues-course syllabi.

Mixed-Major Topic Coverage. Genetics, Cells, and Molecules of Life were present on nearly 90% of the first-semester mixed-major syllabi ($n = 40$). These three topic areas accounted for >75% of the stated instructional time in these courses. Evolution was present on >50% of first-semester mixed-major syllabi, but it only accounted for 8.0% of stated instructional time. Taken together, this meant that all additional core concepts (i.e., Ecology, Diversity of Life, Animals) accounted for 4% of stated instructional time. In first-semester mixed major courses, competency skills (12.5%) were rarely present ($n = 5$) and accounted for less than 1% of stated instructional time. Surprisingly, issues were present on 40% of first-semester mixed-major syllabi ($n = 16$) but still only accounted for nearly 7% of stated instructional time.

Second-semester mixed-major courses were relatively rare within our sample ($n = 13$). However, Ecology (83%), Evolution (75%), Diversity of Life (58%), and Animals (41%) were common concepts indicated on their syllabi. In fact, these four topics represented >60% of the stated instructional time in

TABLE 5. Presence of core concepts determined from an analysis of textbooks, Vision and Change competencies and SSIs in introductory biology courses. Darker colors indicate higher presence of a topic area on the syllabi

Topic area	Nonmajor content (%)	Nonmajor issues (%)	First semester mixed major (%)	Second semester mixed major (%)	First semester major (%)	Second semester major (%)
Evolution	82.7	83.3	53.7	75.0	65.8	57.9
Genetics	86.2	70.8	87.8	41.6	89.5	34.6
Molecules of Life	82.7	75	97.5	16.7	94.7	19.2
Cells	79.3	70.8	97.5	25.0	92.1	30.8
Ecology	72.4	58.3	21.2	83.3	15.8	61.5
Diversity of Life	65.5	25	12.2	58.3	21.1	38.5
Animals (Physiology)	34.5	50	19.5	41.6	13.2	53.8
Plants	10.3	8.3	0	25.0	10.5	38.5
SSI	12.1	100	40.0	76.9	7.5	7.7
Competency Skills	12.1	42	12.5	30.7	25.0	19.2

TABLE 6. Percent of stated instructional days spent on core concepts determined from an analysis of textbooks, Vision and Change competencies and SSIs in introductory biology courses. Other represented topics outside content, issues and competency skills (i.e., syllabus day, exam reviews, careers in biology). Darker colors indicate more time spent on a topic area during the course

Topic Area	Nonmajor Content (%)	Nonmajor Issues (%)	First semester mixed major (%)	Second semester mixed major (%)	First semester major (%)	Second semester major (%)
Evolution	11.5	11.7	8.0	22.8	10.0	15.9
Genetics	16.5	10.5	22.0	7.0	26.0	11.7
Molecules of Life	9.9	9	18.2	3.8	16.7	2.8
Cells	20.8	12.5	34.7	4.8	33.4	10.4
Ecology	10	6.4	3.4	20.5	2.8	19.5
Diversity of Life	14.6	2.8	1.4	9.3	2.8	13.2
Animals (Physiology)	6.7	8.6	3.7	6.6	2.8	16.5
Plants	0.9	0.3	0	3.2	0.8	6.4
Other	6.5	2.6	6.5	1.7	1.4	1.7
SSI	1.8	31.2	6.3	17.2	0.7	0.7
Competency Skills	0.8	4.4	0.6	3.4	2.3	2.3

second-semester mixed-major courses. Meaning, all other core concepts accounted for 7% of stated instructional time. Surprisingly, nearly a third of in the second-semester mixed-major courses syllabi analyzed (n = 4) contained competency skills (30.7%) and a staggering 76.9% contained SSIs (n = 10). Together, competencies (12.2%) and issues (17.2%) accounted for nearly 30% of stated instructional time in second-semester mixed-major courses.

Major Topic Coverage. Genetics, Cells, and Molecules of Life were present in nearly 90% of the first-semester major syllabi (n = 40). These three topic areas accounted for >75% of the stated instructional time in the first-semester major courses. Evolution was present in 65.8% of syllabi but only represented 10% of stated instructional time. Together, all other content topic areas accounted for fewer than 3% of stated instructional time in first-semester major courses. Only 25% of first-semester major syllabi (n = 10) included competency skills, which accounted for 3% of stated instructional time. Similarly, only 7.5% of first-semester major syllabi included issues (n = 3), which accounted for < 1% of stated instructional time.

There was more variation in topic coverage for second-semester major courses (n = 26). Only Evolution, Ecology, and Animals were present in >50% of the syllabi. These three core concepts accounted for 52% of stated instructional time. Evolution was present in 57.9% of second-semester major syllabi and represented 15.9% of stated instructional time. Cells and Genetics, common content topic areas in first-semester major courses, still accounted for 10% of stated instructional time in second-semester major courses. Only 19.2% (n = 5) of second-semester major syllabi included competency skills, which accounted for 3% of stated instructional time. Similarly, only 8% (n = 2) of second-semester major syllabi included SSIs, which accounted for <1% of stated instructional time.

CLO Analysis

Cognitive Level. The cognitive level of CLOs was remarkably similar across course types (Figure 2). A nearly identical percentage of CLOs did not have a Bloom's verb present for nonmajor content (8.8%), nonmajor issues (8.0%), mixed major (9.1%) and major courses (9.0%). CLOs were more often LOCS than HOCS for nonmajor content (LOCS: 55%, HOCS: 37%), nonmajor issues (LOCS: 45%, HOCS: 42%), mixed major (LOCS: 46%, HOCS: 42%), and major courses (LOCS: 48%, HOCS: 42%). Finally, few CLOs focused on affective outcomes (i.e., appreciate, care) for nonmajor content (0.9%), nonmajor issues (4.9%), mixed major (3.2%), and major courses (1.2%).

Competency Skills. Less than half of CLOs included a competency skill for nonmajor content (40.4%), mixed major (36.7%), and major courses (36.6%; Figure 3). However, 61.8% of nonmajor issue course CLOs included a competency skill.

When competency skills were present in CLOs, more than 50% of the time, they focused on the Process of Science skills (Figure 4), which included objectives like analyzing/interpreting data, assessing course credibility and asking scientific questions. Quantitative Reasoning, which included objectives like creating and interpreting scientific graphs, accounted for 9.5% of major CLOs but 5% or less for all other courses. Modeling and Interdisciplinary Nature of Science accounted for less than 5% of CLOs for all course types. Communication and Collaboration were most common in mixed major CLOs (27.7%) but also accounted for 18.4% of major CLOs, 16.0% of content-nonmajor and 14.0% of issues-nonmajor courses. Science and Society competency skills were most common in nonmajor courses (19.0% in content and 26.1% in issues) compared with major (8.8%) and mixed major courses (6.4%). Science and Society CLOs focus on how science intersects with society and vice versa.

Technical Quality. We first analyzed the technical quality of CLOs at the course level. Few courses presented full sets of CLOs that adhered to best practices – meaning every CLO that was present on their syllabi did not violate best practices: nonmajor 27% (n = 18), 27% mixed major (n = 12), and 35% major courses (n = 22).

We analyzed technical quality on the individual CLO level. Across course types, the majority of individual CLOs adhered to best practices: non-major 66% (n = 298), mixed major 58% (n = 144), and major 69% (n = 286). The most common violations of best practices observed in individual CLOs were including verbs that were not measurable, using more than one verb,

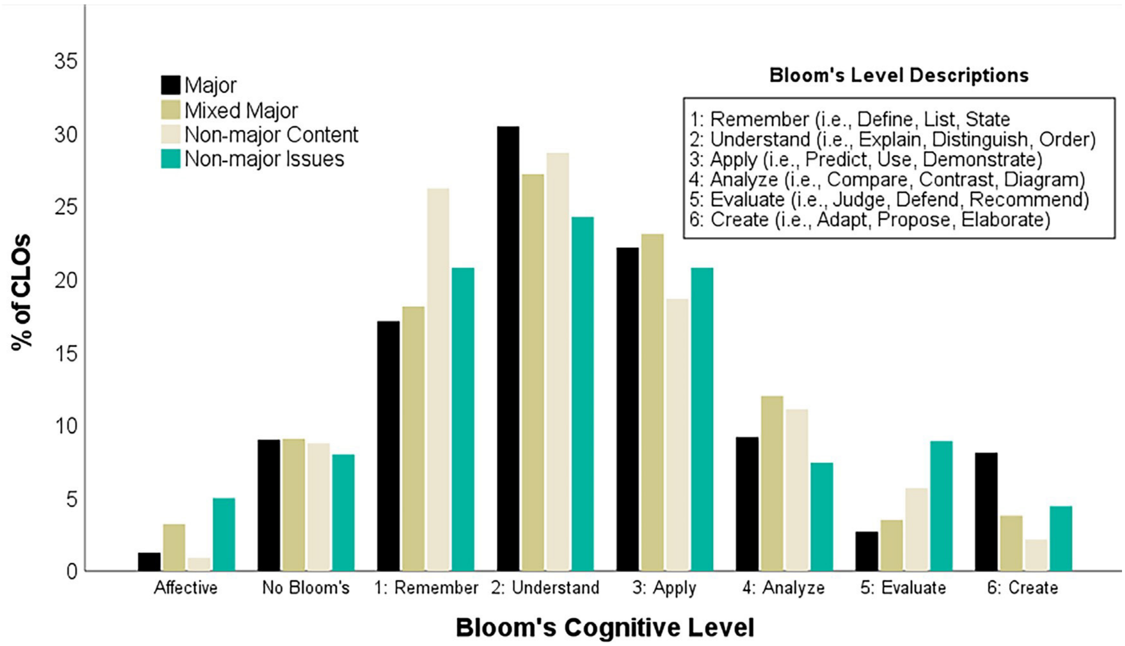

FIGURE 2. The percentage of CLOs for each cognitive level according to Bloom's Taxonomy across all introductory biology courses.

and including overly wordy stems (Table 7). In fact, 33% of nonmajor CLOs ($n = 148$), 42% of mixed major CLOs ($n = 101$), and 30% of major CLOs ($n = 126$) included nonmeasurable verbs or did not state the desired student performance/behavior using concrete action, or operational, verbs. However, taken together, we did not find apparent differences in technical issues across course types.

DISCUSSION

For more than a decade, college biology instructors have had a national consensus for programmatic level learning (i.e., broad content and competencies) for biology major courses because of Vision and Change (AAAS, 2011). Vision and Change was innovative because it provided a unifying framework to establish the content and competencies needed for biology majors. Yet, despite the resources developed as a result of Vision and Change, including aligning instruction with the content and competencies at the programmatic level (Brownell *et al.*, 2014; Clemmons *et al.*, 2020), the current landscape of introductory biology as defined through the lens of syllabi indicates that we are far from effectively implementing this initiative into practice at the course level.

Our analysis of the stated curriculum on 188 syllabi for introductory biology illustrates that the college biology community has not yet achieved the goals set forth by Vision and Change. What we know about the current state of introductory biology is this: CLOs are approximately half LOCS and half HOCS; most CLOs have at least one technical mistake; the majority of CLOs are focused on content; and competencies are not often included in courses other than nonmajor issues-based courses. It should be encouraging that nearly one-third of syllabi included competency-based CLOs (Figure 3); however, most focused on the Process of Science, with very few focused on other critical skills for science literacy (Figure 4). Our findings both expand–by providing information about courses for nonmajors and mixed majors–and mirror other recent characterizations of introductory biology instruction: faculty still tend to prioritize LOCS and factual content (Derting *et al.*, 2016; Momsen *et al.*, 2010; Heil *et al.*, 2023).

Our analysis revealed an expected pattern in the content covered for introductory major and mixed major courses:

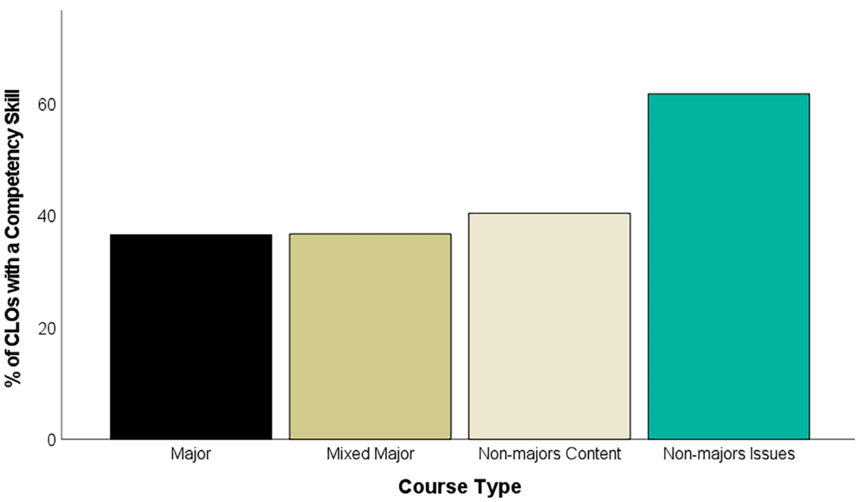

FIGURE 3. The percentage of CLOs focused on Vision and Change competency skills across all introductory biology courses.

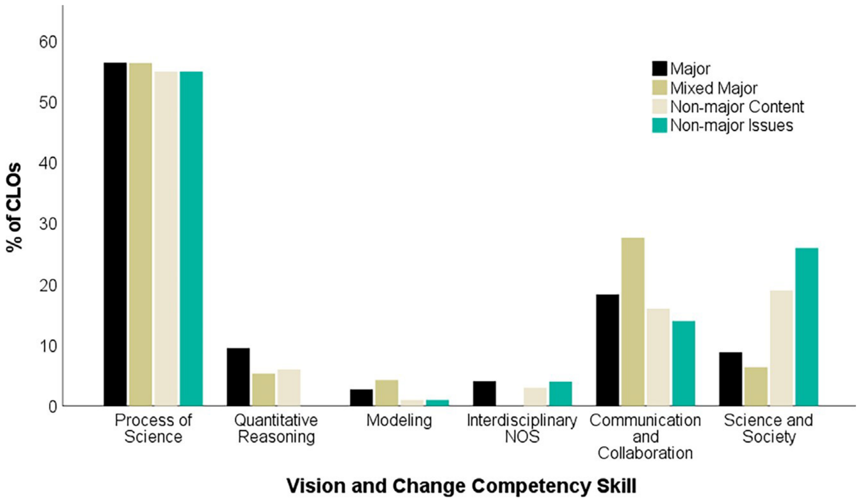

FIGURE 4. The most frequently occurring Vision and Change competency skills in CLOs across all introductory biology courses.

major and mixed major syllabi represented a march through content, following a typical textbook table of contents. Faculty focus on Molecules of Life, Cells and Genetics during the first semester and then Ecology, Diversity of Life and Animal Physiology in the second semester. Evolution was the only content threaded through both semesters on the syllabi. We found introductory major and mixed major biology courses rarely explicitly stated competency skills and SSIs on their syllabus, despite Vision and Change and recent curricular directives (Brownell *et al.*, 2014; Clemmons *et al.*, 2020). Yet, we did find a large percentage of second-semester mixed major courses focused on SSIs, however, our sample size was too low to make any generalizations ($n = 13$).

The syllabus analysis also revealed that about half of the nonmajor courses are, in essence, a survey of the major courses rather than courses designed specifically with goals for nonmajors' learning in mind (Figure 2). Similar to first-semester major and mixed major courses, content-based nonmajor syllabi represented a march through content. While there is a national policy to guide curricular decisions for introductory biology majors, college biology faculty lack similar guidance for nonmajor courses. Yet, for nonmajors, these courses maybe even more important as they may represent the single opportunity for students to practice and develop science literacy skills that are critical for decision-making students face both personally and societally (Gormally and Heil, 2022). Encouragingly, we found that faculty included more competencies on issues-based nonmajor syllabi.

TABLE 7. Technical issues observed in individual CLOs from introductory biology courses

Technical issue	Major (%)	Mixed-major (%)	Nonmajor (%)
No Verbs	2.9	15.5	4.7
Overly Wordy Stem	6.8	5.5	6.2
Not Measurable Verbs	27.9	25.7	28.4
>1 Verb	5.4	20.8	8.5
Missing CLOs	1.9	11.5	1.9

Our work contributes more evidence that faculty struggle to write LOs, which has previously been documented at the lesson level (Orr *et al.*, 2022). Other research has documented faculty resistance to using CLOs. For example, faculty often view creating LOs as an administrative task and believe that LOs hinder student creativity and critical thinking (Lightner and Benander, 2010). Moreover, faculty cite limitations of Bloom's verbs in creating LOs and believe that there is no need to create LOs for students because students should just know what is important to learn (Lightner and Benander, 2010).

This work makes it clear that when it comes to reinventing instructional practices for introductory biology, faculty cannot "go it alone." Faculty need professional development opportunities that support collaborative efforts for sustainable course transformation, and incentives are important for effective course redevelopment efforts. Incentives motivate faculty as well as provide the necessary resources and wherewithal to make these overarching changes (Chasteen *et al.*, 2011; Pepper *et al.*, 2012; Orr *et al.*, 2024). These incentives include creating a sense of need and urgency to do this work, funding to support curricular change work, credit, and acknowledgement for faculty contributions (Chasteen *et al.*, 2011; Pepper *et al.*, 2012; Ezell *et al.* 2019). For example, a learning circle of faculty gathering for "brown bag" meetings could be established as a way for departmental faculty to develop LOs together (Chasteen *et al.*, 2011). Additionally, successful transformation interventions can leverage systems thinking principles (Demarais *et al.*, 2022). Institutions and programs seeking to make curricular change might look to strategies used by the Partnership for Undergraduate Life Sciences Education (PULSE), such as funded workshops bringing together teams of faculty and administrators from an institution to work through a customized departmental change process together on both PLOs and CLOs (Demarais *et al.*, 2022; Clark and Hsu, 2023). Evidence suggests that more faculty are supportive of creating and using LOs after being shown the effectiveness of LOs–even those faculty who were initially resistant (Lightner and Benander, 2010). To most effectively write, revise, and use PLOs and CLOs, we recommend following recommendations provided by Clark and Hsu (2023) and Orr *et al.* (2022).

Limitations and Future Directions

We recognize our analysis of slightly overrepresented doctoral universities and slightly underrepresented 2-y institutions; however, the outcomes obtained from this study can be used by future researchers to deeply explore nuanced differences between faculty profiles and institution types.

Secondly, we recognize that we used what was stated on a syllabus to characterize the learning happening in the classroom. We understand that instructors may teach SSIs or Vision and Change competencies but not list them on their syllabus.

Future studies might analyze assessment items and conduct instructor observations to further characterize the amount of time spent on each core concept, SSI, or competency. Additionally, researchers might conduct interviews with faculty about their syllabi and approach to instruction.

CONCLUSION

Our findings suggest that there is much work to do if Vision and Change is to become more than simply a vision–to be actualized as change. It is clear that there is a need to articulate LOs at multiple levels–at the program level, course level, and instructional level for the most effective systemic change (Clark and Hsu, 2023). A recent nationally endorsed set of lesson-level LOs for a year-long introductory biology course for majors was published that provides a foundation (Hennessey and Freeman, 2024). These LOs support individual class sessions and provide instructors with a framework for course design that is better connected to content. However, analysis of CLOs included in our 188 syllabi makes it clear that faculty need professional development opportunities to develop CLOs. Recently, Orr *et al.* (2024) provided a roadmap for planning course transformation using LOs. More research is needed to examine the barriers preventing faculty from teaching HOCS in order to design effective professional development opportunities.

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