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A case study of actual versus desired inclusion of community-derived core concepts into neuroscience courses in different disciplines at a large university

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Neuroscience is an inherently interdisciplinary and rapidly evolving field. While many universities have neuroscience or related majors, they are highly heterogeneous, and it is unclear how their content aligns with a recent proposal of what ideas make up the field of neuroscience. It is therefore important to document and assess the alignment of neuroscience curricula with core concepts in the field. Recently, a large effort by some members of the neuroscience education community described eight core concepts for undergraduate neuroscience curricula. In this paper, we focus primarily on courses in biology, cognitive science, and psychology at a large university, surveying the recent and current course instructors of these courses to ask them (1) to what extent these community-derived core concepts are incorporated into their classes and (2) to what extent these concepts should be incorporated into their classes. In addition, we map core concepts onto course syllabi. We found that core concepts are well-represented across disciplines, and identified differences between departments' inclusion of core concepts. We found that instructors cover fewer core concepts than they desire, and that two core concepts, "Evolution" and "Gene-environment interactions", were less frequently addressed across disciplines. We consider barriers to instructors' ability to align course content with core concepts, both within and across disciplines. In this effort, we provide an example of how departments can evaluate their alignment of major requirements with the neuroscience core concepts.

KEYWORDS

neuroscience education, undergraduate education, core concepts, curriculum reform, neurobiology education, neuroscience curricula, curricular alignment

1 Introduction

Educators across Science, Technology, Engineering, and Mathematics (STEM) disciplines have been called to align their teaching with core concepts: foundational principles that can serve as a knowledge framework for course and curriculum design (AAAS, 2011; Michael and McFarland, 2011; Hestenes et al., 1992; Wilson Sayres et al., 2018). Aligning teaching and assessments with core concepts can provide coherence within and across disciplines (AAAS, 2011). Core concepts have been framed and inventoried in many STEM fields, including chemistry (Barbera, 2013), physics (Hestenes et al., 1992), and biology (AAAS, 2011). Within biology, core concepts for individual branches or fields have also been identified, including those in microbiology (Merkel and the ASM Task Force on Curriculum Guidelines for Undergraduate Microbiology, 2012), bioinformatics (Wilson Sayres et al., 2018), physiology (Crosswhite and Anderson, 2020; Michael and McFarland, 2011, 2020), kinesiology (Hudson, 1995), and anatomy (Smith et al., 2016).

Neuroscience is a rapidly growing field that may especially benefit from a centralized list of core concepts because of its interdisciplinary nature (Ramos et al., 2016, 2011). As a field that pulls together many disciplinary threads, it incorporates principles of biology, chemistry, psychology, cognitive science, computer science, physics, philosophy, and mathematics (Modo and Kinchin, 2011; Ramirez, 1997). Neuroscience also includes many subdisciplines, the overlapping specializations within neuroscience, including behavioral, cellular, molecular, clinical, cognitive, computational, and developmental neuroscience (Churchland et al., 1993). Ideally, a neuroscience curriculum would not just be multidisciplinary but interdisciplinary: capable of training students to integrate terminology, methodology, and analyses from across disciplines (Modo and Kinchin, 2011). Modo and Kinchin (2011) posit that interdisciplinary learning in neuroscience can be fostered through a spiral curriculum, wherein students are repeatedly exposed to concepts from various perspectives and at different levels of complexity. Neuroscience instructors could promote spiral curricula by designing their courses with a focus on centralized core concepts.

However, designing neuroscience majors and curricula has been difficult because of its interdisciplinary nature. Although some institutions have a neuroscience department, most "neuroscience" or "neurobiology" majors are multidisciplinary curriculum tracks, where students take classes distributed across departments as diverse as Biology, Cognitive Science, and Psychology (Pinard-Welyczko et al., 2017). A previous study of neuroscience major requirements across institutions found that most of them emphasize the natural sciences over social sciences or humanities (Pinard-Welyczko et al., 2017), but the requirements may differ depending on the department in which the major or course is housed. Given the different roots and histories of the different disciplines that compose neuroscience, it would not be surprising if neuroscience was interpreted differently across departments, which in turn may cause instructors from these disciplines to value different core concepts and competencies (Wiertelak et al., 2018; Wiertelak and Ramirez, 2008). For example, biologists (and neurobiologists, within) primarily study brain function in health and disease from a physiological perspective, whereas cognitive scientists emphasize computational functions of the brain, with a focus on abstract phenomena, like cognition and intelligence. Psychology studies the brain and mind through the lens of behavior and mental processes.

Further, Biology, Cognitive Science, and Psychology departments are each tackling their own intradisciplinary debates (Nez et al., 2019; Howell et al., 2014; Gentner, 2019; Spivey, 2023) over their core conceptual pillars and may therefore differ in their perspectives on core concepts for neuroscience. Biology core concepts were introduced in the 2011 Vision and Change framework published by the American Association for the Advancement of Science (AAAS), and have since been widely adapted (reviewed by Aikens (2020)) and integrated into curricular resources (AAAS, 2011; Clemmons et al., 2020). However, within the fields of Psychology (Howell et al., 2014; APA Board, 2023) and Cognitive Science (Nez et al., 2019), there is some disagreement on core curricula and content, and in Cognitive Science there is debate whether it is even desirable to conform to one theoretical framework or core curriculum (Gentner, 2019; Nez et al., 2019; Spivey, 2023).

Despite these difficulties, throughout the past few decades, neuroscientists have come together to create shared curricula, competencies, and core concepts for neuroscience. For example, the Faculty for Undergraduate Neuroscience (FUN) group has brought together faculty approximately every decade to create "blueprints" for neuroscience majors and minors (Wiertelak et al., 2018; Wiertelak and Ramirez, 2008). Most recently, Chen et al. (2023) identified eight core concepts in neuroscience: "Communication modalities," "Emergence," "Evolution," "Gene-environment interactions," "Information integration," "Nervous system function," "Plasticity," and "Structure-function." These core concepts were sourced through an iterative, community-driven process with input from neuroscience educators (Chen et al., 2022, 2023).

Since core concepts should be overarching and applicable across subdisciplines (Chen et al., 2022), a key step in developing core concept inventories is evaluating how instructors across subdisciplines teach and assess core concepts through faculty and student surveys and curriculum mapping. There are at least three parts to a curriculum, including the intended or planned curriculum, the enacted curriculum that is created and delivered by instructors, and the curriculum experienced by students. (Erickson and Shultz, 1992; Matthews et al., 2013; Mercer-Mapstone and Matthews, 2017; Porter and Smithson, 2001). Previous work has found that enacted curriculum, represented by curriculum mapping and self-reported teaching from instructors, often differs from recommended core concepts and competencies (Tangalakis et al., 2023; Stanescu et al., 2020; Clemmons et al., 2022). For example, Tangalakis et al. (2023) compared learning outcomes from 17 physiology curricula across institutions and found that the majority of course learning outcomes were not aligned with the core concepts in physiology (Crosswhite and Anderson, 2020; Michael and McFarland, 2011, 2020). Further, alignment with core concepts differed widely across institutions, ranging from 11% to 61% alignment (Tangalakis et al., 2023). Separately, seven physiology programs self-reported coverage of core concepts in their curricula and, while all core concepts were covered, no two institutions covered the same concepts to the same extent (Stanescu et al., 2020). Additionally, individual courses alone did not cover all core concepts (Stanescu et al., 2020). In another study, Clemmons et al. (2020) found that instructors taught fewer learning outcomes than those listed on the BioSkills Guide, a list of outcomes derived from biology's Vision and Change core competency inventory (AAAS, 2011). Some learning outcomes, when taught, were assessed more than others, but there was poor alignment between teaching and assessment of core competencies in some categories (Clemmons et al., 2022). There were also differences in continuity with core competencies across course levels and course types—upper and lower division courses and laboratory and lecture courses emphasized different learning outcomes (Clemmons et al., 2022). Clemmons et al. (2022) grouped courses into six subdiscipline categories and found that, although some core competencies were equally likely to be taught in all subdisciplines, some subdisciplines were less likely to report teaching some core competencies compared to others. These findings suggest that alignment is often scaffolded based on course sequencing and varies across courses, subdisciplines, and institutions. Thus, curriculum mapping at regular intervals and upon creation of new core concept inventories is necessary to ensure complete coverage of core concepts and competencies.

Given the importance of curriculum mapping, it is curious how few studies have been done on curriculum mapping using the core concepts. A recent review article by Stocker and Duncan (2024) describes inclusion of neuroscience core concepts in a neuroscience minor curriculum housed in the psychology department at a medium-sized primarily undergraduate institution (PUI). Notably, they reflected on three core concepts that were not thoroughly covered in the minor curriculum: "Evolution," "Gene-environment interactions," and "Structure-function." Other than this informal evaluation, previous studies of the core concepts in neuroscience have only assessed instructor opinions (Chen et al., 2022, 2023). The interdisciplinary nature of neuroscience may make it less likely for course curricula across departments to align with the proposed core concepts. Notably, the respondents for the survey that produced these core concepts were primarily recruited from three biology-focused organizations: FUN, the American Physiological Society (APS), and the Society for the Advancement of Biology Education Research (SABER) (Chen et al., 2022). Cognitive scientists and psychologists may be the minority in these organizations. Thus, the core concepts may not apply as well to neuroscience as conceptualized by these disciplines.

To investigate whether and how courses in Biology, Cognitive Science, and Psychology use the core concepts, we propose to use a case study methodology to analyze their use in these disciplines at a single institution. At many universities, there is only one neuroscience major that spans across various disciplines, so it is difficult to ascertain whether these core concepts apply as well in these different disciplines (Pinard-Welyczko et al., 2017). However, at the university in this case study, there are multiple neuroscience or neurobiology majors housed in different departments, each with its own fundamental neuroscience coursework, which makes it possible to see what constitutes "neuroscience" within each discipline. Restricting the study to one institution also controls for institutional characteristics such as the general makeup of the student body and term length. The authors acknowledge that case study results in discipline-based education should not be overgeneralized (Kanim and Cid, 2020; Henrich et al., 2010) and curriculum mapping projects such as the current study and those described above (Erickson and Shultz, 1992; Matthews et al., 2013; Mercer-Mapstone and Matthews, 2017; Porter and Smithson, 2001; Tangalakis et al., 2023; Stanescu et al., 2020; Clemmons et al., 2022; Crosswhite and Anderson, 2020; Michael and McFarland, 2011, 2020) may not be reflective of curricula across all institutions, given differences in departmental structures, major requirements, and courses. However, case studies may raise important questions and indicate trends in core concept alignment that may be relevant at other institutions with multiple neuroscience-related majors or even those with similarly interdisciplinary majors. Additionally, case studies can serve as helpful methodological examples for other institutions. Here, we show how a simple survey and straightforward syllabus coding can identify gaps in curricula and uncover differences in core concept coverage between biology, cognitive science, and psychology departments. We predicted that neuroscience courses differ depending on the department in which they are housed.

Instructors' desire to teach core competencies may also be inconsistent with how they enact their courses and how students experience their teaching (Clemmons et al., 2022; Tangalakis et al., 2023). Instructor surveys have previously been used to assess instructor perceptions of the importance of core concepts (Stanescu et al., 2020; Tangalakis et al., 2023; Chen et al., 2023), but, to the authors' knowledge, no one has directly compared how important a core concept is perceived to be and whether it is actually taught, even through self-report. Other studies suggest that instructors sometimes do not teach everything they perceive to be important. For example, course syllabi communicate the intended curriculum, but instructors tend to report teaching more core competencies than those listed on their syllabi (Clemmons et al., 2022). As a whole, these findings indicate that, while core concepts may be inventoried and agreed upon by instructors, in practice they may not be consistently taught or assessed.

Therefore, in order to fully understand how neuroscience core concepts are used in practice, it is important to assess instructor alignment with the neuroscience core concepts. As neuroscience instructors, we expected that instructor alignment with core concepts and instructor opinions would differ across Biology, Cognitive Science, and Psychology departments. We therefore sought to evaluate integration of core concepts using instructor surveys and human coding of syllabi to address two research questions:

- RQ1: To what extent are the community-derived core concepts incorporated into neuroscience classes offered by different departments, and how does this vary by discipline? More specifically, we collected self-reported data and coded syllabi to compare inclusion of core concepts in neuroscience courses housed in the Biology, Cognitive Science, and Psychology departments at a large research institution.
- RQ2: To what extent do instructors believe these concepts should be incorporated into their classes, and how does this vary by discipline? We assessed instructor opinions through closed- and open-ended survey questions in order to determine to what extent and why instructors' actual teaching of these concepts might differ from their desired teaching.

2 Materials and methods

2.1 Study context

This case study occurred at a large, public university in the western United States with very high research activity (Indiana University Center for Postsecondary Research, 2021).

TABLE 1 Characteristics of analyzed departments, courses and instructors.

Discipline	Biology	Cognitive science	Psychology
Total undergraduate enrollment, 2023–2024	665	506*	211
Number of fundamental neuroscience courses	2	3	2
Instructors recruited	6	5	4
% of instructors who took the survey	67% (4/6)	80% (4/5)	100% (4/4)
% of instructors with analyzed syllabi	100% (6/6)**	40% (2/5)	50% (2/4)

*Enrollment is for both neuroscience-related Cognitive Science majors combined.
** Two instructors co-taught one course and thus shared the same syllabus.

This university has four undergraduate majors with the words “neuroscience” or “neurobiology” in the name of the major: one housed in the School of Biological Sciences, one housed in the Department of Psychology, and two housed in the Department of Cognitive Science. The two majors in Cognitive Science share the same introductory neuroscience coursework. Each of these majors requires its own separate fundamental, broadly-focused neuroscience courses that are taught within its own department, although many of these majors allow students to take neuroscience-related courses from other majors as electives. Thus, the fundamental neuroscience coursework of these majors can be thought of as corresponding to the disciplines of Biology, Cognitive Science, and Psychology. Total enrollment in these majors as of the 2023-2024 academic year was derived from institutional dashboards and is given in Table 1 (UCSD Institutional Research, 2024). The university is on the quarter system, so courses take place over 10 weeks of instruction during the academic year, or 5 weeks of instruction during the summer (meeting twice as often each week).

2.2 Survey development

The survey was designed to ask about the presence of each of the eight neuroscience core concepts in an instructor’s course and its course components and about the instructor’s desired inclusion of these concepts. It is important to note here that instructors in our study were not necessarily aware of the core concepts in neuroscience, so we assessed general “alignment” of their curricula with core concepts, rather than intentional “adherence” with the recommended outcome by, say, organizing the curriculum around these concepts. To address construct validity based on evidence from test content and response processes, a draft version of the survey was shared with a neuroscience instructor from the recruited set (Knekta et al., 2019). That instructor confirmed that the survey questions were clear and addressed the core concepts, and they recommended only superficial changes. The full text of the final survey is included as Supplemental material 1.

2.3 Data collection

Human subjects approval was granted by the University of California, San Diego, IRB Project #808986. Instructors consented to having their survey responses analyzed for this study by completing a consent form as part of the survey.

As the goal of this study was to analyze course content alignment with the neuroscience core concepts, we searched for courses within the three disciplines that formed the “fundamental neuroscience” curriculum. We defined these courses as ones that were intended to form part of a series that addressed neuroscience at a broad level, not those that focused on particular topics within neuroscience such as “learning and memory,” and were required for all students in the major. These courses could be either lecture or laboratory courses and, generally speaking, were designed for sophomores or juniors as prerequisites for more specialized neuroscience courses. The number of such courses in each discipline is given in Table 1. It should also be noted that all of our courses were upper-division courses required for their respective majors, and we did not assess any stand-alone “introductory” neuroscience courses designed for first-year or general education students, which may have included the concepts with more breadth but less depth.

We then recruited all instructors of record from these courses from the past 3–5 years, as listed in the institution’s course registration website, via email. The authors are all biologists who teach one of these courses, but they were excluded from the study. One course was co-taught in one quarter, and both instructors were recruited. Instructors who had taught a given course several times were only counted once and asked to complete the survey once. However, if an instructor had taught multiple courses, they were counted once per course and asked to complete the survey once per course. Since the survey did not ask for names or personal identifiers, survey data was analyzed blindly. The number of instructors recruited and the percent who agreed to participate are documented in Table 1.

Instructors varied in formal job type and included non-tenure-track lecturers, tenure-track and tenured teaching professors, and tenure-track and tenured research-focused professors. Instructor demographics and characteristics were not analyzed further because of small sample sizes and the need to protect instructor identity.

2.4 Quantitative survey analysis

The questions on the survey that were analyzed as part of this study are documented in Table 2. To address RQ1, we asked instructors to share to what extent each core concept was part of their course. To analyze this data, responses were grouped by discipline.

We also asked instructors to share which components of their courses addressed each core concept. Although we gave instructors several course components to choose from, we discovered that the only consistent course element present in all courses was lectures. In addition, while not all courses had exams or assignments, all courses had at least one of those. Therefore, in our analysis, we

TABLE 2 Survey questions analyzed as part of this study.

Research question	Question text	Answer choices
RQ1	The proposed core concepts above are for an entire undergraduate neuroscience curriculum. Your one course may not cover all these topics. To what extent are each of the core concepts **currently** a part of your course content (including lectures and assignments)?	For each of the core concepts, 4 point scale: • Not at all • A little bit (less than one class session; a small portion of one assessment) • Somewhat (about one class session; a portion of one or more assessment) • Significantly (more than one class session; multiple assessments)
RQ1	Which aspects of your class include each of the core concepts?	For each of the core concepts, various course components, including lectures, assignments, and exams
RQ2	Do you feel the core concepts listed above cover the necessary concepts in neuroscience? Why or why not?	(Open-ended)
RQ2	To what extent do you believe each of the core concepts **should** be a part of your course content (including lectures and assignments)?	For each of the core concepts, 4 point scale from "Not at all" to "Significantly" identical to above
RQ2	Are there discrepancies between what you are teaching and what you feel you should be teaching? If so, what is driving these discrepancies?	(Open-ended)

focused on the categories "lectures" and "assessments," with the "assessments" category being a combination of the components "exams" and "assignments."

To address RQ2, we asked instructors to share to what extent each core concept should be part of their course. Responses were grouped by discipline. To compare the actual versus desired inclusion of these core concepts, we first converted each level to a numerical value, with "not at all" being assigned a 0 and "significantly" being assigned a 3. Then, for each concept, we subtracted the averaged actual inclusion across all instructors from the averaged desired inclusion to get a difference score for that concept.

2.5 Qualitative survey analysis

We analyzed the responses to open-ended questions on the survey using inductive qualitative analysis (Thomas, 2006). For each question, after reading all the survey responses together, the authors jointly agreed on codes that emerged from the data and coded all responses by group consensus. Both open-ended questions were used to address RQ2 (Table 2).

2.6 Syllabus analysis

In addition to analyzing the instructor's self-reported inclusion of the core concepts in each course, we also addressed RQ1 by using data from syllabi. Although instructors may teach and assess content not listed on their syllabi, instructors typically do teach the topics and learning outcomes listed on their syllabi (Clemmons et al., 2022). Syllabi were either provided by instructors via email or taken from the institution's publicly available website that contains course syllabi. To determine whether each of the core concepts was present in each of the courses, we looked at the course schedule, which contained the topics taught on each date or week of the course. If topic-level learning objectives were also provided within the syllabus, they were used to help determine whether a topic fit within a core concept. When it was not clear whether a topic fit within a core concept, for example if a topic could be taught with or without the inclusion of that concept, the topic was not used as evidence the core concept was taught within that class. Topics could be classified under more than one core concept. Table 3 shows some examples of topics that were classified under various core concepts.

TABLE 3 Example course topics for each core concept.

Core concept	Example course topics
Communication modalities	The action potential, the active membrane, neural communication, synaptic transmission
Emergence	Cells of the nervous system, neural circuits, neurons & glia
Evolution	Evolution of the brain, neural evolution
Gene-environment interactions	Neural development
Information processing	Synapses & drugs, synaptic integration & postsynaptic potentials, synaptic transmission
Nervous system functions	Circadian rhythms & sleep, hunger, emotional behaviors, sensory transduction
Plasticity	Learning & memory, synaptic plasticity
Structure-function relationship	Nervous system cell types, morphology, & functions, structural basis of ion flux

Each syllabus was coded by at least two authors, and disagreements were resolved by consensus. To analyze this data, syllabi were grouped by discipline.

2.7 Positionality statement

The three authors of the current study acknowledge our positionality in this study as teaching professors in the

Neurobiology department of our institution who were all trained in neuroscience from a biological perspective. We limited bias to the best of our ability by establishing consistent coding standards and using consensus coding. However, we acknowledge that even with these precautions, there may be bias in our methods, analyses, and interpretations of the data.

3 Results

3.1 Courses across disciplines vary in inclusion of core concepts

To address RQ1, we asked neuroscience instructors in Biology, Cognitive Science, and Psychology departments to rate the inclusion of the eight different core concepts in their courses. We specifically recruited instructors that taught courses designed to introduce students to "neuroscience" (see METHODS for details). The responses (n = 12) were divided into Biology (n = 4), Cognitive Science (n = 4), and Psychology (n = 4) courses (for a full breakdown of participants, see Table 1). There were seven unique courses in the sample, ranging from large enrollment lecture courses to laboratory classes.

We noted several interesting differences in the inclusion of the eight core concepts (Figure 1, left). First, all three disciplines had a strong emphasis on "Emergence," with only one Psychology course indicating that it was not at all included. "Plasticity" was also included in most courses. Across disciplines, "Evolution," "Gene-environment interactions," and "Nervous system functions" were the least included.

Second, there were several disparities between disciplines. "Communication modalities" and "Information processing" were both strongly represented in Cognitive Science and Biology but slightly less so in the Psychology courses. On the other hand, "Evolution" was at least somewhat represented in about half of Psychology and Cognitive Science but barely included in the Biology courses.

3.2 Syllabi provide additional insight into disciplinary differences

To address RQ1, we also reviewed course syllabi for their inclusion of the core concepts (see Table 3 for examples of course topics that were matched with core concepts). Overall, the core concepts were fairly well represented across disciplines, with most appearing in most or all of the syllabi we reviewed (Figure 2). The differences in core concept inclusion that we observed in our survey responses were echoed in course syllabi, with "Evolution" appearing less than all of the other concepts across course discipline and no mentions of it in the Cognitive Science syllabi. "Gene-environment interactions" only appeared in 3 of 6 Biology syllabi and neither of the Psychology syllabi, but was evident in both Cognitive Science syllabi that we reviewed.

3.3 Core concepts are integrated into various aspects of courses

In addition, we asked instructors which aspects of their courses featured each of the core concepts to illuminate the priority of these concepts—the most important concepts should show up on assessments, as students shape their study strategies and their approaches to learning based on their perceptions of course assessments (Struyven et al., 2005). Overall, core concepts were slightly more likely to be included in lectures (mean across concepts = 87.5%) than assessments (mean across concepts = 80.2%), which included both exams and other assignments. This difference was most notable for "Evolution," which was much more likely to show up in lectures than assessments (see Figure 3, right). Biology courses had a slight disparity between lectures and assignments for "Gene-environment interactions," "Nervous system functions," and "Plasticity," which were all more represented in lectures than assessments. Psychology instructors reported including many of the core concepts in assessments more than lectures (Figure 3).

3.4 Open-ended responses highlight missing concepts by discipline

In open-ended comments, we were able to probe the areas that were not covered by the community-derived list of concepts to see whether these differed by discipline. For example, several Cognitive Science and Psychology instructors noted that their classes featured a stronger emphasis on behavior and cognition. When considering the "Plasticity" core concept, these instructors also noted that they cover plasticity beyond the kind that is "experience-dependent," specifically, neuromodulation. On the other hand, several Biology instructors noted the absence of a core concept that described neurons based on principles of physics or chemistry: "Students should appreciate that nervous systems are built on principles of physics and chemistry, and that these low-level interactions ultimately drive neural activity and behavior."

3.5 Instructors would like to include more core concepts in their courses

To understand the difference between what instructors currently teach and what they think they should be teaching (RQ2), we asked the instructors to what extent they believed the core concepts should be included in their courses. We saw similar weighting of the core concepts in the desired inclusion of them as in the actual inclusion, with "Emergence" showing the strongest responses for both actual and desired inclusion (Figures 1 right, 4A). Overall, the patterns across disciplines held, with all instructors wishing for more inclusion of each concept.

We also evaluated individual instructor responses to observe incongruities between the actual and desired inclusion of concepts. As seen in Figure 4, the overall trend is that instructors believe they should be teaching each of the core concepts more in each of their classes. In particular, instructors across disciplines strongly indicated that they believed "Evolution,"

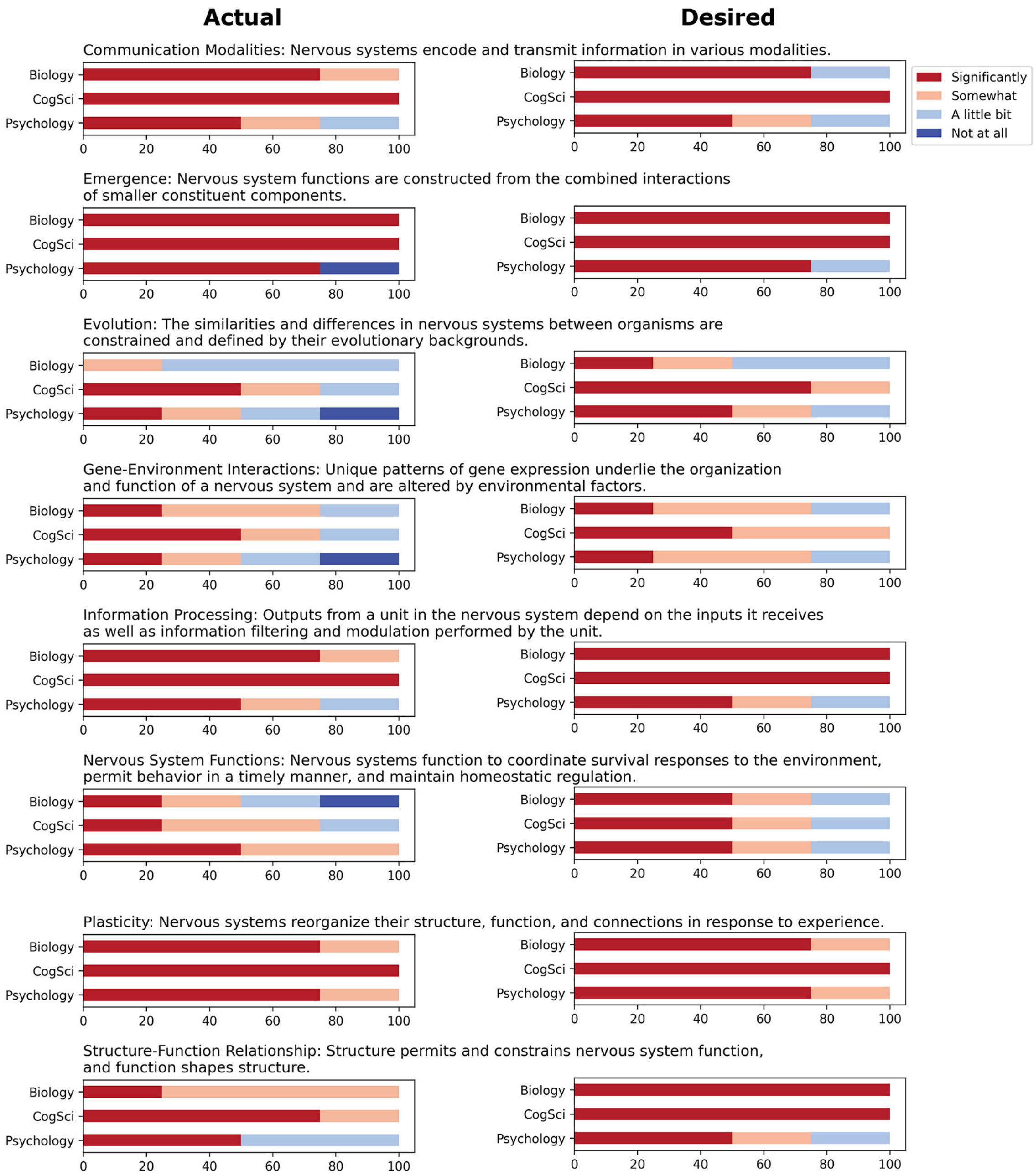

FIGURE 1
Comparison between actual **(left)** vs. desired **(right)** inclusion of core concepts within courses in different disciplines.

"Gene-environment interactions," and "Structure-function relationship," three of the least included core concepts (Figure 1), should be included in their course content (Figure 4). There was a notable desire within biology, specifically, to increase focus on "Nervous system functions" (green bars in Figure 4A). Many instructors who answered "Significantly" did not change their responses between their actual and desired representation of concepts, often staying at that rating (e.g., for "Communication modalities."

The sentiments indicated in these survey responses were also illustrated in open-ended responses, in which instructors were asked to reflect on their actual versus desired inclusion of the core concepts. One code that emerged from the open-ended responses was time constraints on coverage. Instructors noted value in each of the core concepts but were concerned with content overload. In one biology instructor's words, "I'd like to cover more topics, but am concerned it would overwhelm the students." For "Evolution" specifically, another instructor wrote that they give comparative anatomy across species a "contextual head nod" rather than full treatment due to time constraints. Similarly, yet another instructor, whose lecture is paired with a laboratory course, noted that the priorities were to teach topics directly related to

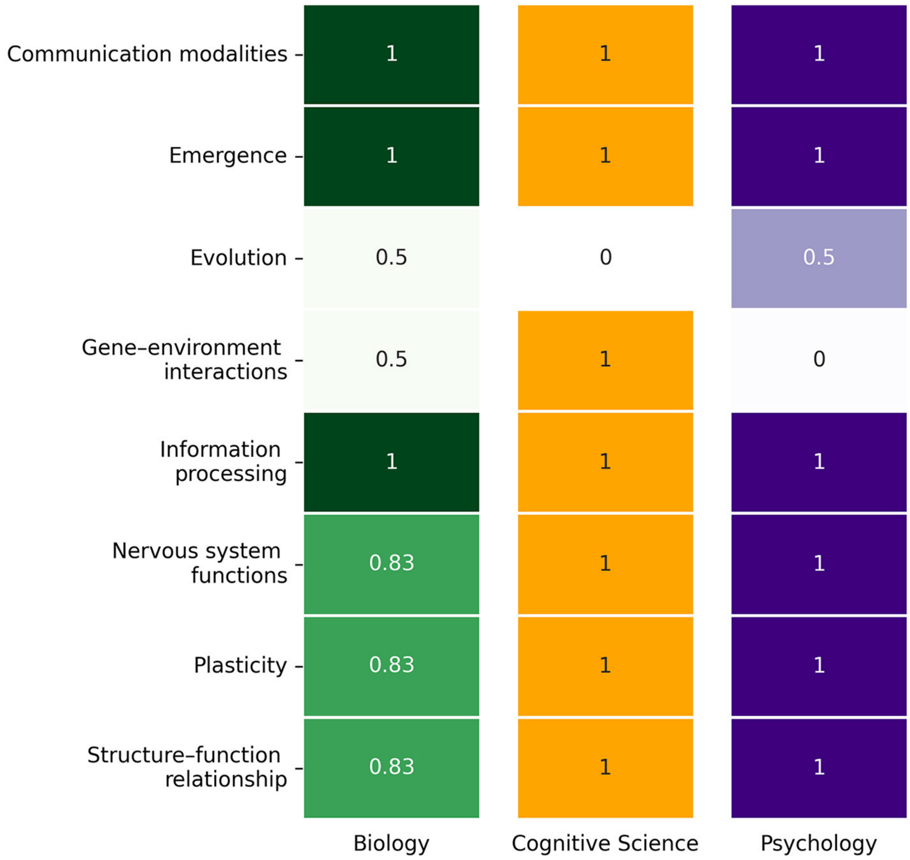

FIGURE 2
Inclusion of core concepts as measured through course syllabi. Numbers indicate the proportion of syllabi that contained a given core concept.

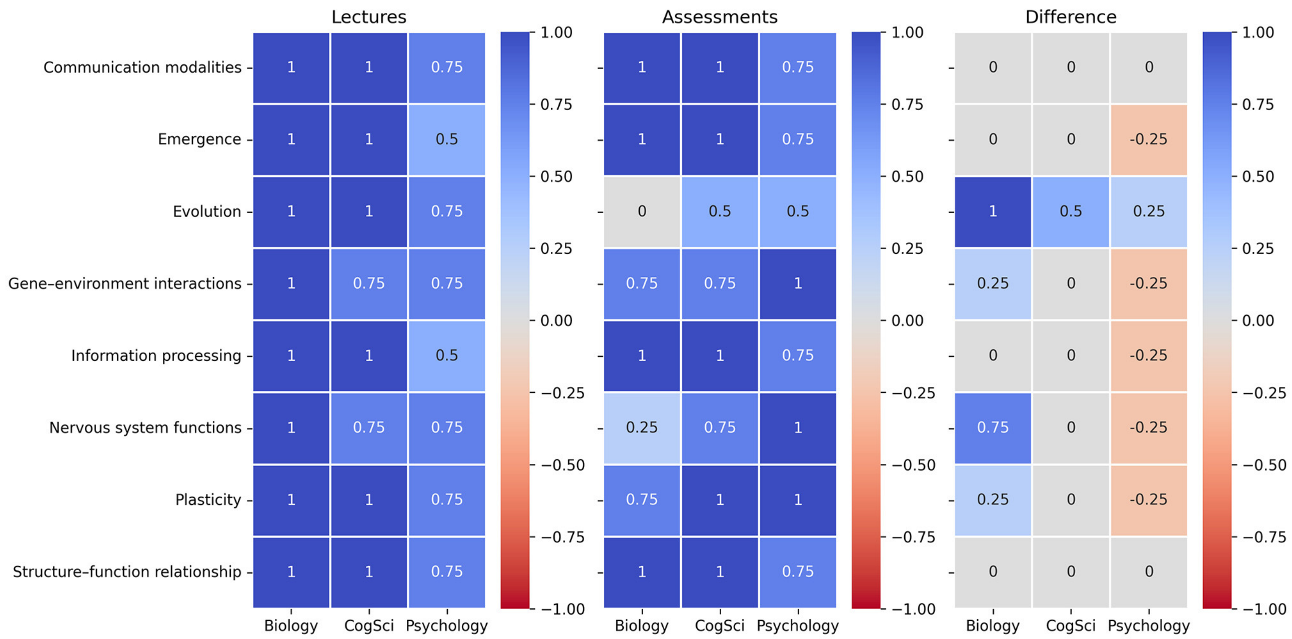

FIGURE 3
Inclusion of core concepts into lectures **(left)** and/or course assessments **(center)** across different disciplines. Values represent the proportion of responses that included a core concept in a given course aspect. "Difference" **(right)** represents lectures − assessments.

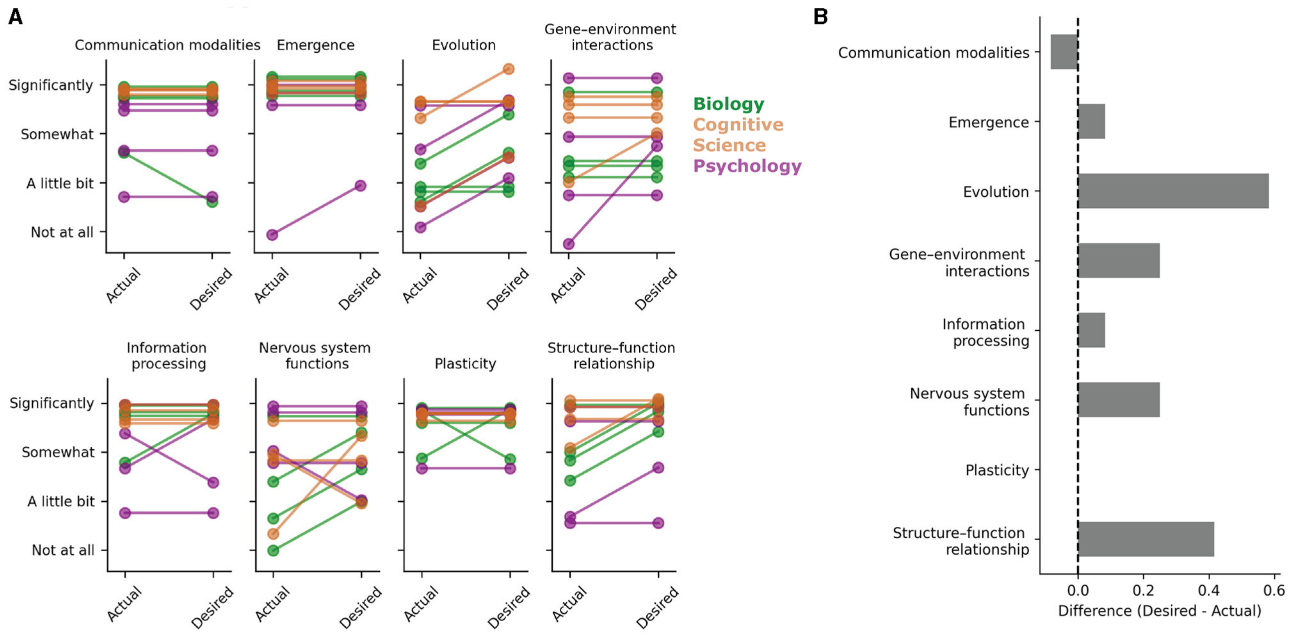

FIGURE 4
(A) Current inclusion ("Actual") vs. desired inclusion ("Desired") of core concepts. Each line is an individual response, with color indicating which discipline (Biology: green, Cognitive Science: goldenrod, Psychology: pink). Darker shading indicates overlapping responses. Jitter was added to the y-axis so that individual responses can be seen. **(B)** Likert-style items were converted to numerical values 0 through 3 to compute differences across all instructors in their desired versus actual teaching of each core concept.

laboratory activities: "I could be teaching more about evolution and gene expression, but these do not directly map onto the lab activities we are doing, and we need to cover the concepts related to lab."

Another code that emerged was the idea that some concepts were best taught in other courses. For example, several Biology instructors noted that some of the core concepts were more appropriate for a "systems neuroscience" course, as theirs was labeled as "cellular": "In [my course], I think there should be a bit more connection between what the nervous system is doing and behavior. The discrepancy arises because the course catalog says it's explicitly cellular neurobiology, so we should be focusing on cells."

4 Discussion

This case study uses both instructor self-report and analysis of course syllabi to illustrate differences in the inclusion of eight community-derived core concepts in neuroscience courses across three different disciplines. Overall, these core concepts were well-represented across disciplines, but two in particular, "Evolution" and "Gene-environment interactions," were underrepresented regardless of how we assessed their inclusion (see Figures 1, 2). We also observed that although "Evolution" appeared in lectures, it was less likely to be assessed. Finally, instructors felt that they should be teaching more about "Gene-environment interactions," "Evolution," and "Structure-function."

4.1 Core concepts are well-represented across disciplines

Although the core concepts were born out of biology, our case study speaks to the adaptability of these concepts for both psychology and cognitive science. The core concepts were developed in 2020–21 in conversation predominantly with biology instructors through multiple biology-focused professional organizations (Chen et al., 2022, 2023). Nevertheless, we found that many psychology and cognitive science courses feature these core concepts as well and that there were few stark differences in whether instructors from different fields address these concepts. It is notable that core concepts such as "Gene-environment interactions," which is firmly rooted in biology, are taught in disciplines outside of biology. Importantly, additional concepts that are core to psychology and cognitive science, but missing from the biology-oriented neuroscience inventory may be overlooked by instructors who rely on the neuroscience inventory for their course planning.

While there was fairly good representation of core concepts regardless of discipline, not all concepts were included to equal degrees. This was to be expected because the core concepts were meant to be covered over an entire undergraduate curriculum, so it would be ambitious to cover them all in one course (Chen et al., 2023). Our work is consistent with other curriculum mapping efforts showing that no one physiology course covered all the physiology core concepts (Stanescu et al., 2020) and no one biology course covered all biology core competencies (Clemmons et al., 2022). As we note below, we may have also observed less inclusion of these concepts given the short quarter system at this university.

Nonetheless, the shorter quarter system may have helped us isolate what instructors view as high-priority, non-negotiable topics. Biology, Cognitive Science, and Psychology instructors all agreed that it was important for students to understand that the nervous system is made of small interacting components ("Emergence"). In Biology and Cognitive Science, there was also strong support for the idea that nervous systems encode and transmit information ("Communication modalities") and that individual units transform inputs into outputs ("Information processing"). Perhaps not surprisingly, Cognitive Science and Psychology had better representation of some of the bigger-picture ideas, such as the idea that nervous systems respond to experience ("Plasticity") and that nervous systems function to respond to the environment ("Nervous system functions"). Indeed, we not only saw that instructors self-reported different uses of the concepts but also that these concepts were included in different aspects of the course. Instructors make choices about what topics to include in lectures, assessments, or both, and this can be representative of their respective priorities. This finding corresponds with a similar experiment, which found that some core competencies in biology were assessed more than others (Clemmons et al., 2022). The choice of what to assess in a course also impacts student learning—in one study, students were more likely to report that a concept was taught if it was assessed (Clemmons et al., 2022). In that same study, instructors listed a narrower range of learning outcomes on syllabi than they reported teaching (Clemmons et al., 2022). Therefore, greater inclusion of topics like "Evolution" in lectures as compared to assessment may be a result of instructors perceiving it as a lower priority in their teaching and may, in turn, cause students to view it as a lower priority in their learning.

4.2 Why aren't instructors talking about Evolution or Gene-environment interactions?

The core concept of "Evolution," which emphasizes that nervous system development and organization is constrained by its evolutionary background, was the least represented core concept across our survey and syllabus analysis. Given that evolution is featured in the Vision & Change in Undergraduate Biology report, it is surprising that this concept is very poorly represented in the Biology courses we surveyed (AAAS, 2011). However, this choice may be because there are several other large, required courses in the Biology department that focus entirely on evolution or related concepts, so instructors may not feel that it is necessary to cover it in a neurobiology course. In contrast, the Psychology or Cognitive Science majors do not have other evolution-focused courses, so these instructors may feel it more necessary to include this concept in their curricula. It may also be that Biology instructors assume they are teaching evolution by discussing it in lecture only, but excluding "Evolution" from assessments may prevent students from recognizing that they learned the concept (Clemmons et al., 2022), as noted above. The same could be true for "Gene-environment interactions"—all Biology majors (including those in Neurobiology) are required to take a genetics course, which is not true for the neuroscience majors in Psychology or Cognitive Sciences. Instructors may therefore be making content choices to differentiate their courses from others in the department.

Even still, relative to the other concepts, the "Evolution" and "Gene-environment interaction" concepts were not well-represented in Cognitive Science or Psychology. It may be that instructors find these core concepts particularly challenging to teach, as they are politically charged (Tolman et al., 2021; Donovan, 2014) and require systems-level thinking and interdisciplinary knowledge of complex phenomena (Todd and Kenyon, 2016; Haskel-Ittah et al., 2020). Though the current institution has faculty with biology expertise in multiple departments, other schools may not have faculty in their cognitive science or psychology departments who are comfortable teaching biologically-based content. For example, a recent evaluation of a neuroscience minor at a small PUI found that the psychology department in which the minor was housed lacked instructors who could deeply teach "Evolution," "Gene-environment interaction," or "Structure-function" (Stocker and Duncan, 2024). A recent article that also focuses on the community-derived core concepts notes that an evolutionary perspective is essential to understanding the origin of nervous systems and provides a list of accessible examples of nervous system evolution for instructors who would like to better incorporate this concept into their teaching and assessments (Striedter, 2023); see also Carlson (2012). However, as Striedter (2023) also notes, fields outside of biology have also been less likely to adapt an evolutionary framework, despite its wide ranging ability to contextualize both animal and human behavior. Similarly, teaching Gene-environment interactions is essential to provide students with a full picture of phenotypic plasticity (Haskel-Ittah et al., 2020), and to combat student misconceptions of genetic determinism (Jamieson and Radick, 2017). Haskel-Ittah et al. (2020) recommend teaching Gene-environment interactions in many different contexts—why not teach it in the context of nervous systems?

4.3 Limitations

Although our study took place at a large R1 university, there were a limited number of instructors who had recently taught classes that could be considered "fundamental neuroscience" courses. We chose to analyze course syllabi to have another window through which we could assess the inclusion of core concepts, but this too was limited by the number of courses. In addition, not all instructors answered the survey or had syllabi available, which further limited our sample size and may have introduced sampling bias. While restricting our case study to one university meant that other contextual factors, like university environment, were controlled for, extending our analysis to other universities would provide a broader view of how instructors in these disciplines address the core concepts. Results of this case study may not generalize across institutions but may be indicative of trends. For example, the current study and a review by Stocker and Duncan (2024) both found similar gaps in curricular alignment with the neuroscience core concepts. Additional, similar case studies at a range of institutions may develop a clearer picture of the current state of neuroscience curricula.

Further, we assessed the inclusion of these concepts at a university on the quarter system, in which courses tend to cover less content than semester systems. It may be possible to more comprehensively include all of the core concepts in a semester system with 13 or more weeks of instruction. In order to evaluate content validity, a broader, cross-institutional study which includes introductory courses and different semester lengths would be better positioned to confirm if our observations hold across more departments and course levels (see Tangalakis et al., 2023 for an example).

Our survey is limited it in that the instructors may or may not have been familiar with the neuroscience core concepts: while a description of each core concept was provided to respondents, their own interpretations of the core concepts may have biased their self-report, and they may not have appropriately distinguished between concepts that are similar at the surface, such as "Evolution" and "Gene-environment interactions." In addition, in our syllabus analysis, we found it difficult to accurately infer the representation of a core concept from short phrases on syllabi. Other researchers have noted this challenge in the coding of course learning outcomes from syllabi (Tangalakis et al., 2023). We tried to be conservative in our coding of the syllabi, but as a result our analysis may underestimate the inclusion of some of the core concepts.

Moreover, it is important to remember that instructors' teaching goals are not always acknowledged or experienced by students. Previous research has found numerous incongruities between instructors' enacted coverage of core competencies and concepts and student learning experiences (Clemmons et al., 2022; Stanescu et al., 2020). Overall, students report more frequent teaching of learning outcomes compared to their instructors, with greater student-instructor disparities for particular competencies. Importantly, student-instructor agreement on whether a competency is taught is more likely when the competency is assessed (Clemmons et al., 2022). Therefore, further research on the student experience is necessary to determine whether the students experienced learning or gained expertise in the core concepts the instructors were trying to teach and how that may differ by discipline.

Finally, this list of core concepts is not definitive, and many educators (including some in our sample) have raised concerns about the absence of key neuroscientific ideas, such as the integration of physics or chemistry or an emphasis on behavior. While not the aim of this study, further development of the core concepts inventory may be necessary to approach a cross-discipline consensus on the inventory. Beyond the concepts highlighted in this list, students also need core competencies, such as the ability to communicate research findings, analyze and visualize data, and consider the many biases in neuroscience research and the resulting impact on diverse populations (Juavinett, 2022; Shah and Juavinett, 2022; La Scala et al., 2023; Dotson and Duarte, 2020). The core concepts here, and therefore the present study, do not include such competencies. If we are to fully understand how well we are training our students for a diverse and evolving neuroscience workforce, additional work is needed to understand how well students in different disciplines are trained in such competencies.

4.4 Conclusion

Neuroscience is a relatively new field that requires conceptual understanding ranging from physics to psychology. As such, it is both challenged and positioned to train students for an evolving and interdisciplinary biomedical landscape. In this case study, we have illustrated how different disciplines at one university are rising to this challenge, underscoring the importance of students receiving a comprehensive neuroscience education regardless of their home department.

Data availability statement

The raw data used for this analysis is not freely available to protect human subject confidentiality. De-identified data will be made available upon request.

Ethics statement

The studies involving humans were approved by the UC San Diego Institutional Review Board. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

IM: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. MO: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing. AJ: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2024.1463992/full#supplementary-material

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